Postgres Pro Enterprise 14.18.1 Documentation

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Preface

This book is the official documentation of Postgres Pro Enterprise. It has been written by the Postgres Pro developers, PostgreSQL community, and other volunteers in parallel to the development of the PostgreSQL and Postgres Pro software. It describes all the functionality that the current version of Postgres Pro officially supports.

To make the large amount of information about Postgres Pro manageable, this book has been organized in several parts. Each part is targeted at a different class of users, or at users in different stages of their Postgres Pro experience:

- Part I is an informal introduction for new users.
- Part II documents the SQL query language environment, including data types and functions, as well as user-level performance tuning. Every Postgres Pro user should read this.
- Part III describes the installation and administration of the server. Everyone who runs a Postgres Pro server, be it for private use or for others, should read this part.
- Part IV describes the programming interfaces for Postgres Pro client programs.
- Part V contains information for advanced users about the extensibility capabilities of the server. Topics include user-defined data types and functions.
- Part VI contains reference information about SQL commands, client and server programs. This part supports the other parts with structured information sorted by command or program.
- Part VII contains assorted information that might be of use to Postgres Pro developers.

1. What Is Postgres Pro Enterprise?

Postgres Pro Enterprise is an object-relational database management system (ORDBMS), developed by Postgres Professional in the Postgres Pro fork of *PostgreSQL*, which is in turn based on *POSTGRES, Version 4.2*, developed at the University of California at Berkeley Computer Science Department. POSTGRES pioneered many concepts that only became available in some commercial database systems much later.

Postgres Pro Enterprise runs on all major Linux and Windows operating systems. Like PostgreSQL, Postgres Pro Enterprise is *ACID*-compliant.

Both PostgreSQL and Postgres Pro Enterprise support a large part of the SQL standard and offer many modern features:

- complex queries
- foreign keys
- triggers
- updatable views
- transactional integrity
- multiversion concurrency control

Besides, PostgreSQL and Postgres Pro can be extended by the user in many ways, for example by adding new

- data types
- functions
- operators
- aggregate functions
- index methods
- procedural languages

2. Difference between Postgres Pro Enterprise and PostgreSQL

Postgres Pro provides the most actual PostgreSQL version with some additional patches applied and extensions added. It includes new features developed by Postgres Professional, as well as third-party patches already accepted by the PostgreSQL community for the upcoming PostgreSQL versions. Postgres Pro Enterprise users thus have early access to important features and fixes.

> **Note**
>
> Postgres Pro Enterprise is provided under the following license: *https://postgrespro.com/products/postgrespro/eula*. Make sure to review the license terms before downloading Postgres Pro Enterprise.

Postgres Pro Enterprise provides the following enhancements over PostgreSQL:

- 64-bit transaction IDs that are not subject to wraparound. (See Section 24.1.5.)
- Page-level compression. (See Chapter 33.)
- Support for autonomous transactions. (See Chapter 16.)
- Lazy placement of temporary tables on disk. Disk space for temporary tables is allocated only when they exceed the temp_buffers size and have to be spilled to disk. Since disk space for temporary tables is not reserved in advance anymore, it allows to significantly reduce disk usage when working with multiple small temporary tables.
- Resource prioritization experimental feature, which allows to allocate more resources to high-priority sessions. (See Section 18.4.6.)
- Automatic page repair via streaming replication from standby in case of data corruption. (See Section 26.2.5.3.)
- Fair lightweight lock scheduling after the specified number of shared locks is acquired. (See lwlock_shared_limit parameter description.)
- Controlling the amount of cache used by prepared statements. With plan_cache_lru_size or plan_cache_lru_memsize configuration parameters enabled, query trees and generic plans of the least recently used statements are evicted from cache once the specified limit is reached.
- Improved prioritization of sequential and index scans. (See seq_scan_startup_cost_first_row parameter description.)
- Improved multi-host connection handling and failover by libpq. (See hostorder and failover_timeout parameter descriptions.)
- Enabling libpq to forget the entered password, which allows to prevent reconnections when required by a security policy. (See reusepass parameter description.)
- Support for timestamp output in pg_waldump.
- Support for relaxed synchronous replication restrictions, which allows the primary server to continue running while some of the standbys are temporarily unavailable. (See synchronous_standby_gap parameter description.)
- Built-in connection pooler that can limit the number of backends when working with multiple clients, without imposing restrictions on using session configuration parameters, prepared statements, or temporary tables. (See Chapter 34 for details.)
- The *autoprepare* mode that allows to implicitly prepare frequently used statements, thus eliminating the cost of their compilation and planning on each subsequent execution. (See Section 14.6.)
- Support for changing configuration of other sessions. For example, you can use this feature to switch on debug messages to trace sessions with unexpected behavior. (See Section 9.27.1.)
- K-nearest neighbors (k-NN) algorithm for B-tree indexes. (See Section 11.13.)
- An improved version of pgbench that handles transactions with serialization or deadlock errors, as well as supports compound commands.
- Removing a practically reachable limit on the number of entries in ACL (access control list, i.e., privileges list) associated with tables and indexes.
- The pgpro_stat_wal_activity view that shows the size of WAL files generated by each process.

- Restoration of corrupted WAL data from in-memory WAL buffers.
- Verification of unique constraints in B-tree indexes in the `amcheck` module.
- Login event triggers, which fire when a user connects to the database after authentication. For example, you can use this feature to verify the connection and assign roles according to circumstances, or for session data initialization.
- Lock deduplication that allows to effectively store in memory and track all exclusive locks held by a standby server's startup process during WAL replay.
- Optimized mechanism for working with table metadata, which allows obtaining information about attributes using the system cache instead of direct reading from the system catalog.

The following enhancements are inherited from Postgres Pro Standard:

- Improved deadlock detection mechanism that does not cause performance degradation.
- Better planning speed and accuracy for various query types.
- Reduced memory consumption in complex queries that involve multiple tables.
- Displaying planning time in the output of the auto_explain module.
- NUL byte replacement with the specified ASCII code while loading data using the `COPY FROM` command. (See nul_byte_replacement_on_import parameter description.)

  `'\u0000'` character replacement with the specified unicode character when calling a function processing JSONB (See unicode_nul_character_replacement_in_jsonb parameter description.)
- ICU collation support on all platforms to provide platform-independent sort for various locales. By default, the `icu` collation provider is used for all locales except `C` and `POSIX`. (See Section 23.2.2.)
- PTRACK implementation, which enables pg_probackup to track page changes on the fly when creating incremental backups.
- Support for reading `pg_control` of previous PostgreSQL/Postgres Pro major versions by pgpro_controldata.
- Cluster compatibility verification, which allows you to determine whether the current Postgres Pro version is compatible with the specified cluster and identify all parameters that can affect the compatibility without starting the cluster. (See pgpro_controldata and `-Z` option of postgres.)
- Changing the `restore_command` parameter without restarting the server.
- Improvements for command-line editing using WinEditLine in the Windows version of psql, including autocomplete support in psql console and changing the psql default encoding to UTF-8.
- Unified structure of binary installation packages across all Linux distributions, which facilitates migration between them and allows installing PostgreSQL-based products side by side, without any conflicts. (See Chapter 17.)
- Operation log, which stores information about system events such as an upgrade, execution of pg_resetwal and so on, which is highly useful for vendor's technical support. Recording to the operation log is only done at the system level, and SQL functions are used to read it. (See Section 9.27.12.)
- Advanced authentication policies that provide effective password management and access control. (See CREATE PROFILE and ALTER ROLE).
- Built-in data security mechanisms that enable sanitizing an object by filling it with zeroes before deletion. Zeroing can be done before purging files in external memory and removing outdated row versions (page vacuum), freeing RAM, and deleting or overwriting WAL files. (Certified edition only.)
- Collection of statistics about vacuuming tables and indexes. The collected information is displayed by pgpro_stats and pgpro_pwr.
- Getting information on crashes of a backend, which is enabled by the crash_info configuration parameter and controlled by more of them.
- Optimized memory consumption during selectivity estimation for each array element.

Postgres Pro Enterprise also includes the following additional modules and applications:

- apache_age extension that provides graph database functionality.
- aqo extension for adaptive query optimization.
- dump_stat module that allows to save and restore database statistics when dumping/restoring the database.

- fasttrun module that provides transaction-unsafe function to truncate temporary tables without growing `pg_class` size.
- fulleq module that provides additional equivalence operator for compatibility with Microsoft SQL Server.
- hunspell-dict module that provides dictionaries for several languages.
- in_memory module that enables you to store data in Postgres Pro shared memory.
- jsquery module that provides a specific language for effective index-supported querying of JSONB data.
- mamonsu monitoring service, which is implemented as a Zabbix agent.
- mchar module that provides additional data type for compatibility with Microsoft SQL Server.
- multimaster extension that turns Postgres Pro Enterprise into a synchronous shared-nothing cluster to provide Online Transaction Processing (OLTP) scalability for read transactions and high availability with automatic disaster recovery.
- online_analyze module that provides a set of changes to immediately update statistics after `INSERT`, `UPDATE`, `DELETE` or `SELECT INTO` operations applied for affected tables.
- pgbadger application that rapidly analyzes Postgres Pro logs, producing detailed reports and graphs.
- pgbouncer connection pooler.
- pg_hint_plan module that controls the execution plan by providing hints to the planner.
- pg_integrity_check module that calculates and validates checksums for controlled files. (Certified edition only.)
- pg_pathman module that provides optimized partitioning mechanism and functions to manage partitions, as well as declarative syntax. Starting from Postgres Pro 12, using pg_pathman is not recommended. Use vanilla declarative partitioning instead, as described in Section 5.11.
- pg_proaudit extension that enables detailed logging of various security events.
- pg_probackup, a backup and recovery manager.
- pgpro_controldata, an application to display control information of a PostgreSQL/Postgres Pro database cluster and compatibility information for a cluster and/or server.
- pgpro_datactl, a utility to manage Postgres Pro data files.
- pgpro_pwr extension that enables you to generate workload reports, which help to discover most resource-intensive activities in your database.
- pgpro_scheduler module that provides background workers for task scheduling.
- pgpro_stats extension that tracks execution statistics of SQL statements, calculates wait event statistics and provides other useful metrics that are not collected elsewhere in PostgreSQL. It also provides tracing of application sessions and can create views that emulate other statistic collecting extensions.
- pg_query_state module that enables you to get the current state of query execution for a backend.
- pg_repack utility for reorganizing tables.
- pg_transfer module that provides support for relocatable tables.
- pg_tsparser module, which is an alternative text search parser.
- pg_variables module that provides functions for working with variables of various types. To facilitate migration of Oracle code that processes collections, these functions include those that allow working with general collection variables, whose elements can be accessed by a key that can have either integer or text type, and those that provide iterator functionality for any collections.
- pg_wait_sampling extension for sampling-based statistics of wait events. With this extension, you can get an insight into the server activity, including the current wait events for all processes and background workers.
- plantuner module that provides hints for the planner to disable or enable indexes for query execution.
- rum module that provides RUM index based on GIN.
- shared_ispell module that enables storing dictionaries in shared memory.

Postgres Pro Enterprise releases follow PostgreSQL releases, though sometimes occur more frequently. The Postgres Pro Enterprise versioning scheme is based on the PostgreSQL one and has an additional decimal place.

3. A Brief History of PostgreSQL

The object-relational database management system now known as PostgreSQL is derived from the POSTGRES package written at the University of California at Berkeley. With decades of development behind it, PostgreSQL is now the most advanced open-source database available anywhere.

3.1. The Berkeley POSTGRES Project

The POSTGRES project, led by Professor Michael Stonebraker, was sponsored by the Defense Advanced Research Projects Agency (DARPA), the Army Research Office (ARO), the National Science Foundation (NSF), and ESL, Inc. The implementation of POSTGRES began in 1986. The initial concepts for the system were presented in ston86, and the definition of the initial data model appeared in rowe87. The design of the rule system at that time was described in ston87a. The rationale and architecture of the storage manager were detailed in ston87b.

POSTGRES has undergone several major releases since then. The first "demoware" system became operational in 1987 and was shown at the 1988 ACM-SIGMOD Conference. Version 1, described in ston90a, was released to a few external users in June 1989. In response to a critique of the first rule system (ston89), the rule system was redesigned (ston90b), and Version 2 was released in June 1990 with the new rule system. Version 3 appeared in 1991 and added support for multiple storage managers, an improved query executor, and a rewritten rule system. For the most part, subsequent releases until Postgres95 (see below) focused on portability and reliability.

POSTGRES has been used to implement many different research and production applications. These include: a financial data analysis system, a jet engine performance monitoring package, an asteroid tracking database, a medical information database, and several geographic information systems. POSTGRES has also been used as an educational tool at several universities. Finally, Illustra Information Technologies (later merged into *Informix*, which is now owned by *IBM*) picked up the code and commercialized it. In late 1992, POSTGRES became the primary data manager for the Sequoia 2000 scientific computing project described in ston92.

The size of the external user community nearly doubled during 1993. It became increasingly obvious that maintenance of the prototype code and support was taking up large amounts of time that should have been devoted to database research. In an effort to reduce this support burden, the Berkeley POSTGRES project officially ended with Version 4.2.

3.2. Postgres95

In 1994, Andrew Yu and Jolly Chen added an SQL language interpreter to POSTGRES. Under a new name, Postgres95 was subsequently released to the web to find its own way in the world as an open-source descendant of the original POSTGRES Berkeley code.

Postgres95 code was completely ANSI C and trimmed in size by 25%. Many internal changes improved performance and maintainability. Postgres95 release 1.0.x ran about 30–50% faster on the Wisconsin Benchmark compared to POSTGRES, Version 4.2. Apart from bug fixes, the following were the major enhancements:

- The query language PostQUEL was replaced with SQL (implemented in the server). (Interface library libpq was named after PostQUEL.) Subqueries were not supported until PostgreSQL (see below), but they could be imitated in Postgres95 with user-defined SQL functions. Aggregate functions were re-implemented. Support for the `GROUP BY` query clause was also added.
- A new program (psql) was provided for interactive SQL queries, which used GNU Readline. This largely superseded the old monitor program.
- A new front-end library, `libpgtcl`, supported Tcl-based clients. A sample shell, `pgtclsh`, provided new Tcl commands to interface Tcl programs with the Postgres95 server.
- The large-object interface was overhauled. The inversion large objects were the only mechanism for storing large objects. (The inversion file system was removed.)
- The instance-level rule system was removed. Rules were still available as rewrite rules.
- A short tutorial introducing regular SQL features as well as those of Postgres95 was distributed with the source code

- GNU make (instead of BSD make) was used for the build. Also, Postgres95 could be compiled with an unpatched GCC (data alignment of doubles was fixed).

3.3. PostgreSQL

By 1996, it became clear that the name “Postgres95” would not stand the test of time. We chose a new name, PostgreSQL, to reflect the relationship between the original POSTGRES and the more recent versions with SQL capability. At the same time, we set the version numbering to start at 6.0, putting the numbers back into the sequence originally begun by the Berkeley POSTGRES project.

Postgres is still considered an official project name, both because of tradition and because people find it easier to pronounce Postgres than PostgreSQL.

The emphasis during development of Postgres95 was on identifying and understanding existing problems in the server code. With PostgreSQL, the emphasis has shifted to augmenting features and capabilities, although work continues in all areas.

4. Conventions

The following conventions are used in the synopsis of a command: brackets (`[` and `]`) indicate optional parts. Braces (`{` and `}`) and vertical lines (`|`) indicate that you must choose one alternative. Dots (`...`) mean that the preceding element can be repeated. All other symbols, including parentheses, should be taken literally.

Where it enhances the clarity, SQL commands are preceded by the prompt `=>`, and shell commands are preceded by the prompt `$`. Normally, prompts are not shown, though.

An *administrator* is generally a person who is in charge of installing and running the server. A *user* could be anyone who is using, or wants to use, any part of the Postgres Pro system. These terms should not be interpreted too narrowly; this book does not have fixed presumptions about system administration procedures.

5. Bug Reporting Guidelines

When you find a bug in Postgres Pro we want to hear about it. Your bug reports play an important part in making Postgres Pro more reliable because even the utmost care cannot guarantee that every part of Postgres Pro will work on every platform under every circumstance.

The following suggestions are intended to assist you in forming bug reports that can be handled in an effective fashion. No one is required to follow them but doing so tends to be to everyone's advantage.

5.1. Identifying Bugs

Before you report a bug, please read and re-read the documentation to verify that you can really do whatever it is you are trying. If it is not clear from the documentation whether you can do something or not, please report that too; it is a bug in the documentation. If it turns out that a program does something different from what the documentation says, that is a bug. That might include, but is not limited to, the following circumstances:

- A program terminates with a fatal signal or an operating system error message that would point to a problem in the program. (A counterexample might be a “disk full” message, since you have to fix that yourself.)
- A program produces the wrong output for any given input.
- A program refuses to accept valid input (as defined in the documentation).
- A program accepts invalid input without a notice or error message. But keep in mind that your idea of invalid input might be our idea of an extension or compatibility with traditional practice.
- Postgres Pro fails to install according to the instructions on supported platforms.

Here “program” refers to any executable, not only the backend process.

Being slow or resource-hogging is not necessarily a bug. Failing to comply to the SQL standard is not necessarily a bug either, unless compliance for the specific feature is explicitly claimed.

5.2. What to Report

When reporting a bug, make sure to state all the facts. Each bug report should contain the following items:

- The exact sequence of steps *from program start-up* necessary to reproduce the problem. This should be self-contained; it is not enough to send in a bare `SELECT` statement without the preceding `CREATE TABLE` and `INSERT` statements, if the output should depend on the data in the tables.

  The best format for a test case for SQL-related problems is a file that can be run through the psql frontend that shows the problem. (Be sure to not have anything in your `~/.psqlrc` start-up file.) An easy way to create this file is to use pg_dump to dump out the table declarations and data needed to set the scene, then add the problem query. You are encouraged to minimize the size of your example, but this is not absolutely necessary. If the bug is reproducible, we will find it either way.

  If your application uses some other client interface, such as PHP, then please try to isolate the offending queries.

- The output you got. If there is an error message, show it. If the program terminates with an operating system error, say which. If nothing at all happens, say so. Even if the result of your test case is a program crash or otherwise obvious it might not happen on our platform. The easiest thing is to copy the output from the terminal, if possible.

  > **Note**
  >
  > If you are reporting an error message, please obtain the most verbose form of the message. In psql, say `\set VERBOSITY verbose` beforehand. If you are extracting the message from the server log, set the run-time parameter log_error_verbosity to `verbose` so that all details are logged.

  > **Note**
  >
  > In case of fatal errors, the error message reported by the client might not contain all the information available. Please also look at the log output of the database server.

- The output you expect is very important to state. Please provide the expected output, if applicable.
- Any command line options and other start-up options, including any relevant environment variables or configuration files that you changed from the default.
- Anything you did at all differently from the installation instructions.
- The Postgres Pro version. You can run the command `SELECT pgpro_version();` to find out the version of the server you are connected to. Most executable programs also support a `--version` option; at least `postgres --version` and `psql --version` should work.
- Platform information. This includes the kernel name and version, C library, processor, memory information, and so on.

5.3. Where to Report Bugs

In general, send bug reports to our support email address at <bugs@postgrespro.ru>. You are requested to use a descriptive subject for your email message, perhaps parts of the error message.

Do not send bug reports specific to Postgres Pro to the PostgreSQL support email address, as Postgres Pro is not supported by the PostgreSQL community. But you can send reports to <pgsql-bugs@lists.postgresql.org> for any bugs related to PostgreSQL.

Even if your bug is not specific to Postgres Pro, do not send bug reports to any of the user mailing lists, such as <pgsql-sql@lists.postgresql.org> or <pgsql-general@lists.postgresql.org>. These mailing lists are for answering user questions, and their subscribers normally do not wish to receive bug reports. More importantly, they are unlikely to fix them.

Also, please do *not* send reports to the developers' mailing list <pgsql-hackers@lists.postgresql.org>. This list is for discussing the development of PostgreSQL, and it would be nice if the community could keep the bug reports separate. The community might choose to take up a discussion about your bug report on pgsql-hackers, if the PostgreSQL-related problem needs more review.

Part I. Tutorial

Welcome to the Postgres Pro Tutorial. The following few chapters are intended to give a simple introduction to Postgres Pro, relational database concepts, and the SQL language to those who are new to any one of these aspects. We only assume some general knowledge about how to use computers. No particular Unix or programming experience is required. This part is mainly intended to give you some hands-on experience with important aspects of the Postgres Pro system. It makes no attempt to be a complete or thorough treatment of the topics it covers.

After you have worked through this tutorial you might want to move on to reading Part II to gain a more formal knowledge of the SQL language, or Part IV for information about developing applications for Postgres Pro. When learning SQL, you can use the demo database described in Appendix M. Those who set up and manage their own server should also read Part III.

Chapter 1. Getting Started

1.1. Installation

Before you can use Postgres Pro you need to install it, of course. It is possible that Postgres Pro is already installed at your site, either because it was included in your operating system distribution or because the system administrator already installed it. If that is the case, you should obtain information from the operating system documentation or your system administrator about how to access Postgres Pro.

If you are installing Postgres Pro yourself, then see instructions on installation (Chapter 17), and return to this guide when the installation is complete. Be sure to follow closely the section about setting up the appropriate environment variables.

If your site administrator has not set things up in the default way, you might have some more work to do. For example, if the database server machine is a remote machine, you will need to set the `PGHOST` environment variable to the name of the database server machine. The environment variable `PGPORT` might also have to be set. The bottom line is this: if you try to start an application program and it complains that it cannot connect to the database, you should consult your site administrator or, if that is you, the documentation to make sure that your environment is properly set up. If you did not understand the preceding paragraph then read the next section.

1.2. Architectural Fundamentals

Before we proceed, you should understand the basic Postgres Pro system architecture. Understanding how the parts of Postgres Pro interact will make this chapter somewhat clearer.

In database jargon, Postgres Pro uses a client/server model. A Postgres Pro session consists of the following cooperating processes (programs):

- A server process, which manages the database files, accepts connections to the database from client applications, and performs database actions on behalf of the clients. The database server program is called `postgres`.
- The user's client (frontend) application that wants to perform database operations. Client applications can be very diverse in nature: a client could be a text-oriented tool, a graphical application, a web server that accesses the database to display web pages, or a specialized database maintenance tool. Some client applications are supplied with the Postgres Pro distribution; most are developed by users.

As is typical of client/server applications, the client and the server can be on different hosts. In that case they communicate over a TCP/IP network connection. You should keep this in mind, because the files that can be accessed on a client machine might not be accessible (or might only be accessible using a different file name) on the database server machine.

The Postgres Pro server can handle multiple concurrent connections from clients. To achieve this it starts (“forks”) a new process for each connection. From that point on, the client and the new server process communicate without intervention by the original `postgres` process. Thus, the supervisor server process is always running, waiting for client connections, whereas client and associated server processes come and go. (All of this is of course invisible to the user. We only mention it here for completeness.)

1.3. Creating a Database

The first test to see whether you can access the database server is to try to create a database. A running Postgres Pro server can manage many databases. Typically, a separate database is used for each project or for each user.

Possibly, your site administrator has already created a database for your use. In that case you can omit this step and skip ahead to the next section.

To create a new database, in this example named `mydb`, you use the following command:

```
$ createdb mydb
```

If this produces no response then this step was successful and you can skip over the remainder of this section.

If you see a message similar to:

```
createdb: command not found
```

then Postgres Pro was not installed properly. Either it was not installed at all or your shell's search path was not set to include it. Try calling the command with an absolute path instead:

```
$ /usr/local/pgsql/bin/createdb mydb
```

The path at your site might be different. Contact your site administrator or check the installation instructions to correct the situation.

Another response could be this:

```
createdb: error: connection to server on socket "/tmp/.s.PGSQL.5432" failed: No such
 file or directory
        Is the server running locally and accepting connections on that socket?
```

This means that the server was not started, or it is not listening where `createdb` expects to contact it. Again, check the installation instructions or consult the administrator.

Another response could be this:

```
createdb: error: connection to server on socket "/tmp/.s.PGSQL.5432" failed: FATAL:
 role "joe" does not exist
```

where your own login name is mentioned. This will happen if the administrator has not created a Postgres Pro user account for you. (Postgres Pro user accounts are distinct from operating system user accounts.) If you are the administrator, see Chapter 21 for help creating accounts. You will need to become the operating system user under which Postgres Pro was installed (usually `postgres`) to create the first user account. It could also be that you were assigned a Postgres Pro user name that is different from your operating system user name; in that case you need to use the `-U` switch or set the `PGUSER` environment variable to specify your Postgres Pro user name.

If you have a user account but it does not have the privileges required to create a database, you will see the following:

```
createdb: error: database creation failed: ERROR:  permission denied to create database
```

Not every user has authorization to create new databases. If Postgres Pro refuses to create databases for you then the site administrator needs to grant you permission to create databases. Consult your site administrator if this occurs. If you installed Postgres Pro yourself then you should log in for the purposes of this tutorial under the user account that you started the server as. [1]

You can also create databases with other names. Postgres Pro allows you to create any number of databases at a given site. Database names must have an alphabetic first character and are limited to 63 bytes in length. A convenient choice is to create a database with the same name as your current user name. Many tools assume that database name as the default, so it can save you some typing. To create that database, simply type:

```
$ createdb
```

If you do not want to use your database anymore you can remove it. For example, if you are the owner (creator) of the database `mydb`, you can destroy it using the following command:

```
$ dropdb mydb
```

[1] As an explanation for why this works: Postgres Pro user names are separate from operating system user accounts. When you connect to a database, you can choose what Postgres Pro user name to connect as; if you don't, it will default to the same name as your current operating system account. As it happens, there will always be a Postgres Pro user account that has the same name as the operating system user that started the server, and it also happens that that user always has permission to create databases. Instead of logging in as that user you can also specify the `-U` option everywhere to select a Postgres Pro user name to connect as.

(For this command, the database name does not default to the user account name. You always need to specify it.) This action physically removes all files associated with the database and cannot be undone, so this should only be done with a great deal of forethought.

More about `createdb` and `dropdb` can be found in createdb and dropdb respectively.

1.4. Accessing a Database

Once you have created a database, you can access it by:

- Running the Postgres Pro interactive terminal program, called *psql*, which allows you to interactively enter, edit, and execute SQL commands.
- Using an existing graphical frontend tool like pgAdmin or an office suite with ODBC or JDBC support to create and manipulate a database. These possibilities are not covered in this tutorial.
- Writing a custom application, using one of the several available language bindings. These possibilities are discussed further in Part IV.

You probably want to start up `psql` to try the examples in this tutorial. It can be activated for the `mydb` database by typing the command:

```
$ psql mydb
```

If you do not supply the database name then it will default to your user account name. You already discovered this scheme in the previous section using `createdb`.

In `psql`, you will be greeted with the following message:

```
psql (14.18.1)
Type "help" for help.

mydb=>
```

The last line could also be:

```
mydb=#
```

That would mean you are a database superuser, which is most likely the case if you installed the Postgres Pro instance yourself. Being a superuser means that you are not subject to access controls. For the purposes of this tutorial that is not important.

If you encounter problems starting `psql` then go back to the previous section. The diagnostics of `createdb` and `psql` are similar, and if the former worked the latter should work as well.

The last line printed out by `psql` is the prompt, and it indicates that `psql` is listening to you and that you can type SQL queries into a work space maintained by `psql`. Try out these commands:

```
mydb=> SELECT pgpro_version();
                                          version
-------------------------------------------------------------------------
-----------------------
 PostgresPro 14.18.1 on x86_64-pc-linux-gnu, compiled by gcc (Debian 4.9.2-10) 4.9.2,
 64-bit
(1 row)

mydb=> SELECT current_date;
    date
------------
 2016-01-07
(1 row)

mydb=> SELECT 2 + 2;
 ?column?
----------
```

```
         4
(1 row)
```

The `psql` program has a number of internal commands that are not SQL commands. They begin with the backslash character, "`\`". For example, you can get help on the syntax of various Postgres Pro SQL commands by typing:

```
mydb=> \h
```

To get out of `psql`, type:

```
mydb=> \q
```

and `psql` will quit and return you to your command shell. (For more internal commands, type `\?` at the `psql` prompt.) The full capabilities of `psql` are documented in psql. In this tutorial we will not use these features explicitly, but you can use them yourself when it is helpful.

Chapter 2. The SQL Language

2.1. Introduction

This chapter provides an overview of how to use SQL to perform simple operations. This tutorial is only intended to give you an introduction and is in no way a complete tutorial on SQL. Numerous books have been written on SQL, including melt93 and date97. You should be aware that some Postgres Pro language features are extensions to the standard.

In the examples that follow, we assume that you have created a database named `mydb`, as described in the previous chapter, and have been able to start psql.

2.2. Concepts

Postgres Pro is a *relational database management system* (RDBMS). That means it is a system for managing data stored in *relations*. Relation is essentially a mathematical term for *table*. The notion of storing data in tables is so commonplace today that it might seem inherently obvious, but there are a number of other ways of organizing databases. Files and directories on Unix-like operating systems form an example of a hierarchical database. A more modern development is the object-oriented database.

Each table is a named collection of *rows*. Each row of a given table has the same set of named *columns*, and each column is of a specific data type. Whereas columns have a fixed order in each row, it is important to remember that SQL does not guarantee the order of the rows within the table in any way (although they can be explicitly sorted for display).

Tables are grouped into databases, and a collection of databases managed by a single Postgres Pro server instance constitutes a database *cluster*.

2.3. Creating a New Table

You can create a new table by specifying the table name, along with all column names and their types:

```
CREATE TABLE weather (
    city            varchar(80),
    temp_lo         int,           -- low temperature
    temp_hi         int,           -- high temperature
    prcp            real,          -- precipitation
    date            date
);
```

You can enter this into `psql` with the line breaks. `psql` will recognize that the command is not terminated until the semicolon.

White space (i.e., spaces, tabs, and newlines) can be used freely in SQL commands. That means you can type the command aligned differently than above, or even all on one line. Two dashes (“`--`”) introduce comments. Whatever follows them is ignored up to the end of the line. SQL is case insensitive about key words and identifiers, except when identifiers are double-quoted to preserve the case (not done above).

`varchar(80)` specifies a data type that can store arbitrary character strings up to 80 characters in length. `int` is the normal integer type. `real` is a type for storing single precision floating-point numbers. `date` should be self-explanatory. (Yes, the column of type `date` is also named `date`. This might be convenient or confusing — you choose.)

Postgres Pro supports the standard SQL types `int`, `smallint`, `real`, `double precision`, `char(N)`, `varchar(N)`, `date`, `time`, `timestamp`, and `interval`, as well as other types of general utility and a rich set of geometric types. Postgres Pro can be customized with an arbitrary number of user-defined data types. Consequently, type names are not key words in the syntax, except where required to support special cases in the SQL standard.

The second example will store cities and their associated geographical location:

```
CREATE TABLE cities (
    name            varchar(80),
    location        point
);
```

The `point` type is an example of a Postgres Pro-specific data type.

Finally, it should be mentioned that if you don't need a table any longer or want to recreate it differently you can remove it using the following command:

```
DROP TABLE tablename;
```

2.4. Populating a Table With Rows

The `INSERT` statement is used to populate a table with rows:

```
INSERT INTO weather VALUES ('San Francisco', 46, 50, 0.25, '1994-11-27');
```

Note that all data types use rather obvious input formats. Constants that are not simple numeric values usually must be surrounded by single quotes (`'`), as in the example. The `date` type is actually quite flexible in what it accepts, but for this tutorial we will stick to the unambiguous format shown here.

The `point` type requires a coordinate pair as input, as shown here:

```
INSERT INTO cities VALUES ('San Francisco', '(-194.0, 53.0)');
```

The syntax used so far requires you to remember the order of the columns. An alternative syntax allows you to list the columns explicitly:

```
INSERT INTO weather (city, temp_lo, temp_hi, prcp, date)
    VALUES ('San Francisco', 43, 57, 0.0, '1994-11-29');
```

You can list the columns in a different order if you wish or even omit some columns, e.g., if the precipitation is unknown:

```
INSERT INTO weather (date, city, temp_hi, temp_lo)
    VALUES ('1994-11-29', 'Hayward', 54, 37);
```

Many developers consider explicitly listing the columns better style than relying on the order implicitly.

Please enter all the commands shown above so you have some data to work with in the following sections.

You could also have used `COPY` to load large amounts of data from flat-text files. This is usually faster because the `COPY` command is optimized for this application while allowing less flexibility than `INSERT`. An example would be:

```
COPY weather FROM '/home/user/weather.txt';
```

where the file name for the source file must be available on the machine running the backend process, not the client, since the backend process reads the file directly. You can read more about the `COPY` command in COPY.

2.5. Querying a Table

To retrieve data from a table, the table is *queried*. An SQL `SELECT` statement is used to do this. The statement is divided into a select list (the part that lists the columns to be returned), a table list (the part that lists the tables from which to retrieve the data), and an optional qualification (the part that specifies any restrictions). For example, to retrieve all the rows of table `weather`, type:

```
SELECT * FROM weather;
```

Here `*` is a shorthand for “all columns”. [1] So the same result would be had with:

[1] While `SELECT *` is useful for off-the-cuff queries, it is widely considered bad style in production code, since adding a column to the table would change the results.

```
SELECT city, temp_lo, temp_hi, prcp, date FROM weather;
```

The output should be:

```
     city      | temp_lo | temp_hi | prcp |    date
---------------+---------+---------+------+------------
 San Francisco |      46 |      50 | 0.25 | 1994-11-27
 San Francisco |      43 |      57 |    0 | 1994-11-29
 Hayward       |      37 |      54 |      | 1994-11-29
(3 rows)
```

You can write expressions, not just simple column references, in the select list. For example, you can do:

```
SELECT city, (temp_hi+temp_lo)/2 AS temp_avg, date FROM weather;
```

This should give:

```
     city      | temp_avg |    date
---------------+----------+------------
 San Francisco |       48 | 1994-11-27
 San Francisco |       50 | 1994-11-29
 Hayward       |       45 | 1994-11-29
(3 rows)
```

Notice how the `AS` clause is used to relabel the output column. (The `AS` clause is optional.)

A query can be “qualified” by adding a `WHERE` clause that specifies which rows are wanted. The `WHERE` clause contains a Boolean (truth value) expression, and only rows for which the Boolean expression is true are returned. The usual Boolean operators (`AND`, `OR`, and `NOT`) are allowed in the qualification. For example, the following retrieves the weather of San Francisco on rainy days:

```
SELECT * FROM weather
    WHERE city = 'San Francisco' AND prcp > 0.0;
```

Result:

```
     city      | temp_lo | temp_hi | prcp |    date
---------------+---------+---------+------+------------
 San Francisco |      46 |      50 | 0.25 | 1994-11-27
(1 row)
```

You can request that the results of a query be returned in sorted order:

```
SELECT * FROM weather
    ORDER BY city;
```

```
     city      | temp_lo | temp_hi | prcp |    date
---------------+---------+---------+------+------------
 Hayward       |      37 |      54 |      | 1994-11-29
 San Francisco |      43 |      57 |    0 | 1994-11-29
 San Francisco |      46 |      50 | 0.25 | 1994-11-27
```

In this example, the sort order isn't fully specified, and so you might get the San Francisco rows in either order. But you'd always get the results shown above if you do:

```
SELECT * FROM weather
    ORDER BY city, temp_lo;
```

You can request that duplicate rows be removed from the result of a query:

```
SELECT DISTINCT city
    FROM weather;
```

```
     city
---------------
 Hayward
 San Francisco
```

```
(2 rows)
```

Here again, the result row ordering might vary. You can ensure consistent results by using DISTINCT and ORDER BY together: [2]

```
SELECT DISTINCT city
    FROM weather
    ORDER BY city;
```

2.6. Joins Between Tables

Thus far, our queries have only accessed one table at a time. Queries can access multiple tables at once, or access the same table in such a way that multiple rows of the table are being processed at the same time. Queries that access multiple tables (or multiple instances of the same table) at one time are called *join* queries. They combine rows from one table with rows from a second table, with an expression specifying which rows are to be paired. For example, to return all the weather records together with the location of the associated city, the database needs to compare the city column of each row of the weather table with the name column of all rows in the cities table, and select the pairs of rows where these values match.[3] This would be accomplished by the following query:

```
SELECT * FROM weather JOIN cities ON city = name;
```

```
     city      | temp_lo | temp_hi | prcp |    date    |     name      | location
---------------+---------+---------+------+------------+---------------+-----------
 San Francisco |      46 |      50 | 0.25 | 1994-11-27 | San Francisco | (-194,53)
 San Francisco |      43 |      57 |    0 | 1994-11-29 | San Francisco | (-194,53)
(2 rows)
```

Observe two things about the result set:

- There is no result row for the city of Hayward. This is because there is no matching entry in the cities table for Hayward, so the join ignores the unmatched rows in the weather table. We will see shortly how this can be fixed.
- There are two columns containing the city name. This is correct because the lists of columns from the weather and cities tables are concatenated. In practice this is undesirable, though, so you will probably want to list the output columns explicitly rather than using *:

  ```
  SELECT city, temp_lo, temp_hi, prcp, date, location
      FROM weather JOIN cities ON city = name;
  ```

Since the columns all had different names, the parser automatically found which table they belong to. If there were duplicate column names in the two tables you'd need to *qualify* the column names to show which one you meant, as in:

```
SELECT weather.city, weather.temp_lo, weather.temp_hi,
       weather.prcp, weather.date, cities.location
    FROM weather JOIN cities ON weather.city = cities.name;
```

It is widely considered good style to qualify all column names in a join query, so that the query won't fail if a duplicate column name is later added to one of the tables.

Join queries of the kind seen thus far can also be written in this form:

```
SELECT *
    FROM weather, cities
    WHERE city = name;
```

This syntax pre-dates the JOIN/ON syntax, which was introduced in SQL-92. The tables are simply listed in the FROM clause, and the comparison expression is added to the WHERE clause. The results from this older

[2] In some database systems, including older versions of Postgres Pro, the implementation of DISTINCT automatically orders the rows and so ORDER BY is unnecessary. But this is not required by the SQL standard, and current Postgres Pro does not guarantee that DISTINCT causes the rows to be ordered.
[3] This is only a conceptual model. The join is usually performed in a more efficient manner than actually comparing each possible pair of rows, but this is invisible to the user.

implicit syntax and the newer explicit JOIN/ON syntax are identical. But for a reader of the query, the explicit syntax makes its meaning easier to understand: The join condition is introduced by its own key word whereas previously the condition was mixed into the WHERE clause together with other conditions.

Now we will figure out how we can get the Hayward records back in. What we want the query to do is to scan the weather table and for each row to find the matching cities row(s). If no matching row is found we want some “empty values” to be substituted for the cities table's columns. This kind of query is called an *outer join*. (The joins we have seen so far are *inner joins*.) The command looks like this:

```
SELECT *
    FROM weather LEFT OUTER JOIN cities ON weather.city = cities.name;
```

```
     city      | temp_lo | temp_hi | prcp |    date    |     name      | location
---------------+---------+---------+------+------------+---------------+-----------
 Hayward       |      37 |      54 |      | 1994-11-29 |               |
 San Francisco |      46 |      50 | 0.25 | 1994-11-27 | San Francisco | (-194,53)
 San Francisco |      43 |      57 |    0 | 1994-11-29 | San Francisco | (-194,53)
(3 rows)
```

This query is called a *left outer join* because the table mentioned on the left of the join operator will have each of its rows in the output at least once, whereas the table on the right will only have those rows output that match some row of the left table. When outputting a left-table row for which there is no right-table match, empty (null) values are substituted for the right-table columns.

Exercise: There are also right outer joins and full outer joins. Try to find out what those do.

We can also join a table against itself. This is called a *self join*. As an example, suppose we wish to find all the weather records that are in the temperature range of other weather records. So we need to compare the temp_lo and temp_hi columns of each weather row to the temp_lo and temp_hi columns of all other weather rows. We can do this with the following query:

```
SELECT w1.city, w1.temp_lo AS low, w1.temp_hi AS high,
       w2.city, w2.temp_lo AS low, w2.temp_hi AS high
    FROM weather w1 JOIN weather w2
        ON w1.temp_lo < w2.temp_lo AND w1.temp_hi > w2.temp_hi;
```

```
     city      | low | high |     city      | low | high
---------------+-----+------+---------------+-----+------
 San Francisco |  43 |   57 | San Francisco |  46 |   50
 Hayward       |  37 |   54 | San Francisco |  46 |   50
(2 rows)
```

Here we have relabeled the weather table as w1 and w2 to be able to distinguish the left and right side of the join. You can also use these kinds of aliases in other queries to save some typing, e.g.:

```
SELECT *
    FROM weather w JOIN cities c ON w.city = c.name;
```

You will encounter this style of abbreviating quite frequently.

2.7. Aggregate Functions

Like most other relational database products, Postgres Pro supports *aggregate functions*. An aggregate function computes a single result from multiple input rows. For example, there are aggregates to compute the count, sum, avg (average), max (maximum) and min (minimum) over a set of rows.

As an example, we can find the highest low-temperature reading anywhere with:

```
SELECT max(temp_lo) FROM weather;
```

```
 max
-----
  46
```

```
(1 row)
```

If we wanted to know what city (or cities) that reading occurred in, we might try:

```
SELECT city FROM weather WHERE temp_lo = max(temp_lo);     WRONG
```

but this will not work since the aggregate `max` cannot be used in the `WHERE` clause. (This restriction exists because the `WHERE` clause determines which rows will be included in the aggregate calculation; so obviously it has to be evaluated before aggregate functions are computed.) However, as is often the case the query can be restated to accomplish the desired result, here by using a *subquery*:

```
SELECT city FROM weather
    WHERE temp_lo = (SELECT max(temp_lo) FROM weather);

     city
---------------
 San Francisco
(1 row)
```

This is OK because the subquery is an independent computation that computes its own aggregate separately from what is happening in the outer query.

Aggregates are also very useful in combination with `GROUP BY` clauses. For example, we can get the number of readings and the maximum low temperature observed in each city with:

```
SELECT city, count(*), max(temp_lo)
    FROM weather
    GROUP BY city;

     city      | count | max
---------------+-------+-----
 Hayward       |     1 |  37
 San Francisco |     2 |  46
(2 rows)
```

which gives us one output row per city. Each aggregate result is computed over the table rows matching that city. We can filter these grouped rows using `HAVING`:

```
SELECT city, count(*), max(temp_lo)
    FROM weather
    GROUP BY city
    HAVING max(temp_lo) < 40;

  city   | count | max
---------+-------+-----
 Hayward |     1 |  37
(1 row)
```

which gives us the same results for only the cities that have all `temp_lo` values below 40. Finally, if we only care about cities whose names begin with "`S`", we might do:

```
SELECT city, count(*), max(temp_lo)
    FROM weather
    WHERE city LIKE 'S%'            -- 1
    GROUP BY city;

     city      | count | max
---------------+-------+-----
 San Francisco |     2 |  46
(1 row)
```

1 The `LIKE` operator does pattern matching and is explained in Section 9.7.

It is important to understand the interaction between aggregates and SQL's `WHERE` and `HAVING` clauses. The fundamental difference between `WHERE` and `HAVING` is this: `WHERE` selects input rows before groups

and aggregates are computed (thus, it controls which rows go into the aggregate computation), whereas HAVING selects group rows after groups and aggregates are computed. Thus, the WHERE clause must not contain aggregate functions; it makes no sense to try to use an aggregate to determine which rows will be inputs to the aggregates. On the other hand, the HAVING clause always contains aggregate functions. (Strictly speaking, you are allowed to write a HAVING clause that doesn't use aggregates, but it's seldom useful. The same condition could be used more efficiently at the WHERE stage.)

In the previous example, we can apply the city name restriction in WHERE, since it needs no aggregate. This is more efficient than adding the restriction to HAVING, because we avoid doing the grouping and aggregate calculations for all rows that fail the WHERE check.

Another way to select the rows that go into an aggregate computation is to use FILTER, which is a per-aggregate option:

```
SELECT city, count(*) FILTER (WHERE temp_lo < 45), max(temp_lo)
    FROM weather
    GROUP BY city;
```

```
     city      | count | max
---------------+-------+-----
 Hayward       |     1 |  37
 San Francisco |     1 |  46
(2 rows)
```

FILTER is much like WHERE, except that it removes rows only from the input of the particular aggregate function that it is attached to. Here, the count aggregate counts only rows with temp_lo below 45; but the max aggregate is still applied to all rows, so it still finds the reading of 46.

2.8. Updates

You can update existing rows using the UPDATE command. Suppose you discover the temperature readings are all off by 2 degrees after November 28. You can correct the data as follows:

```
UPDATE weather
    SET temp_hi = temp_hi - 2,  temp_lo = temp_lo - 2
    WHERE date > '1994-11-28';
```

Look at the new state of the data:

```
SELECT * FROM weather;
```

```
     city      | temp_lo | temp_hi | prcp |    date
---------------+---------+---------+------+------------
 San Francisco |      46 |      50 | 0.25 | 1994-11-27
 San Francisco |      41 |      55 |    0 | 1994-11-29
 Hayward       |      35 |      52 |      | 1994-11-29
(3 rows)
```

2.9. Deletions

Rows can be removed from a table using the DELETE command. Suppose you are no longer interested in the weather of Hayward. Then you can do the following to delete those rows from the table:

```
DELETE FROM weather WHERE city = 'Hayward';
```

All weather records belonging to Hayward are removed.

```
SELECT * FROM weather;
```

```
     city      | temp_lo | temp_hi | prcp |    date
---------------+---------+---------+------+------------
 San Francisco |      46 |      50 | 0.25 | 1994-11-27
 San Francisco |      41 |      55 |    0 | 1994-11-29
```

```
(2 rows)
```

One should be wary of statements of the form

```
DELETE FROM tablename;
```

Without a qualification, `DELETE` will remove *all* rows from the given table, leaving it empty. The system will not request confirmation before doing this!

Chapter 3. Advanced Features

3.1. Introduction

In the previous chapter we have covered the basics of using SQL to store and access your data in Postgres Pro. We will now discuss some more advanced features of SQL that simplify management and prevent loss or corruption of your data. Finally, we will look at some Postgres Pro extensions.

This chapter will on occasion refer to examples found in Chapter 2 to change or improve them, so it will be useful to have read that chapter. Some examples from this chapter can also be found in `advanced.sql` in the tutorial directory. This file also contains some sample data to load, which is not repeated here. (Refer to Section 2.1 for how to use the file.)

3.2. Views

Refer back to the queries in Section 2.6. Suppose the combined listing of weather records and city location is of particular interest to your application, but you do not want to type the query each time you need it. You can create a *view* over the query, which gives a name to the query that you can refer to like an ordinary table:

```
CREATE VIEW myview AS
    SELECT name, temp_lo, temp_hi, prcp, date, location
        FROM weather, cities
        WHERE city = name;

SELECT * FROM myview;
```

Making liberal use of views is a key aspect of good SQL database design. Views allow you to encapsulate the details of the structure of your tables, which might change as your application evolves, behind consistent interfaces.

Views can be used in almost any place a real table can be used. Building views upon other views is not uncommon.

3.3. Foreign Keys

Recall the `weather` and `cities` tables from Chapter 2. Consider the following problem: You want to make sure that no one can insert rows in the `weather` table that do not have a matching entry in the `cities` table. This is called maintaining the *referential integrity* of your data. In simplistic database systems this would be implemented (if at all) by first looking at the `cities` table to check if a matching record exists, and then inserting or rejecting the new `weather` records. This approach has a number of problems and is very inconvenient, so Postgres Pro can do this for you.

The new declaration of the tables would look like this:

```
CREATE TABLE cities (
        name     varchar(80) primary key,
        location point
);

CREATE TABLE weather (
        city      varchar(80) references cities(name),
        temp_lo   int,
        temp_hi   int,
        prcp      real,
        date      date
);
```

Now try inserting an invalid record:

```
INSERT INTO weather VALUES ('Berkeley', 45, 53, 0.0, '1994-11-28');

ERROR:  insert or update on table "weather" violates foreign key constraint
 "weather_city_fkey"
DETAIL:  Key (city)=(Berkeley) is not present in table "cities".
```

The behavior of foreign keys can be finely tuned to your application. We will not go beyond this simple example in this tutorial, but just refer you to Chapter 5 for more information. Making correct use of foreign keys will definitely improve the quality of your database applications, so you are strongly encouraged to learn about them.

3.4. Transactions

Transactions are a fundamental concept of all database systems. The essential point of a transaction is that it bundles multiple steps into a single, all-or-nothing operation. The intermediate states between the steps are not visible to other concurrent transactions, and if some failure occurs that prevents the transaction from completing, then none of the steps affect the database at all.

For example, consider a bank database that contains balances for various customer accounts, as well as total deposit balances for branches. Suppose that we want to record a payment of $100.00 from Alice's account to Bob's account. Simplifying outrageously, the SQL commands for this might look like:

```
UPDATE accounts SET balance = balance - 100.00
    WHERE name = 'Alice';
UPDATE branches SET balance = balance - 100.00
    WHERE name = (SELECT branch_name FROM accounts WHERE name = 'Alice');
UPDATE accounts SET balance = balance + 100.00
    WHERE name = 'Bob';
UPDATE branches SET balance = balance + 100.00
    WHERE name = (SELECT branch_name FROM accounts WHERE name = 'Bob');
```

The details of these commands are not important here; the important point is that there are several separate updates involved to accomplish this rather simple operation. Our bank's officers will want to be assured that either all these updates happen, or none of them happen. It would certainly not do for a system failure to result in Bob receiving $100.00 that was not debited from Alice. Nor would Alice long remain a happy customer if she was debited without Bob being credited. We need a guarantee that if something goes wrong partway through the operation, none of the steps executed so far will take effect. Grouping the updates into a *transaction* gives us this guarantee. A transaction is said to be *atomic*: from the point of view of other transactions, it either happens completely or not at all.

We also want a guarantee that once a transaction is completed and acknowledged by the database system, it has indeed been permanently recorded and won't be lost even if a crash ensues shortly thereafter. For example, if we are recording a cash withdrawal by Bob, we do not want any chance that the debit to his account will disappear in a crash just after he walks out the bank door. A transactional database guarantees that all the updates made by a transaction are logged in permanent storage (i.e., on disk) before the transaction is reported complete.

Another important property of transactional databases is closely related to the notion of atomic updates: when multiple transactions are running concurrently, each one should not be able to see the incomplete changes made by others. For example, if one transaction is busy totalling all the branch balances, it would not do for it to include the debit from Alice's branch but not the credit to Bob's branch, nor vice versa. So transactions must be all-or-nothing not only in terms of their permanent effect on the database, but also in terms of their visibility as they happen. The updates made so far by an open transaction are invisible to other transactions until the transaction completes, whereupon all the updates become visible simultaneously.

In Postgres Pro, a transaction is set up by surrounding the SQL commands of the transaction with `BEGIN` and `COMMIT` commands. So our banking transaction would actually look like:

```
BEGIN;
UPDATE accounts SET balance = balance - 100.00
```

```
    WHERE name = 'Alice';
-- etc etc
COMMIT;
```

If, partway through the transaction, we decide we do not want to commit (perhaps we just noticed that Alice's balance went negative), we can issue the command ROLLBACK instead of COMMIT, and all our updates so far will be canceled.

Postgres Pro actually treats every SQL statement as being executed within a transaction. If you do not issue a BEGIN command, then each individual statement has an implicit BEGIN and (if successful) COMMIT wrapped around it. A group of statements surrounded by BEGIN and COMMIT is sometimes called a *transaction block*.

> **Note**
>
> Some client libraries issue BEGIN and COMMIT commands automatically, so that you might get the effect of transaction blocks without asking. Check the documentation for the interface you are using.

It's possible to control the statements in a transaction in a more granular fashion through the use of *savepoints*. Savepoints allow you to selectively discard parts of the transaction, while committing the rest. After defining a savepoint with SAVEPOINT, you can if needed roll back to the savepoint with ROLLBACK TO. All the transaction's database changes between defining the savepoint and rolling back to it are discarded, but changes earlier than the savepoint are kept.

After rolling back to a savepoint, it continues to be defined, so you can roll back to it several times. Conversely, if you are sure you won't need to roll back to a particular savepoint again, it can be released, so the system can free some resources. Keep in mind that either releasing or rolling back to a savepoint will automatically release all savepoints that were defined after it.

All this is happening within the transaction block, so none of it is visible to other database sessions. When and if you commit the transaction block, the committed actions become visible as a unit to other sessions, while the rolled-back actions never become visible at all.

Remembering the bank database, suppose we debit $100.00 from Alice's account, and credit Bob's account, only to find later that we should have credited Wally's account. We could do it using savepoints like this:

```
BEGIN;
UPDATE accounts SET balance = balance - 100.00
    WHERE name = 'Alice';
SAVEPOINT my_savepoint;
UPDATE accounts SET balance = balance + 100.00
    WHERE name = 'Bob';
-- oops ... forget that and use Wally's account
ROLLBACK TO my_savepoint;
UPDATE accounts SET balance = balance + 100.00
    WHERE name = 'Wally';
COMMIT;
```

This example is, of course, oversimplified, but there's a lot of control possible in a transaction block through the use of savepoints. Moreover, ROLLBACK TO is the only way to regain control of a transaction block that was put in aborted state by the system due to an error, short of rolling it back completely and starting again.

3.5. Window Functions

A *window function* performs a calculation across a set of table rows that are somehow related to the current row. This is comparable to the type of calculation that can be done with an aggregate function.

However, window functions do not cause rows to become grouped into a single output row like non-window aggregate calls would. Instead, the rows retain their separate identities. Behind the scenes, the window function is able to access more than just the current row of the query result.

Here is an example that shows how to compare each employee's salary with the average salary in his or her department:

```
SELECT depname, empno, salary, avg(salary) OVER (PARTITION BY depname) FROM empsalary;
```

```
  depname  | empno | salary |          avg
-----------+-------+--------+-----------------------
 develop   |    11 |   5200 | 5020.0000000000000000
 develop   |     7 |   4200 | 5020.0000000000000000
 develop   |     9 |   4500 | 5020.0000000000000000
 develop   |     8 |   6000 | 5020.0000000000000000
 develop   |    10 |   5200 | 5020.0000000000000000
 personnel |     5 |   3500 | 3700.0000000000000000
 personnel |     2 |   3900 | 3700.0000000000000000
 sales     |     3 |   4800 | 4866.6666666666666667
 sales     |     1 |   5000 | 4866.6666666666666667
 sales     |     4 |   4800 | 4866.6666666666666667
(10 rows)
```

The first three output columns come directly from the table `empsalary`, and there is one output row for each row in the table. The fourth column represents an average taken across all the table rows that have the same `depname` value as the current row. (This actually is the same function as the non-window `avg` aggregate, but the `OVER` clause causes it to be treated as a window function and computed across the window frame.)

A window function call always contains an `OVER` clause directly following the window function's name and argument(s). This is what syntactically distinguishes it from a normal function or non-window aggregate. The `OVER` clause determines exactly how the rows of the query are split up for processing by the window function. The `PARTITION BY` clause within `OVER` divides the rows into groups, or partitions, that share the same values of the `PARTITION BY` expression(s). For each row, the window function is computed across the rows that fall into the same partition as the current row.

You can also control the order in which rows are processed by window functions using `ORDER BY` within `OVER`. (The window `ORDER BY` does not even have to match the order in which the rows are output.) Here is an example:

```
SELECT depname, empno, salary,
       rank() OVER (PARTITION BY depname ORDER BY salary DESC)
FROM empsalary;
```

```
  depname  | empno | salary | rank
-----------+-------+--------+------
 develop   |     8 |   6000 |    1
 develop   |    10 |   5200 |    2
 develop   |    11 |   5200 |    2
 develop   |     9 |   4500 |    4
 develop   |     7 |   4200 |    5
 personnel |     2 |   3900 |    1
 personnel |     5 |   3500 |    2
 sales     |     1 |   5000 |    1
 sales     |     4 |   4800 |    2
 sales     |     3 |   4800 |    2
(10 rows)
```

As shown here, the `rank` function produces a numerical rank for each distinct `ORDER BY` value in the current row's partition, using the order defined by the `ORDER BY` clause. `rank` needs no explicit parameter, because its behavior is entirely determined by the `OVER` clause.

The rows considered by a window function are those of the “virtual table” produced by the query's FROM clause as filtered by its WHERE, GROUP BY, and HAVING clauses if any. For example, a row removed because it does not meet the WHERE condition is not seen by any window function. A query can contain multiple window functions that slice up the data in different ways using different OVER clauses, but they all act on the same collection of rows defined by this virtual table.

We already saw that ORDER BY can be omitted if the ordering of rows is not important. It is also possible to omit PARTITION BY, in which case there is a single partition containing all rows.

There is another important concept associated with window functions: for each row, there is a set of rows within its partition called its *window frame*. Some window functions act only on the rows of the window frame, rather than of the whole partition. By default, if ORDER BY is supplied then the frame consists of all rows from the start of the partition up through the current row, plus any following rows that are equal to the current row according to the ORDER BY clause. When ORDER BY is omitted the default frame consists of all rows in the partition. [1] Here is an example using sum:

```
SELECT salary, sum(salary) OVER () FROM empsalary;
```

```
 salary |  sum
--------+-------
   5200 | 47100
   5000 | 47100
   3500 | 47100
   4800 | 47100
   3900 | 47100
   4200 | 47100
   4500 | 47100
   4800 | 47100
   6000 | 47100
   5200 | 47100
(10 rows)
```

Above, since there is no ORDER BY in the OVER clause, the window frame is the same as the partition, which for lack of PARTITION BY is the whole table; in other words each sum is taken over the whole table and so we get the same result for each output row. But if we add an ORDER BY clause, we get very different results:

```
SELECT salary, sum(salary) OVER (ORDER BY salary) FROM empsalary;
```

```
 salary |  sum
--------+-------
   3500 |  3500
   3900 |  7400
   4200 | 11600
   4500 | 16100
   4800 | 25700
   4800 | 25700
   5000 | 30700
   5200 | 41100
   5200 | 41100
   6000 | 47100
(10 rows)
```

Here the sum is taken from the first (lowest) salary up through the current one, including any duplicates of the current one (notice the results for the duplicated salaries).

Window functions are permitted only in the SELECT list and the ORDER BY clause of the query. They are forbidden elsewhere, such as in GROUP BY, HAVING and WHERE clauses. This is because they logically execute after the processing of those clauses. Also, window functions execute after non-window aggregate

[1] There are options to define the window frame in other ways, but this tutorial does not cover them. See Section 4.2.8 for details.

functions. This means it is valid to include an aggregate function call in the arguments of a window function, but not vice versa.

If there is a need to filter or group rows after the window calculations are performed, you can use a sub-select. For example:

```
SELECT depname, empno, salary, enroll_date
FROM
  (SELECT depname, empno, salary, enroll_date,
          rank() OVER (PARTITION BY depname ORDER BY salary DESC, empno) AS pos
     FROM empsalary
  ) AS ss
WHERE pos < 3;
```

The above query only shows the rows from the inner query having `rank` less than 3.

When a query involves multiple window functions, it is possible to write out each one with a separate `OVER` clause, but this is duplicative and error-prone if the same windowing behavior is wanted for several functions. Instead, each windowing behavior can be named in a `WINDOW` clause and then referenced in `OVER`. For example:

```
SELECT sum(salary) OVER w, avg(salary) OVER w
  FROM empsalary
  WINDOW w AS (PARTITION BY depname ORDER BY salary DESC);
```

More details about window functions can be found in Section 4.2.8, Section 9.22, Section 7.2.5, and the SELECT reference page.

3.6. Inheritance

Inheritance is a concept from object-oriented databases. It opens up interesting new possibilities of database design.

Let's create two tables: A table `cities` and a table `capitals`. Naturally, capitals are also cities, so you want some way to show the capitals implicitly when you list all cities. If you're really clever you might invent some scheme like this:

```
CREATE TABLE capitals (
  name       text,
  population real,
  elevation  int,    -- (in ft)
  state      char(2)
);

CREATE TABLE non_capitals (
  name       text,
  population real,
  elevation  int     -- (in ft)
);

CREATE VIEW cities AS
  SELECT name, population, elevation FROM capitals
    UNION
  SELECT name, population, elevation FROM non_capitals;
```

This works OK as far as querying goes, but it gets ugly when you need to update several rows, for one thing.

A better solution is this:

```
CREATE TABLE cities (
  name       text,
```

```
  population real,
  elevation  int     -- (in ft)
);

CREATE TABLE capitals (
  state      char(2) UNIQUE NOT NULL
) INHERITS (cities);
```

In this case, a row of `capitals` *inherits* all columns (`name`, `population`, and `elevation`) from its *parent*, `cities`. The type of the column `name` is `text`, a native Postgres Pro type for variable length character strings. The `capitals` table has an additional column, `state`, which shows its state abbreviation. In Postgres Pro, a table can inherit from zero or more other tables.

For example, the following query finds the names of all cities, including state capitals, that are located at an elevation over 500 feet:

```
SELECT name, elevation
  FROM cities
  WHERE elevation > 500;
```

which returns:

```
   name    | elevation
-----------+-----------
 Las Vegas |      2174
 Mariposa  |      1953
 Madison   |       845
(3 rows)
```

On the other hand, the following query finds all the cities that are not state capitals and are situated at an elevation over 500 feet:

```
SELECT name, elevation
    FROM ONLY cities
    WHERE elevation > 500;
```

```
   name    | elevation
-----------+-----------
 Las Vegas |      2174
 Mariposa  |      1953
(2 rows)
```

Here the `ONLY` before `cities` indicates that the query should be run over only the `cities` table, and not tables below `cities` in the inheritance hierarchy. Many of the commands that we have already discussed — `SELECT`, `UPDATE`, and `DELETE` — support this `ONLY` notation.

> **Note**
>
> Although inheritance is frequently useful, it has not been integrated with unique constraints or foreign keys, which limits its usefulness. See Section 5.10 for more detail.

3.7. Conclusion

Postgres Pro has many features not touched upon in this tutorial introduction, which has been oriented toward newer users of SQL. These features are discussed in more detail in the remainder of this book.

If you feel you need more introductory material, please visit the PostgreSQL *web site* for links to more resources.

Part II. The SQL Language

This part describes the use of the SQL language in Postgres Pro. We start with describing the general syntax of SQL, then explain how to create the structures to hold data, how to populate the database, and how to query it. The middle part lists the available data types and functions for use in SQL commands. The rest treats several aspects that are important for tuning a database for optimal performance.

The information in this part is arranged so that a novice user can follow it start to end to gain a full understanding of the topics without having to refer forward too many times. The chapters are intended to be self-contained, so that advanced users can read the chapters individually as they choose. The information in this part is presented in a narrative fashion in topical units. Readers looking for a complete description of a particular command should see Part VI.

Readers of this part should know how to connect to a Postgres Pro database and issue SQL commands. Readers that are unfamiliar with these issues are encouraged to read Part I first. SQL commands are typically entered using the Postgres Pro interactive terminal psql, but other programs that have similar functionality can be used as well.

Chapter 4. SQL Syntax

This chapter describes the syntax of SQL. It forms the foundation for understanding the following chapters which will go into detail about how SQL commands are applied to define and modify data.

We also advise users who are already familiar with SQL to read this chapter carefully because it contains several rules and concepts that are implemented inconsistently among SQL databases or that are specific to Postgres Pro.

4.1. Lexical Structure

SQL input consists of a sequence of *commands*. A command is composed of a sequence of *tokens*, terminated by a semicolon (";"). The end of the input stream also terminates a command. Which tokens are valid depends on the syntax of the particular command.

A token can be a *key word*, an *identifier*, a *quoted identifier*, a *literal* (or constant), or a special character symbol. Tokens are normally separated by whitespace (space, tab, newline), but need not be if there is no ambiguity (which is generally only the case if a special character is adjacent to some other token type).

For example, the following is (syntactically) valid SQL input:

```
SELECT * FROM MY_TABLE;
UPDATE MY_TABLE SET A = 5;
INSERT INTO MY_TABLE VALUES (3, 'hi there');
```

This is a sequence of three commands, one per line (although this is not required; more than one command can be on a line, and commands can usefully be split across lines).

Additionally, *comments* can occur in SQL input. They are not tokens, they are effectively equivalent to whitespace.

The SQL syntax is not very consistent regarding what tokens identify commands and which are operands or parameters. The first few tokens are generally the command name, so in the above example we would usually speak of a "SELECT", an "UPDATE", and an "INSERT" command. But for instance the `UPDATE` command always requires a `SET` token to appear in a certain position, and this particular variation of `INSERT` also requires a `VALUES` in order to be complete. The precise syntax rules for each command are described in Part VI.

4.1.1. Identifiers and Key Words

Tokens such as `SELECT`, `UPDATE`, or `VALUES` in the example above are examples of *key words*, that is, words that have a fixed meaning in the SQL language. The tokens `MY_TABLE` and `A` are examples of *identifiers*. They identify names of tables, columns, or other database objects, depending on the command they are used in. Therefore they are sometimes simply called "names". Key words and identifiers have the same lexical structure, meaning that one cannot know whether a token is an identifier or a key word without knowing the language. A complete list of key words can be found in Appendix C.

SQL identifiers and key words must begin with a letter (`a-z`, but also letters with diacritical marks and non-Latin letters) or an underscore (_). Subsequent characters in an identifier or key word can be letters, underscores, digits (`0-9`), or dollar signs (`$`). Note that dollar signs are not allowed in identifiers according to the letter of the SQL standard, so their use might render applications less portable. The SQL standard will not define a key word that contains digits or starts or ends with an underscore, so identifiers of this form are safe against possible conflict with future extensions of the standard.

The system uses no more than `NAMEDATALEN`-1 bytes of an identifier; longer names can be written in commands, but they will be truncated. By default, `NAMEDATALEN` is 64 so the maximum identifier length is 63 bytes.

Key words and unquoted identifiers are case insensitive. Therefore:

```
UPDATE MY_TABLE SET A = 5;
```

can equivalently be written as:

```
uPDaTE my_TabLE SeT a = 5;
```

A convention often used is to write key words in upper case and names in lower case, e.g.:

```
UPDATE my_table SET a = 5;
```

There is a second kind of identifier: the *delimited identifier* or *quoted identifier*. It is formed by enclosing an arbitrary sequence of characters in double-quotes (`"`). A delimited identifier is always an identifier, never a key word. So `"select"` could be used to refer to a column or table named “select”, whereas an unquoted `select` would be taken as a key word and would therefore provoke a parse error when used where a table or column name is expected. The example can be written with quoted identifiers like this:

```
UPDATE "my_table" SET "a" = 5;
```

Quoted identifiers can contain any character, except the character with code zero. (To include a double quote, write two double quotes.) This allows constructing table or column names that would otherwise not be possible, such as ones containing spaces or ampersands. The length limitation still applies.

Quoting an identifier also makes it case-sensitive, whereas unquoted names are always folded to lower case. For example, the identifiers `FOO`, `foo`, and `"foo"` are considered the same by Postgres Pro, but `"Foo"` and `"FOO"` are different from these three and each other. (The folding of unquoted names to lower case in Postgres Pro is incompatible with the SQL standard, which says that unquoted names should be folded to upper case. Thus, `foo` should be equivalent to `"FOO"` not `"foo"` according to the standard. If you want to write portable applications you are advised to always quote a particular name or never quote it.)

A variant of quoted identifiers allows including escaped Unicode characters identified by their code points. This variant starts with `U&` (upper or lower case U followed by ampersand) immediately before the opening double quote, without any spaces in between, for example `U&"foo"`. (Note that this creates an ambiguity with the operator `&`. Use spaces around the operator to avoid this problem.) Inside the quotes, Unicode characters can be specified in escaped form by writing a backslash followed by the four-digit hexadecimal code point number or alternatively a backslash followed by a plus sign followed by a six-digit hexadecimal code point number. For example, the identifier `"data"` could be written as

```
U&"d\0061t\+000061"
```

The following less trivial example writes the Russian word “slon” (elephant) in Cyrillic letters:

```
U&"\0441\043B\043E\043D"
```

If a different escape character than backslash is desired, it can be specified using the `UESCAPE`clause after the string, for example:

```
U&"d!0061t!+000061" UESCAPE '!'
```

The escape character can be any single character other than a hexadecimal digit, the plus sign, a single quote, a double quote, or a whitespace character. Note that the escape character is written in single quotes, not double quotes, after `UESCAPE`.

To include the escape character in the identifier literally, write it twice.

Either the 4-digit or the 6-digit escape form can be used to specify UTF-16 surrogate pairs to compose characters with code points larger than U+FFFF, although the availability of the 6-digit form technically makes this unnecessary. (Surrogate pairs are not stored directly, but are combined into a single code point.)

If the server encoding is not UTF-8, the Unicode code point identified by one of these escape sequences is converted to the actual server encoding; an error is reported if that's not possible.

4.1.2. Constants

There are three kinds of *implicitly-typed constants* in Postgres Pro: strings, bit strings, and numbers. Constants can also be specified with explicit types, which can enable more accurate representation and more efficient handling by the system. These alternatives are discussed in the following subsections.

4.1.2.1. String Constants

A string constant in SQL is an arbitrary sequence of characters bounded by single quotes (`'`), for example `'This is a string'`. To include a single-quote character within a string constant, write two adjacent single quotes, e.g., `'Dianne''s horse'`. Note that this is *not* the same as a double-quote character (`"`).

Two string constants that are only separated by whitespace *with at least one newline* are concatenated and effectively treated as if the string had been written as one constant. For example:

```
SELECT 'foo'
'bar';
```

is equivalent to:

```
SELECT 'foobar';
```

but:

```
SELECT 'foo'      'bar';
```

is not valid syntax. (This slightly bizarre behavior is specified by SQL; Postgres Pro is following the standard.)

4.1.2.2. String Constants with C-Style Escapes

Postgres Pro also accepts “escape” string constants, which are an extension to the SQL standard. An escape string constant is specified by writing the letter `E` (upper or lower case) just before the opening single quote, e.g., `E'foo'`. (When continuing an escape string constant across lines, write `E` only before the first opening quote.) Within an escape string, a backslash character (`\`) begins a C-like *backslash escape* sequence, in which the combination of backslash and following character(s) represent a special byte value, as shown in Table 4.1.

Table 4.1. Backslash Escape Sequences

Backslash Escape Sequence	Interpretation
`\b`	backspace
`\f`	form feed
`\n`	newline
`\r`	carriage return
`\t`	tab
`\`*o*, `\`*oo*, `\`*ooo* (*o* = 0–7)	octal byte value
`\x`*h*, `\x`*hh* (*h* = 0–9, A–F)	hexadecimal byte value
`\u`*xxxx*, `\U`*xxxxxxxx* (*x* = 0–9, A–F)	16 or 32-bit hexadecimal Unicode character value

Any other character following a backslash is taken literally. Thus, to include a backslash character, write two backslashes (`\\`). Also, a single quote can be included in an escape string by writing `\'`, in addition to the normal way of `''`.

It is your responsibility that the byte sequences you create, especially when using the octal or hexadecimal escapes, compose valid characters in the server character set encoding. A useful alternative is to use Unicode escapes or the alternative Unicode escape syntax, explained in Section 4.1.2.3; then the server will check that the character conversion is possible.

> **Caution**
>
> If the configuration parameter standard_conforming_strings is `off`, then Postgres Pro recognizes backslash escapes in both regular and escape string constants. However, as of PostgreSQL 9.1, the default is `on`, meaning that backslash escapes are recognized only in escape string constants. This behavior is more standards-compliant, but might break applications which rely on the historical behavior, where backslash escapes were always recognized. As a workaround, you can set this

parameter to `off`, but it is better to migrate away from using backslash escapes. If you need to use a backslash escape to represent a special character, write the string constant with an `E`.

In addition to `standard_conforming_strings`, the configuration parameters escape_string_warning and backslash_quote govern treatment of backslashes in string constants.

The character with the code zero cannot be in a string constant.

4.1.2.3. String Constants with Unicode Escapes

Postgres Pro also supports another type of escape syntax for strings that allows specifying arbitrary Unicode characters by code point. A Unicode escape string constant starts with `U&` (upper or lower case letter U followed by ampersand) immediately before the opening quote, without any spaces in between, for example `U&'foo'`. (Note that this creates an ambiguity with the operator `&`. Use spaces around the operator to avoid this problem.) Inside the quotes, Unicode characters can be specified in escaped form by writing a backslash followed by the four-digit hexadecimal code point number or alternatively a backslash followed by a plus sign followed by a six-digit hexadecimal code point number. For example, the string `'data'` could be written as

```
U&'d\0061t\+000061'
```

The following less trivial example writes the Russian word “slon” (elephant) in Cyrillic letters:

```
U&'\0441\043B\043E\043D'
```

If a different escape character than backslash is desired, it can be specified using the `UESCAPE`clause after the string, for example:

```
U&'d!0061t!+000061' UESCAPE '!'
```

The escape character can be any single character other than a hexadecimal digit, the plus sign, a single quote, a double quote, or a whitespace character.

To include the escape character in the string literally, write it twice.

Either the 4-digit or the 6-digit escape form can be used to specify UTF-16 surrogate pairs to compose characters with code points larger than U+FFFF, although the availability of the 6-digit form technically makes this unnecessary. (Surrogate pairs are not stored directly, but are combined into a single code point.)

If the server encoding is not UTF-8, the Unicode code point identified by one of these escape sequences is converted to the actual server encoding; an error is reported if that's not possible.

Also, the Unicode escape syntax for string constants only works when the configuration parameter standard_conforming_strings is turned on. This is because otherwise this syntax could confuse clients that parse the SQL statements to the point that it could lead to SQL injections and similar security issues. If the parameter is set to off, this syntax will be rejected with an error message.

4.1.2.4. Dollar-Quoted String Constants

While the standard syntax for specifying string constants is usually convenient, it can be difficult to understand when the desired string contains many single quotes, since each of those must be doubled. To allow more readable queries in such situations, Postgres Pro provides another way, called “dollar quoting”, to write string constants. A dollar-quoted string constant consists of a dollar sign (`$`), an optional “tag” of zero or more characters, another dollar sign, an arbitrary sequence of characters that makes up the string content, a dollar sign, the same tag that began this dollar quote, and a dollar sign. For example, here are two different ways to specify the string “Dianne's horse” using dollar quoting:

```
$$Dianne's horse$$
$SomeTag$Dianne's horse$SomeTag$
```

Notice that inside the dollar-quoted string, single quotes can be used without needing to be escaped. Indeed, no characters inside a dollar-quoted string are ever escaped: the string content is always written

literally. Backslashes are not special, and neither are dollar signs, unless they are part of a sequence matching the opening tag.

It is possible to nest dollar-quoted string constants by choosing different tags at each nesting level. This is most commonly used in writing function definitions. For example:

```
$function$
BEGIN
    RETURN ($1 ~ $q$[\t\r\n\v\\]$q$);
END;
$function$
```

Here, the sequence `$q$[\t\r\n\v\\]$q$` represents a dollar-quoted literal string `[\t\r\n\v\\]`, which will be recognized when the function body is executed by Postgres Pro. But since the sequence does not match the outer dollar quoting delimiter `$function$`, it is just some more characters within the constant so far as the outer string is concerned.

The tag, if any, of a dollar-quoted string follows the same rules as an unquoted identifier, except that it cannot contain a dollar sign. Tags are case sensitive, so `$tag$String content$tag$` is correct, but `$TAG$String content$tag$` is not.

A dollar-quoted string that follows a keyword or identifier must be separated from it by whitespace; otherwise the dollar quoting delimiter would be taken as part of the preceding identifier.

Dollar quoting is not part of the SQL standard, but it is often a more convenient way to write complicated string literals than the standard-compliant single quote syntax. It is particularly useful when representing string constants inside other constants, as is often needed in procedural function definitions. With single-quote syntax, each backslash in the above example would have to be written as four backslashes, which would be reduced to two backslashes in parsing the original string constant, and then to one when the inner string constant is re-parsed during function execution.

4.1.2.5. Bit-String Constants

Bit-string constants look like regular string constants with a `B` (upper or lower case) immediately before the opening quote (no intervening whitespace), e.g., `B'1001'`. The only characters allowed within bit-string constants are `0` and `1`.

Alternatively, bit-string constants can be specified in hexadecimal notation, using a leading `X` (upper or lower case), e.g., `X'1FF'`. This notation is equivalent to a bit-string constant with four binary digits for each hexadecimal digit.

Both forms of bit-string constant can be continued across lines in the same way as regular string constants. Dollar quoting cannot be used in a bit-string constant.

4.1.2.6. Numeric Constants

Numeric constants are accepted in these general forms:

digits
digits.[*digits*][e[+-]*digits*]
[*digits*].*digits*[e[+-]*digits*]
*digits*e[+-]*digits*

where *digits* is one or more decimal digits (0 through 9). At least one digit must be before or after the decimal point, if one is used. At least one digit must follow the exponent marker (e), if one is present. There cannot be any spaces or other characters embedded in the constant. Note that any leading plus or minus sign is not actually considered part of the constant; it is an operator applied to the constant.

These are some examples of valid numeric constants:

42
3.5
4.

.001
5e2
1.925e-3

A numeric constant that contains neither a decimal point nor an exponent is initially presumed to be type `integer` if its value fits in type `integer` (32 bits); otherwise it is presumed to be type `bigint` if its value fits in type `bigint` (64 bits); otherwise it is taken to be type `numeric`. Constants that contain decimal points and/or exponents are always initially presumed to be type `numeric`.

The initially assigned data type of a numeric constant is just a starting point for the type resolution algorithms. In most cases the constant will be automatically coerced to the most appropriate type depending on context. When necessary, you can force a numeric value to be interpreted as a specific data type by casting it. For example, you can force a numeric value to be treated as type `real` (`float4`) by writing:

```
REAL '1.23'  -- string style
1.23::REAL   -- Postgres Pro (historical) style
```

These are actually just special cases of the general casting notations discussed next.

4.1.2.7. Constants of Other Types

A constant of an *arbitrary* type can be entered using any one of the following notations:

```
type 'string'
'string'::type
CAST ( 'string' AS type )
```

The string constant's text is passed to the input conversion routine for the type called *type*. The result is a constant of the indicated type. The explicit type cast can be omitted if there is no ambiguity as to the type the constant must be (for example, when it is assigned directly to a table column), in which case it is automatically coerced.

The string constant can be written using either regular SQL notation or dollar-quoting.

It is also possible to specify a type coercion using a function-like syntax:

```
typename ( 'string' )
```

but not all type names can be used in this way; see Section 4.2.9 for details.

The `::`, `CAST()`, and function-call syntaxes can also be used to specify run-time type conversions of arbitrary expressions, as discussed in Section 4.2.9. To avoid syntactic ambiguity, the *type* `'string'` syntax can only be used to specify the type of a simple literal constant. Another restriction on the *type* `'string'` syntax is that it does not work for array types; use `::` or `CAST()` to specify the type of an array constant.

The `CAST()` syntax conforms to SQL. The *type* `'string'` syntax is a generalization of the standard: SQL specifies this syntax only for a few data types, but Postgres Pro allows it for all types. The syntax with `::` is historical Postgres Pro usage, as is the function-call syntax.

4.1.3. Operators

An operator name is a sequence of up to `NAMEDATALEN`-1 (63 by default) characters from the following list:

+ - * / < > = ~ ! @ # % ^ & | ` ?

There are a few restrictions on operator names, however:

- `--` and `/*` cannot appear anywhere in an operator name, since they will be taken as the start of a comment.
- A multiple-character operator name cannot end in `+` or `-`, unless the name also contains at least one of these characters:

  ~ ! @ # % ^ & | ` ?

For example, `@-` is an allowed operator name, but `*-` is not. This restriction allows Postgres Pro to parse SQL-compliant queries without requiring spaces between tokens.

When working with non-SQL-standard operator names, you will usually need to separate adjacent operators with spaces to avoid ambiguity. For example, if you have defined a prefix operator named `@`, you cannot write `X*@Y`; you must write `X* @Y` to ensure that Postgres Pro reads it as two operator names not one.

4.1.4. Special Characters

Some characters that are not alphanumeric have a special meaning that is different from being an operator. Details on the usage can be found at the location where the respective syntax element is described. This section only exists to advise the existence and summarize the purposes of these characters.

- A dollar sign (`$`) followed by digits is used to represent a positional parameter in the body of a function definition or a prepared statement. In other contexts the dollar sign can be part of an identifier or a dollar-quoted string constant.
- Parentheses (`()`) have their usual meaning to group expressions and enforce precedence. In some cases parentheses are required as part of the fixed syntax of a particular SQL command.
- Brackets (`[]`) are used to select the elements of an array. See Section 8.15 for more information on arrays.
- Commas (`,`) are used in some syntactical constructs to separate the elements of a list.
- The semicolon (`;`) terminates an SQL command. It cannot appear anywhere within a command, except within a string constant or quoted identifier.
- The colon (`:`) is used to select “slices” from arrays. (See Section 8.15.) In certain SQL dialects (such as Embedded SQL), the colon is used to prefix variable names.
- The asterisk (`*`) is used in some contexts to denote all the fields of a table row or composite value. It also has a special meaning when used as the argument of an aggregate function, namely that the aggregate does not require any explicit parameter.
- The period (`.`) is used in numeric constants, and to separate schema, table, and column names.

4.1.5. Comments

A comment is a sequence of characters beginning with double dashes and extending to the end of the line, e.g.:

```
-- This is a standard SQL comment
```

Alternatively, C-style block comments can be used:

```
/* multiline comment
 * with nesting: /* nested block comment */
 */
```

where the comment begins with `/*` and extends to the matching occurrence of `*/`. These block comments nest, as specified in the SQL standard but unlike C, so that one can comment out larger blocks of code that might contain existing block comments.

A comment is removed from the input stream before further syntax analysis and is effectively replaced by whitespace.

4.1.6. Operator Precedence

Table 4.2 shows the precedence and associativity of the operators in Postgres Pro. Most operators have the same precedence and are left-associative. The precedence and associativity of the operators is hardwired into the parser. Add parentheses if you want an expression with multiple operators to be parsed in some other way than what the precedence rules imply.

Table 4.2. Operator Precedence (highest to lowest)

Operator/Element	Associativity	Description
.	left	table/column name separator
::	left	Postgres Pro-style typecast
[ ]	left	array element selection
+ -	right	unary plus, unary minus
COLLATE	left	collation selection
AT	left	AT TIME ZONE
^	left	exponentiation
* / %	left	multiplication, division, modulo
+ -	left	addition, subtraction
(any other operator)	left	all other native and user-defined operators
BETWEEN IN LIKE ILIKE SIMILAR		range containment, set membership, string matching
< > = <= >= <>		comparison operators
IS ISNULL NOTNULL		IS TRUE, IS FALSE, IS NULL, IS DISTINCT FROM, etc
NOT	right	logical negation
AND	left	logical conjunction
OR	left	logical disjunction

Note that the operator precedence rules also apply to user-defined operators that have the same names as the built-in operators mentioned above. For example, if you define a "+" operator for some custom data type it will have the same precedence as the built-in "+" operator, no matter what yours does.

When a schema-qualified operator name is used in the OPERATOR syntax, as for example in:

```
SELECT 3 OPERATOR(pg_catalog.+) 4;
```

the OPERATOR construct is taken to have the default precedence shown in Table 4.2 for "any other operator". This is true no matter which specific operator appears inside OPERATOR().

> **Note**
>
> PostgreSQL versions before 9.5 used slightly different operator precedence rules. In particular, <= >= and <> used to be treated as generic operators; IS tests used to have higher priority; and NOT BETWEEN and related constructs acted inconsistently, being taken in some cases as having the precedence of NOT rather than BETWEEN. These rules were changed for better compliance with the SQL standard and to reduce confusion from inconsistent treatment of logically equivalent constructs. In most cases, these changes will result in no behavioral change, or perhaps in "no such operator" failures which can be resolved by adding parentheses. However there are corner cases in which a query might change behavior without any parsing error being reported.

4.2. Value Expressions

Value expressions are used in a variety of contexts, such as in the target list of the SELECT command, as new column values in INSERT or UPDATE, or in search conditions in a number of commands. The result of a value expression is sometimes called a *scalar*, to distinguish it from the result of a table expression (which is a table). Value expressions are therefore also called *scalar expressions* (or even

simply *expressions*). The expression syntax allows the calculation of values from primitive parts using arithmetic, logical, set, and other operations.

A value expression is one of the following:

- A constant or literal value
- A column reference
- A positional parameter reference, in the body of a function definition or prepared statement
- A subscripted expression
- A field selection expression
- An operator invocation
- A function call
- An aggregate expression
- A window function call
- A type cast
- A collation expression
- A scalar subquery
- An array constructor
- A row constructor
- Another value expression in parentheses (used to group subexpressions and override precedence)

In addition to this list, there are a number of constructs that can be classified as an expression but do not follow any general syntax rules. These generally have the semantics of a function or operator and are explained in the appropriate location in Chapter 9. An example is the `IS NULL` clause.

We have already discussed constants in Section 4.1.2. The following sections discuss the remaining options.

4.2.1. Column References

A column can be referenced in the form:

correlation.*columnname*

correlation is the name of a table (possibly qualified with a schema name), or an alias for a table defined by means of a `FROM` clause. The correlation name and separating dot can be omitted if the column name is unique across all the tables being used in the current query. (See also Chapter 7.)

4.2.2. Positional Parameters

A positional parameter reference is used to indicate a value that is supplied externally to an SQL statement. Parameters are used in SQL function definitions and in prepared queries. Some client libraries also support specifying data values separately from the SQL command string, in which case parameters are used to refer to the out-of-line data values. The form of a parameter reference is:

$*number*

For example, consider the definition of a function, `dept`, as:

```
CREATE FUNCTION dept(text) RETURNS dept
    AS $$ SELECT * FROM dept WHERE name = $1 $$
    LANGUAGE SQL;
```

Here the `$1` references the value of the first function argument whenever the function is invoked.

4.2.3. Subscripts

If an expression yields a value of an array type, then a specific element of the array value can be extracted by writing

expression[*subscript*]

or multiple adjacent elements (an "array slice") can be extracted by writing

expression[*lower_subscript*:*upper_subscript*]

(Here, the brackets [ ] are meant to appear literally.) Each *subscript* is itself an expression, which will be rounded to the nearest integer value.

In general the array *expression* must be parenthesized, but the parentheses can be omitted when the expression to be subscripted is just a column reference or positional parameter. Also, multiple subscripts can be concatenated when the original array is multidimensional. For example:

```
mytable.arraycolumn[4]
mytable.two_d_column[17][34]
$1[10:42]
(arrayfunction(a,b))[42]
```

The parentheses in the last example are required. See Section 8.15 for more about arrays.

4.2.4. Field Selection

If an expression yields a value of a composite type (row type), then a specific field of the row can be extracted by writing

expression.*fieldname*

In general the row *expression* must be parenthesized, but the parentheses can be omitted when the expression to be selected from is just a table reference or positional parameter. For example:

```
mytable.mycolumn
$1.somecolumn
(rowfunction(a,b)).col3
```

(Thus, a qualified column reference is actually just a special case of the field selection syntax.) An important special case is extracting a field from a table column that is of a composite type:

```
(compositecol).somefield
(mytable.compositecol).somefield
```

The parentheses are required here to show that `compositecol` is a column name not a table name, or that `mytable` is a table name not a schema name in the second case.

You can ask for all fields of a composite value by writing `.*`:

```
(compositecol).*
```

This notation behaves differently depending on context; see Section 8.16.5 for details.

4.2.5. Operator Invocations

There are two possible syntaxes for an operator invocation:

expression operator expression (binary infix operator)
operator expression (unary prefix operator)

where the *operator* token follows the syntax rules of Section 4.1.3, or is one of the key words `AND`, `OR`, and `NOT`, or is a qualified operator name in the form:

`OPERATOR(`*schema*`.`*operatorname*`)`

Which particular operators exist and whether they are unary or binary depends on what operators have been defined by the system or the user. Chapter 9 describes the built-in operators.

4.2.6. Function Calls

The syntax for a function call is the name of a function (possibly qualified with a schema name), followed by its argument list enclosed in parentheses:

```
function_name ([expression [, expression ... ]] )
```

For example, the following computes the square root of 2:

```
sqrt(2)
```

The list of built-in functions is in Chapter 9. Other functions can be added by the user.

When issuing queries in a database where some users mistrust other users, observe security precautions from Section 10.3 when writing function calls.

The arguments can optionally have names attached. See Section 4.3 for details.

> **Note**
>
> A function that takes a single argument of composite type can optionally be called using field-selection syntax, and conversely field selection can be written in functional style. That is, the notations `col(table)` and `table.col` are interchangeable. This behavior is not SQL-standard but is provided in Postgres Pro because it allows use of functions to emulate "computed fields". For more information see Section 8.16.5.

4.2.7. Aggregate Expressions

An *aggregate expression* represents the application of an aggregate function across the rows selected by a query. An aggregate function reduces multiple inputs to a single output value, such as the sum or average of the inputs. The syntax of an aggregate expression is one of the following:

```
aggregate_name (expression [ , ... ] [ order_by_clause ] ) [ FILTER
 ( WHERE filter_clause ) ]
aggregate_name (ALL expression [ , ... ] [ order_by_clause ] ) [ FILTER
 ( WHERE filter_clause ) ]
aggregate_name (DISTINCT expression [ , ... ] [ order_by_clause ] ) [ FILTER
 ( WHERE filter_clause ) ]
aggregate_name ( * ) [ FILTER ( WHERE filter_clause ) ]
aggregate_name ( [ expression [ , ... ] ] ) WITHIN GROUP ( order_by_clause ) [ FILTER
 ( WHERE filter_clause ) ]
```

where *aggregate_name* is a previously defined aggregate (possibly qualified with a schema name) and *expression* is any value expression that does not itself contain an aggregate expression or a window function call. The optional *order_by_clause* and *filter_clause* are described below.

The first form of aggregate expression invokes the aggregate once for each input row. The second form is the same as the first, since `ALL` is the default. The third form invokes the aggregate once for each distinct value of the expression (or distinct set of values, for multiple expressions) found in the input rows. The fourth form invokes the aggregate once for each input row; since no particular input value is specified, it is generally only useful for the `count(*)` aggregate function. The last form is used with *ordered-set* aggregate functions, which are described below.

Most aggregate functions ignore null inputs, so that rows in which one or more of the expression(s) yield null are discarded. This can be assumed to be true, unless otherwise specified, for all built-in aggregates.

For example, `count(*)` yields the total number of input rows; `count(f1)` yields the number of input rows in which `f1` is non-null, since `count` ignores nulls; and `count(distinct f1)` yields the number of distinct non-null values of `f1`.

Ordinarily, the input rows are fed to the aggregate function in an unspecified order. In many cases this does not matter; for example, `min` produces the same result no matter what order it receives the inputs in.

However, some aggregate functions (such as `array_agg` and `string_agg`) produce results that depend on the ordering of the input rows. When using such an aggregate, the optional *`order_by_clause`* can be used to specify the desired ordering. The *`order_by_clause`* has the same syntax as for a query-level `ORDER BY` clause, as described in Section 7.5, except that its expressions are always just expressions and cannot be output-column names or numbers. For example:

```
SELECT array_agg(a ORDER BY b DESC) FROM table;
```

When dealing with multiple-argument aggregate functions, note that the `ORDER BY` clause goes after all the aggregate arguments. For example, write this:

```
SELECT string_agg(a, ',' ORDER BY a) FROM table;
```

not this:

```
SELECT string_agg(a ORDER BY a, ',') FROM table;  -- incorrect
```

The latter is syntactically valid, but it represents a call of a single-argument aggregate function with two `ORDER BY` keys (the second one being rather useless since it's a constant).

If `DISTINCT` is specified in addition to an *`order_by_clause`*, then all the `ORDER BY` expressions must match regular arguments of the aggregate; that is, you cannot sort on an expression that is not included in the `DISTINCT` list.

> **Note**
>
> The ability to specify both `DISTINCT` and `ORDER BY` in an aggregate function is a Postgres Pro extension.

Placing `ORDER BY` within the aggregate's regular argument list, as described so far, is used when ordering the input rows for general-purpose and statistical aggregates, for which ordering is optional. There is a subclass of aggregate functions called *ordered-set aggregates* for which an *`order_by_clause`* is *required*, usually because the aggregate's computation is only sensible in terms of a specific ordering of its input rows. Typical examples of ordered-set aggregates include rank and percentile calculations. For an ordered-set aggregate, the *`order_by_clause`* is written inside `WITHIN GROUP (...)`, as shown in the final syntax alternative above. The expressions in the *`order_by_clause`* are evaluated once per input row just like regular aggregate arguments, sorted as per the *`order_by_clause`*'s requirements, and fed to the aggregate function as input arguments. (This is unlike the case for a non-`WITHIN GROUP` *`order_by_clause`*, which is not treated as argument(s) to the aggregate function.) The argument expressions preceding `WITHIN GROUP`, if any, are called *direct arguments* to distinguish them from the *aggregated arguments* listed in the *`order_by_clause`*. Unlike regular aggregate arguments, direct arguments are evaluated only once per aggregate call, not once per input row. This means that they can contain variables only if those variables are grouped by `GROUP BY`; this restriction is the same as if the direct arguments were not inside an aggregate expression at all. Direct arguments are typically used for things like percentile fractions, which only make sense as a single value per aggregation calculation. The direct argument list can be empty; in this case, write just `()` not `(*)`. (Postgres Pro will actually accept either spelling, but only the first way conforms to the SQL standard.)

An example of an ordered-set aggregate call is:

```
SELECT percentile_cont(0.5) WITHIN GROUP (ORDER BY income) FROM households;
 percentile_cont
-----------------
           50489
```

which obtains the 50th percentile, or median, value of the `income` column from table `households`. Here, `0.5` is a direct argument; it would make no sense for the percentile fraction to be a value varying across rows.

If `FILTER` is specified, then only the input rows for which the *`filter_clause`* evaluates to true are fed to the aggregate function; other rows are discarded. For example:

```
SELECT
    count(*) AS unfiltered,
    count(*) FILTER (WHERE i < 5) AS filtered
FROM generate_series(1,10) AS s(i);
 unfiltered | filtered
------------+----------
         10 |        4
(1 row)
```

The predefined aggregate functions are described in Section 9.21. Other aggregate functions can be added by the user.

An aggregate expression can only appear in the result list or `HAVING` clause of a `SELECT` command. It is forbidden in other clauses, such as `WHERE`, because those clauses are logically evaluated before the results of aggregates are formed.

When an aggregate expression appears in a subquery (see Section 4.2.11 and Section 9.23), the aggregate is normally evaluated over the rows of the subquery. But an exception occurs if the aggregate's arguments (and *filter_clause* if any) contain only outer-level variables: the aggregate then belongs to the nearest such outer level, and is evaluated over the rows of that query. The aggregate expression as a whole is then an outer reference for the subquery it appears in, and acts as a constant over any one evaluation of that subquery. The restriction about appearing only in the result list or `HAVING` clause applies with respect to the query level that the aggregate belongs to.

4.2.8. Window Function Calls

A *window function call* represents the application of an aggregate-like function over some portion of the rows selected by a query. Unlike non-window aggregate calls, this is not tied to grouping of the selected rows into a single output row — each row remains separate in the query output. However the window function has access to all the rows that would be part of the current row's group according to the grouping specification (`PARTITION BY` list) of the window function call. The syntax of a window function call is one of the following:

```
function_name ([expression [, expression ... ]]) [ FILTER ( WHERE filter_clause ) ]
 OVER window_name
function_name ([expression [, expression ... ]]) [ FILTER ( WHERE filter_clause ) ]
 OVER ( window_definition )
function_name ( * ) [ FILTER ( WHERE filter_clause ) ] OVER window_name
function_name ( * ) [ FILTER ( WHERE filter_clause ) ] OVER ( window_definition )
```

where *window_definition* has the syntax

```
[ existing_window_name ]
[ PARTITION BY expression [, ...] ]
[ ORDER BY expression [ ASC | DESC | USING operator ] [ NULLS { FIRST | LAST } ]
 [, ...] ]
[ frame_clause ]
```

The optional *frame_clause* can be one of

```
{ RANGE | ROWS | GROUPS } frame_start [ frame_exclusion ]
{ RANGE | ROWS | GROUPS } BETWEEN frame_start AND frame_end [ frame_exclusion ]
```

where *frame_start* and *frame_end* can be one of

```
UNBOUNDED PRECEDING
offset PRECEDING
CURRENT ROW
offset FOLLOWING
UNBOUNDED FOLLOWING
```

and *frame_exclusion* can be one of

```
EXCLUDE CURRENT ROW
EXCLUDE GROUP
EXCLUDE TIES
EXCLUDE NO OTHERS
```

Here, *expression* represents any value expression that does not itself contain window function calls.

window_name is a reference to a named window specification defined in the query's WINDOW clause. Alternatively, a full *window_definition* can be given within parentheses, using the same syntax as for defining a named window in the WINDOW clause; see the SELECT reference page for details. It's worth pointing out that OVER wname is not exactly equivalent to OVER (wname ...); the latter implies copying and modifying the window definition, and will be rejected if the referenced window specification includes a frame clause.

The PARTITION BY clause groups the rows of the query into *partitions*, which are processed separately by the window function. PARTITION BY works similarly to a query-level GROUP BY clause, except that its expressions are always just expressions and cannot be output-column names or numbers. Without PARTITION BY, all rows produced by the query are treated as a single partition. The ORDER BY clause determines the order in which the rows of a partition are processed by the window function. It works similarly to a query-level ORDER BY clause, but likewise cannot use output-column names or numbers. Without ORDER BY, rows are processed in an unspecified order.

The *frame_clause* specifies the set of rows constituting the *window frame*, which is a subset of the current partition, for those window functions that act on the frame instead of the whole partition. The set of rows in the frame can vary depending on which row is the current row. The frame can be specified in RANGE, ROWS or GROUPS mode; in each case, it runs from the *frame_start* to the *frame_end*. If *frame_end* is omitted, the end defaults to CURRENT ROW.

A *frame_start* of UNBOUNDED PRECEDING means that the frame starts with the first row of the partition, and similarly a *frame_end* of UNBOUNDED FOLLOWING means that the frame ends with the last row of the partition.

In RANGE or GROUPS mode, a *frame_start* of CURRENT ROW means the frame starts with the current row's first *peer* row (a row that the window's ORDER BY clause sorts as equivalent to the current row), while a *frame_end* of CURRENT ROW means the frame ends with the current row's last peer row. In ROWS mode, CURRENT ROW simply means the current row.

In the *offset* PRECEDING and *offset* FOLLOWING frame options, the *offset* must be an expression not containing any variables, aggregate functions, or window functions. The meaning of the *offset* depends on the frame mode:

- In ROWS mode, the *offset* must yield a non-null, non-negative integer, and the option means that the frame starts or ends the specified number of rows before or after the current row.
- In GROUPS mode, the *offset* again must yield a non-null, non-negative integer, and the option means that the frame starts or ends the specified number of *peer groups* before or after the current row's peer group, where a peer group is a set of rows that are equivalent in the ORDER BY ordering. (There must be an ORDER BY clause in the window definition to use GROUPS mode.)
- In RANGE mode, these options require that the ORDER BY clause specify exactly one column. The *offset* specifies the maximum difference between the value of that column in the current row and its value in preceding or following rows of the frame. The data type of the *offset* expression varies depending on the data type of the ordering column. For numeric ordering columns it is typically of the same type as the ordering column, but for datetime ordering columns it is an interval. For example, if the ordering column is of type date or timestamp, one could write RANGE BETWEEN '1 day' PRECEDING AND '10 days' FOLLOWING. The *offset* is still required to be non-null and non-negative, though the meaning of “non-negative” depends on its data type.

In any case, the distance to the end of the frame is limited by the distance to the end of the partition, so that for rows near the partition ends the frame might contain fewer rows than elsewhere.

Notice that in both ROWS and GROUPS mode, 0 PRECEDING and 0 FOLLOWING are equivalent to CURRENT ROW. This normally holds in RANGE mode as well, for an appropriate data-type-specific meaning of "zero".

The *frame_exclusion* option allows rows around the current row to be excluded from the frame, even if they would be included according to the frame start and frame end options. EXCLUDE CURRENT ROW excludes the current row from the frame. EXCLUDE GROUP excludes the current row and its ordering peers from the frame. EXCLUDE TIES excludes any peers of the current row from the frame, but not the current row itself. EXCLUDE NO OTHERS simply specifies explicitly the default behavior of not excluding the current row or its peers.

The default framing option is RANGE UNBOUNDED PRECEDING, which is the same as RANGE BETWEEN UNBOUNDED PRECEDING AND CURRENT ROW. With ORDER BY, this sets the frame to be all rows from the partition start up through the current row's last ORDER BY peer. Without ORDER BY, this means all rows of the partition are included in the window frame, since all rows become peers of the current row.

Restrictions are that *frame_start* cannot be UNBOUNDED FOLLOWING, *frame_end* cannot be UNBOUNDED PRECEDING, and the *frame_end* choice cannot appear earlier in the above list of *frame_start* and *frame_end* options than the *frame_start* choice does — for example RANGE BETWEEN CURRENT ROW AND *offset* PRECEDING is not allowed. But, for example, ROWS BETWEEN 7 PRECEDING AND 8 PRECEDING is allowed, even though it would never select any rows.

If FILTER is specified, then only the input rows for which the *filter_clause* evaluates to true are fed to the window function; other rows are discarded. Only window functions that are aggregates accept a FILTER clause.

The built-in window functions are described in Table 9.62. Other window functions can be added by the user. Also, any built-in or user-defined general-purpose or statistical aggregate can be used as a window function. (Ordered-set and hypothetical-set aggregates cannot presently be used as window functions.)

The syntaxes using * are used for calling parameter-less aggregate functions as window functions, for example count(*) OVER (PARTITION BY x ORDER BY y). The asterisk (*) is customarily not used for window-specific functions. Window-specific functions do not allow DISTINCT or ORDER BY to be used within the function argument list.

Window function calls are permitted only in the SELECT list and the ORDER BY clause of the query.

More information about window functions can be found in Section 3.5, Section 9.22, and Section 7.2.5.

4.2.9. Type Casts

A type cast specifies a conversion from one data type to another. Postgres Pro accepts two equivalent syntaxes for type casts:

```
CAST ( expression AS type )
expression::type
```

The CAST syntax conforms to SQL; the syntax with :: is historical Postgres Pro usage.

When a cast is applied to a value expression of a known type, it represents a run-time type conversion. The cast will succeed only if a suitable type conversion operation has been defined. Notice that this is subtly different from the use of casts with constants, as shown in Section 4.1.2.7. A cast applied to an unadorned string literal represents the initial assignment of a type to a literal constant value, and so it will succeed for any type (if the contents of the string literal are acceptable input syntax for the data type).

An explicit type cast can usually be omitted if there is no ambiguity as to the type that a value expression must produce (for example, when it is assigned to a table column); the system will automatically apply a type cast in such cases. However, automatic casting is only done for casts that are marked "OK to apply implicitly" in the system catalogs. Other casts must be invoked with explicit casting syntax. This restriction is intended to prevent surprising conversions from being applied silently.

It is also possible to specify a type cast using a function-like syntax:

```
typename ( expression )
```

However, this only works for types whose names are also valid as function names. For example, `double precision` cannot be used this way, but the equivalent `float8` can. Also, the names `interval`, `time`, and `timestamp` can only be used in this fashion if they are double-quoted, because of syntactic conflicts. Therefore, the use of the function-like cast syntax leads to inconsistencies and should probably be avoided.

> **Note**
>
> The function-like syntax is in fact just a function call. When one of the two standard cast syntaxes is used to do a run-time conversion, it will internally invoke a registered function to perform the conversion. By convention, these conversion functions have the same name as their output type, and thus the "function-like syntax" is nothing more than a direct invocation of the underlying conversion function. Obviously, this is not something that a portable application should rely on. For further details see CREATE CAST.

4.2.10. Collation Expressions

The `COLLATE` clause overrides the collation of an expression. It is appended to the expression it applies to:

```
expr COLLATE collation
```

where *collation* is a possibly schema-qualified identifier. The `COLLATE` clause binds tighter than operators; parentheses can be used when necessary.

If no collation is explicitly specified, the database system either derives a collation from the columns involved in the expression, or it defaults to the default collation of the database if no column is involved in the expression.

The two common uses of the `COLLATE` clause are overriding the sort order in an `ORDER BY` clause, for example:

```
SELECT a, b, c FROM tbl WHERE ... ORDER BY a COLLATE "C";
```

and overriding the collation of a function or operator call that has locale-sensitive results, for example:

```
SELECT * FROM tbl WHERE a > 'foo' COLLATE "C";
```

Note that in the latter case the `COLLATE` clause is attached to an input argument of the operator we wish to affect. It doesn't matter which argument of the operator or function call the `COLLATE` clause is attached to, because the collation that is applied by the operator or function is derived by considering all arguments, and an explicit `COLLATE` clause will override the collations of all other arguments. (Attaching non-matching `COLLATE` clauses to more than one argument, however, is an error. For more details see Section 23.2.) Thus, this gives the same result as the previous example:

```
SELECT * FROM tbl WHERE a COLLATE "C" > 'foo';
```

But this is an error:

```
SELECT * FROM tbl WHERE (a > 'foo') COLLATE "C";
```

because it attempts to apply a collation to the result of the `>` operator, which is of the non-collatable data type `boolean`.

4.2.11. Scalar Subqueries

A scalar subquery is an ordinary `SELECT` query in parentheses that returns exactly one row with one column. (See Chapter 7 for information about writing queries.) The `SELECT` query is executed and the single returned value is used in the surrounding value expression. It is an error to use a query that

returns more than one row or more than one column as a scalar subquery. (But if, during a particular execution, the subquery returns no rows, there is no error; the scalar result is taken to be null.) The subquery can refer to variables from the surrounding query, which will act as constants during any one evaluation of the subquery. See also Section 9.23 for other expressions involving subqueries.

For example, the following finds the largest city population in each state:

```
SELECT name, (SELECT max(pop) FROM cities WHERE cities.state = states.name)
    FROM states;
```

4.2.12. Array Constructors

An array constructor is an expression that builds an array value using values for its member elements. A simple array constructor consists of the key word `ARRAY`, a left square bracket `[`, a list of expressions (separated by commas) for the array element values, and finally a right square bracket `]`. For example:

```
SELECT ARRAY[1,2,3+4];
  array
---------
 {1,2,7}
(1 row)
```

By default, the array element type is the common type of the member expressions, determined using the same rules as for `UNION` or `CASE` constructs (see Section 10.5). You can override this by explicitly casting the array constructor to the desired type, for example:

```
SELECT ARRAY[1,2,22.7]::integer[];
  array
----------
 {1,2,23}
(1 row)
```

This has the same effect as casting each expression to the array element type individually. For more on casting, see Section 4.2.9.

Multidimensional array values can be built by nesting array constructors. In the inner constructors, the key word `ARRAY` can be omitted. For example, these produce the same result:

```
SELECT ARRAY[ARRAY[1,2], ARRAY[3,4]];
     array
---------------
 {{1,2},{3,4}}
(1 row)

SELECT ARRAY[[1,2],[3,4]];
     array
---------------
 {{1,2},{3,4}}
(1 row)
```

Since multidimensional arrays must be rectangular, inner constructors at the same level must produce sub-arrays of identical dimensions. Any cast applied to the outer `ARRAY` constructor propagates automatically to all the inner constructors.

Multidimensional array constructor elements can be anything yielding an array of the proper kind, not only a sub-`ARRAY` construct. For example:

```
CREATE TABLE arr(f1 int[], f2 int[]);

INSERT INTO arr VALUES (ARRAY[[1,2],[3,4]], ARRAY[[5,6],[7,8]]);

SELECT ARRAY[f1, f2, '{{9,10},{11,12}}'::int[]] FROM arr;
                     array
```

```
-----------------------------------------------
 {{{1,2},{3,4}},{{5,6},{7,8}},{{9,10},{11,12}}}
(1 row)
```

You can construct an empty array, but since it's impossible to have an array with no type, you must explicitly cast your empty array to the desired type. For example:

```
SELECT ARRAY[]::integer[];
 array
-------
 {}
(1 row)
```

It is also possible to construct an array from the results of a subquery. In this form, the array constructor is written with the key word `ARRAY` followed by a parenthesized (not bracketed) subquery. For example:

```
SELECT ARRAY(SELECT oid FROM pg_proc WHERE proname LIKE 'bytea%');
                              array
------------------------------------------------------------------
 {2011,1954,1948,1952,1951,1244,1950,2005,1949,1953,2006,31,2412}
(1 row)

SELECT ARRAY(SELECT ARRAY[i, i*2] FROM generate_series(1,5) AS a(i));
              array
----------------------------------
 {{1,2},{2,4},{3,6},{4,8},{5,10}}
(1 row)
```

The subquery must return a single column. If the subquery's output column is of a non-array type, the resulting one-dimensional array will have an element for each row in the subquery result, with an element type matching that of the subquery's output column. If the subquery's output column is of an array type, the result will be an array of the same type but one higher dimension; in this case all the subquery rows must yield arrays of identical dimensionality, else the result would not be rectangular.

The subscripts of an array value built with `ARRAY` always begin with one. For more information about arrays, see Section 8.15.

4.2.13. Row Constructors

A row constructor is an expression that builds a row value (also called a composite value) using values for its member fields. A row constructor consists of the key word `ROW`, a left parenthesis, zero or more expressions (separated by commas) for the row field values, and finally a right parenthesis. For example:

```
SELECT ROW(1,2.5,'this is a test');
```

The key word `ROW` is optional when there is more than one expression in the list.

A row constructor can include the syntax *`rowvalue`*`.*`, which will be expanded to a list of the elements of the row value, just as occurs when the `.*` syntax is used at the top level of a `SELECT` list (see Section 8.16.5). For example, if table `t` has columns `f1` and `f2`, these are the same:

```
SELECT ROW(t.*, 42) FROM t;
SELECT ROW(t.f1, t.f2, 42) FROM t;
```

> **Note**
>
> Before PostgreSQL 8.2, the `.*` syntax was not expanded in row constructors, so that writing `ROW(t.*, 42)` created a two-field row whose first field was another row value. The new behavior is usually more useful. If you need the old behavior of nested row values, write the inner row value without `.*`, for instance `ROW(t, 42)`.

By default, the value created by a `ROW` expression is of an anonymous record type. If necessary, it can be cast to a named composite type — either the row type of a table, or a composite type created with `CREATE TYPE AS`. An explicit cast might be needed to avoid ambiguity. For example:

```
CREATE TABLE mytable(f1 int, f2 float, f3 text);

CREATE FUNCTION getf1(mytable) RETURNS int AS 'SELECT $1.f1' LANGUAGE SQL;

-- No cast needed since only one getf1() exists
SELECT getf1(ROW(1,2.5,'this is a test'));
 getf1
-------
     1
(1 row)

CREATE TYPE myrowtype AS (f1 int, f2 text, f3 numeric);

CREATE FUNCTION getf1(myrowtype) RETURNS int AS 'SELECT $1.f1' LANGUAGE SQL;

-- Now we need a cast to indicate which function to call:
SELECT getf1(ROW(1,2.5,'this is a test'));
ERROR:  function getf1(record) is not unique

SELECT getf1(ROW(1,2.5,'this is a test')::mytable);
 getf1
-------
     1
(1 row)

SELECT getf1(CAST(ROW(11,'this is a test',2.5) AS myrowtype));
 getf1
-------
    11
(1 row)
```

Row constructors can be used to build composite values to be stored in a composite-type table column, or to be passed to a function that accepts a composite parameter. Also, it is possible to compare two row values or test a row with `IS NULL` or `IS NOT NULL`, for example:

```
SELECT ROW(1,2.5,'this is a test') = ROW(1, 3, 'not the same');

SELECT ROW(table.*) IS NULL FROM table;  -- detect all-null rows
```

For more detail see Section 9.24. Row constructors can also be used in connection with subqueries, as discussed in Section 9.23.

4.2.14. Expression Evaluation Rules

The order of evaluation of subexpressions is not defined. In particular, the inputs of an operator or function are not necessarily evaluated left-to-right or in any other fixed order.

Furthermore, if the result of an expression can be determined by evaluating only some parts of it, then other subexpressions might not be evaluated at all. For instance, if one wrote:

```
SELECT true OR somefunc();
```

then `somefunc()` would (probably) not be called at all. The same would be the case if one wrote:

```
SELECT somefunc() OR true;
```

Note that this is not the same as the left-to-right “short-circuiting” of Boolean operators that is found in some programming languages.

As a consequence, it is unwise to use functions with side effects as part of complex expressions. It is particularly dangerous to rely on side effects or evaluation order in WHERE and HAVING clauses, since those clauses are extensively reprocessed as part of developing an execution plan. Boolean expressions (AND/OR/NOT combinations) in those clauses can be reorganized in any manner allowed by the laws of Boolean algebra.

When it is essential to force evaluation order, a CASE construct (see Section 9.18) can be used. For example, this is an untrustworthy way of trying to avoid division by zero in a WHERE clause:

```
SELECT ... WHERE x > 0 AND y/x > 1.5;
```

But this is safe:

```
SELECT ... WHERE CASE WHEN x > 0 THEN y/x > 1.5 ELSE false END;
```

A CASE construct used in this fashion will defeat optimization attempts, so it should only be done when necessary. (In this particular example, it would be better to sidestep the problem by writing `y > 1.5*x` instead.)

CASE is not a cure-all for such issues, however. One limitation of the technique illustrated above is that it does not prevent early evaluation of constant subexpressions. As described in Section 40.7, functions and operators marked IMMUTABLE can be evaluated when the query is planned rather than when it is executed. Thus for example

```
SELECT CASE WHEN x > 0 THEN x ELSE 1/0 END FROM tab;
```

is likely to result in a division-by-zero failure due to the planner trying to simplify the constant subexpression, even if every row in the table has `x > 0` so that the ELSE arm would never be entered at run time.

While that particular example might seem silly, related cases that don't obviously involve constants can occur in queries executed within functions, since the values of function arguments and local variables can be inserted into queries as constants for planning purposes. Within PL/pgSQL functions, for example, using an IF-THEN-ELSE statement to protect a risky computation is much safer than just nesting it in a CASE expression.

Another limitation of the same kind is that a CASE cannot prevent evaluation of an aggregate expression contained within it, because aggregate expressions are computed before other expressions in a SELECT list or HAVING clause are considered. For example, the following query can cause a division-by-zero error despite seemingly having protected against it:

```
SELECT CASE WHEN min(employees) > 0
            THEN avg(expenses / employees)
       END
    FROM departments;
```

The `min()` and `avg()` aggregates are computed concurrently over all the input rows, so if any row has `employees` equal to zero, the division-by-zero error will occur before there is any opportunity to test the result of `min()`. Instead, use a WHERE or FILTER clause to prevent problematic input rows from reaching an aggregate function in the first place.

4.3. Calling Functions

Postgres Pro allows functions that have named parameters to be called using either *positional* or *named* notation. Named notation is especially useful for functions that have a large number of parameters, since it makes the associations between parameters and actual arguments more explicit and reliable. In positional notation, a function call is written with its argument values in the same order as they are defined in the function declaration. In named notation, the arguments are matched to the function parameters by name and can be written in any order. For each notation, also consider the effect of function argument types, documented in Section 10.3.

In either notation, parameters that have default values given in the function declaration need not be written in the call at all. But this is particularly useful in named notation, since any combination of parameters can be omitted; while in positional notation parameters can only be omitted from right to left.

Postgres Pro also supports *mixed* notation, which combines positional and named notation. In this case, positional parameters are written first and named parameters appear after them.

The following examples will illustrate the usage of all three notations, using the following function definition:

```
CREATE FUNCTION concat_lower_or_upper(a text, b text, uppercase boolean DEFAULT false)
RETURNS text
AS
$$
 SELECT CASE
        WHEN $3 THEN UPPER($1 || ' ' || $2)
        ELSE LOWER($1 || ' ' || $2)
        END;
$$
LANGUAGE SQL IMMUTABLE STRICT;
```

Function `concat_lower_or_upper` has two mandatory parameters, `a` and `b`. Additionally there is one optional parameter `uppercase` which defaults to `false`. The `a` and `b` inputs will be concatenated, and forced to either upper or lower case depending on the `uppercase` parameter. The remaining details of this function definition are not important here (see Chapter 40 for more information).

4.3.1. Using Positional Notation

Positional notation is the traditional mechanism for passing arguments to functions in Postgres Pro. An example is:

```
SELECT concat_lower_or_upper('Hello', 'World', true);
 concat_lower_or_upper
-----------------------
 HELLO WORLD
(1 row)
```

All arguments are specified in order. The result is upper case since `uppercase` is specified as `true`. Another example is:

```
SELECT concat_lower_or_upper('Hello', 'World');
 concat_lower_or_upper
-----------------------
 hello world
(1 row)
```

Here, the `uppercase` parameter is omitted, so it receives its default value of `false`, resulting in lower case output. In positional notation, arguments can be omitted from right to left so long as they have defaults.

4.3.2. Using Named Notation

In named notation, each argument's name is specified using `=>` to separate it from the argument expression. For example:

```
SELECT concat_lower_or_upper(a => 'Hello', b => 'World');
 concat_lower_or_upper
-----------------------
 hello world
(1 row)
```

Again, the argument `uppercase` was omitted so it is set to `false` implicitly. One advantage of using named notation is that the arguments may be specified in any order, for example:

```
SELECT concat_lower_or_upper(a => 'Hello', b => 'World', uppercase => true);
 concat_lower_or_upper
-----------------------
```

```
 HELLO WORLD
(1 row)

SELECT concat_lower_or_upper(a => 'Hello', uppercase => true, b => 'World');
 concat_lower_or_upper
-----------------------
 HELLO WORLD
(1 row)
```

An older syntax based on ":=" is supported for backward compatibility:

```
SELECT concat_lower_or_upper(a := 'Hello', uppercase := true, b := 'World');
 concat_lower_or_upper
-----------------------
 HELLO WORLD
(1 row)
```

4.3.3. Using Mixed Notation

The mixed notation combines positional and named notation. However, as already mentioned, named arguments cannot precede positional arguments. For example:

```
SELECT concat_lower_or_upper('Hello', 'World', uppercase => true);
 concat_lower_or_upper
-----------------------
 HELLO WORLD
(1 row)
```

In the above query, the arguments `a` and `b` are specified positionally, while `uppercase` is specified by name. In this example, that adds little except documentation. With a more complex function having numerous parameters that have default values, named or mixed notation can save a great deal of writing and reduce chances for error.

> **Note**
>
> Named and mixed call notations currently cannot be used when calling an aggregate function (but they do work when an aggregate function is used as a window function).

Chapter 5. Data Definition

This chapter covers how one creates the database structures that will hold one's data. In a relational database, the raw data is stored in tables, so the majority of this chapter is devoted to explaining how tables are created and modified and what features are available to control what data is stored in the tables. Subsequently, we discuss how tables can be organized into schemas, and how privileges can be assigned to tables. Finally, we will briefly look at other features that affect the data storage, such as inheritance, table partitioning, views, functions, and triggers.

5.1. Table Basics

A table in a relational database is much like a table on paper: It consists of rows and columns. The number and order of the columns is fixed, and each column has a name. The number of rows is variable — it reflects how much data is stored at a given moment. SQL does not make any guarantees about the order of the rows in a table. When a table is read, the rows will appear in an unspecified order, unless sorting is explicitly requested. This is covered in Chapter 7. Furthermore, SQL does not assign unique identifiers to rows, so it is possible to have several completely identical rows in a table. This is a consequence of the mathematical model that underlies SQL but is usually not desirable. Later in this chapter we will see how to deal with this issue.

Each column has a data type. The data type constrains the set of possible values that can be assigned to a column and assigns semantics to the data stored in the column so that it can be used for computations. For instance, a column declared to be of a numerical type will not accept arbitrary text strings, and the data stored in such a column can be used for mathematical computations. By contrast, a column declared to be of a character string type will accept almost any kind of data but it does not lend itself to mathematical calculations, although other operations such as string concatenation are available.

Postgres Pro includes a sizable set of built-in data types that fit many applications. Users can also define their own data types. Most built-in data types have obvious names and semantics, so we defer a detailed explanation to Chapter 8. Some of the frequently used data types are `integer` for whole numbers, `numeric` for possibly fractional numbers, `text` for character strings, `date` for dates, `time` for time-of-day values, and `timestamp` for values containing both date and time.

To create a table, you use the aptly named CREATE TABLE command. In this command you specify at least a name for the new table, the names of the columns and the data type of each column. For example:

```
CREATE TABLE my_first_table (
    first_column text,
    second_column integer
);
```

This creates a table named `my_first_table` with two columns. The first column is named `first_column` and has a data type of `text`; the second column has the name `second_column` and the type `integer`. The table and column names follow the identifier syntax explained in Section 4.1.1. The type names are usually also identifiers, but there are some exceptions. Note that the column list is comma-separated and surrounded by parentheses.

Of course, the previous example was heavily contrived. Normally, you would give names to your tables and columns that convey what kind of data they store. So let's look at a more realistic example:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric
);
```

(The `numeric` type can store fractional components, as would be typical of monetary amounts.)

> **Tip**
>
> When you create many interrelated tables it is wise to choose a consistent naming pattern for the tables and columns. For instance, there is a choice of using singular or plural nouns for table names, both of which are favored by some theorist or other.

There is a limit on how many columns a table can contain. Depending on the column types, it is between 250 and 1600. However, defining a table with anywhere near this many columns is highly unusual and often a questionable design.

If you no longer need a table, you can remove it using the DROP TABLE command. For example:

```
DROP TABLE my_first_table;
DROP TABLE products;
```

Attempting to drop a table that does not exist is an error. Nevertheless, it is common in SQL script files to unconditionally try to drop each table before creating it, ignoring any error messages, so that the script works whether or not the table exists. (If you like, you can use the `DROP TABLE IF EXISTS` variant to avoid the error messages, but this is not standard SQL.)

If you need to modify a table that already exists, see Section 5.6 later in this chapter.

With the tools discussed so far you can create fully functional tables. The remainder of this chapter is concerned with adding features to the table definition to ensure data integrity, security, or convenience. If you are eager to fill your tables with data now you can skip ahead to Chapter 6 and read the rest of this chapter later.

5.2. Default Values

A column can be assigned a default value. When a new row is created and no values are specified for some of the columns, those columns will be filled with their respective default values. A data manipulation command can also request explicitly that a column be set to its default value, without having to know what that value is. (Details about data manipulation commands are in Chapter 6.)

If no default value is declared explicitly, the default value is the null value. This usually makes sense because a null value can be considered to represent unknown data.

In a table definition, default values are listed after the column data type. For example:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric DEFAULT 9.99
);
```

The default value can be an expression, which will be evaluated whenever the default value is inserted (*not* when the table is created). A common example is for a `timestamp` column to have a default of `CURRENT_TIMESTAMP`, so that it gets set to the time of row insertion. Another common example is generating a “serial number” for each row. In Postgres Pro this is typically done by something like:

```
CREATE TABLE products (
    product_no integer DEFAULT nextval('products_product_no_seq'),
    ...
);
```

where the `nextval()` function supplies successive values from a *sequence object* (see Section 9.17). This arrangement is sufficiently common that there's a special shorthand for it:

```
CREATE TABLE products (
```

```
    product_no SERIAL,
    ...
);
```

The SERIAL shorthand is discussed further in Section 8.1.4.

5.3. Generated Columns

A generated column is a special column that is always computed from other columns. Thus, it is for columns what a view is for tables. There are two kinds of generated columns: stored and virtual. A stored generated column is computed when it is written (inserted or updated) and occupies storage as if it were a normal column. A virtual generated column occupies no storage and is computed when it is read. Thus, a virtual generated column is similar to a view and a stored generated column is similar to a materialized view (except that it is always updated automatically). Postgres Pro currently implements only stored generated columns.

To create a generated column, use the GENERATED ALWAYS AS clause in CREATE TABLE, for example:

```
CREATE TABLE people (
    ...,
    height_cm numeric,
    height_in numeric GENERATED ALWAYS AS (height_cm / 2.54) STORED
);
```

The keyword STORED must be specified to choose the stored kind of generated column. See CREATE TABLE for more details.

A generated column cannot be written to directly. In INSERT or UPDATE commands, a value cannot be specified for a generated column, but the keyword DEFAULT may be specified.

Consider the differences between a column with a default and a generated column. The column default is evaluated once when the row is first inserted if no other value was provided; a generated column is updated whenever the row changes and cannot be overridden. A column default may not refer to other columns of the table; a generation expression would normally do so. A column default can use volatile functions, for example random() or functions referring to the current time; this is not allowed for generated columns.

Several restrictions apply to the definition of generated columns and tables involving generated columns:

- The generation expression can only use immutable functions and cannot use subqueries or reference anything other than the current row in any way.
- A generation expression cannot reference another generated column.
- A generation expression cannot reference a system column, except tableoid.
- A generated column cannot have a column default or an identity definition.
- A generated column cannot be part of a partition key.
- Foreign tables can have generated columns. See CREATE FOREIGN TABLE for details.
- For inheritance:
  - If a parent column is a generated column, a child column must also be a generated column using the same expression. In the definition of the child column, leave off the GENERATED clause, as it will be copied from the parent.
  - In case of multiple inheritance, if one parent column is a generated column, then all parent columns must be generated columns and with the same expression.
  - If a parent column is not a generated column, a child column may be defined to be a generated column or not.

Additional considerations apply to the use of generated columns.

- Generated columns maintain access privileges separately from their underlying base columns. So, it is possible to arrange it so that a particular role can read from a generated column but not from the underlying base columns.
- Generated columns are, conceptually, updated after `BEFORE` triggers have run. Therefore, changes made to base columns in a `BEFORE` trigger will be reflected in generated columns. But conversely, it is not allowed to access generated columns in `BEFORE` triggers.
- Generated columns are skipped for logical replication.

5.4. Constraints

Data types are a way to limit the kind of data that can be stored in a table. For many applications, however, the constraint they provide is too coarse. For example, a column containing a product price should probably only accept positive values. But there is no standard data type that accepts only positive numbers. Another issue is that you might want to constrain column data with respect to other columns or rows. For example, in a table containing product information, there should be only one row for each product number.

To that end, SQL allows you to define constraints on columns and tables. Constraints give you as much control over the data in your tables as you wish. If a user attempts to store data in a column that would violate a constraint, an error is raised. This applies even if the value came from the default value definition.

5.4.1. Check Constraints

A check constraint is the most generic constraint type. It allows you to specify that the value in a certain column must satisfy a Boolean (truth-value) expression. For instance, to require positive product prices, you could use:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric CHECK (price > 0)
);
```

As you see, the constraint definition comes after the data type, just like default value definitions. Default values and constraints can be listed in any order. A check constraint consists of the key word `CHECK` followed by an expression in parentheses. The check constraint expression should involve the column thus constrained, otherwise the constraint would not make too much sense.

You can also give the constraint a separate name. This clarifies error messages and allows you to refer to the constraint when you need to change it. The syntax is:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric CONSTRAINT positive_price CHECK (price > 0)
);
```

So, to specify a named constraint, use the key word `CONSTRAINT` followed by an identifier followed by the constraint definition. (If you don't specify a constraint name in this way, the system chooses a name for you.)

A check constraint can also refer to several columns. Say you store a regular price and a discounted price, and you want to ensure that the discounted price is lower than the regular price:

```
CREATE TABLE products (
    product_no integer,
    name text,
```

```
    price numeric CHECK (price > 0),
    discounted_price numeric CHECK (discounted_price > 0),
    CHECK (price > discounted_price)
);
```

The first two constraints should look familiar. The third one uses a new syntax. It is not attached to a particular column, instead it appears as a separate item in the comma-separated column list. Column definitions and these constraint definitions can be listed in mixed order.

We say that the first two constraints are column constraints, whereas the third one is a table constraint because it is written separately from any one column definition. Column constraints can also be written as table constraints, while the reverse is not necessarily possible, since a column constraint is supposed to refer to only the column it is attached to. (Postgres Pro doesn't enforce that rule, but you should follow it if you want your table definitions to work with other database systems.) The above example could also be written as:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric,
    CHECK (price > 0),
    discounted_price numeric,
    CHECK (discounted_price > 0),
    CHECK (price > discounted_price)
);
```

or even:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric CHECK (price > 0),
    discounted_price numeric,
    CHECK (discounted_price > 0 AND price > discounted_price)
);
```

It's a matter of taste.

Names can be assigned to table constraints in the same way as column constraints:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric,
    CHECK (price > 0),
    discounted_price numeric,
    CHECK (discounted_price > 0),
    CONSTRAINT valid_discount CHECK (price > discounted_price)
);
```

It should be noted that a check constraint is satisfied if the check expression evaluates to true or the null value. Since most expressions will evaluate to the null value if any operand is null, they will not prevent null values in the constrained columns. To ensure that a column does not contain null values, the not-null constraint described in the next section can be used.

Note

Postgres Pro does not support `CHECK` constraints that reference table data other than the new or updated row being checked. While a `CHECK` constraint that violates this rule may appear to work in simple tests, it cannot guarantee that the database will not reach a state in which the constraint

condition is false (due to subsequent changes of the other row(s) involved). This would cause a database dump and restore to fail. The restore could fail even when the complete database state is consistent with the constraint, due to rows not being loaded in an order that will satisfy the constraint. If possible, use `UNIQUE`, `EXCLUDE`, or `FOREIGN KEY` constraints to express cross-row and cross-table restrictions.

If what you desire is a one-time check against other rows at row insertion, rather than a continuously-maintained consistency guarantee, a custom trigger can be used to implement that. (This approach avoids the dump/restore problem because pg_dump does not reinstall triggers until after restoring data, so that the check will not be enforced during a dump/restore.)

Note

Postgres Pro assumes that `CHECK` constraints' conditions are immutable, that is, they will always give the same result for the same input row. This assumption is what justifies examining `CHECK` constraints only when rows are inserted or updated, and not at other times. (The warning above about not referencing other table data is really a special case of this restriction.)

An example of a common way to break this assumption is to reference a user-defined function in a `CHECK` expression, and then change the behavior of that function. Postgres Pro does not disallow that, but it will not notice if there are rows in the table that now violate the `CHECK` constraint. That would cause a subsequent database dump and restore to fail. The recommended way to handle such a change is to drop the constraint (using `ALTER TABLE`), adjust the function definition, and re-add the constraint, thereby rechecking it against all table rows.

5.4.2. Not-Null Constraints

A not-null constraint simply specifies that a column must not assume the null value. A syntax example:

```
CREATE TABLE products (
    product_no integer NOT NULL,
    name text NOT NULL,
    price numeric
);
```

A not-null constraint is always written as a column constraint. A not-null constraint is functionally equivalent to creating a check constraint `CHECK (`*`column_name`*` IS NOT NULL)`, but in Postgres Pro creating an explicit not-null constraint is more efficient. The drawback is that you cannot give explicit names to not-null constraints created this way.

Of course, a column can have more than one constraint. Just write the constraints one after another:

```
CREATE TABLE products (
    product_no integer NOT NULL,
    name text NOT NULL,
    price numeric NOT NULL CHECK (price > 0)
);
```

The order doesn't matter. It does not necessarily determine in which order the constraints are checked.

The `NOT NULL` constraint has an inverse: the `NULL` constraint. This does not mean that the column must be null, which would surely be useless. Instead, this simply selects the default behavior that the column might be null. The `NULL` constraint is not present in the SQL standard and should not be used in portable applications. (It was only added to Postgres Pro to be compatible with some other database systems.) Some users, however, like it because it makes it easy to toggle the constraint in a script file. For example, you could start with:

```
CREATE TABLE products (
    product_no integer NULL,
    name text NULL,
    price numeric NULL
);
```

and then insert the `NOT` key word where desired.

> **Tip**
>
> In most database designs the majority of columns should be marked not null.

5.4.3. Unique Constraints

Unique constraints ensure that the data contained in a column, or a group of columns, is unique among all the rows in the table. The syntax is:

```
CREATE TABLE products (
    product_no integer UNIQUE,
    name text,
    price numeric
);
```

when written as a column constraint, and:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric,
    UNIQUE (product_no)
);
```

when written as a table constraint.

To define a unique constraint for a group of columns, write it as a table constraint with the column names separated by commas:

```
CREATE TABLE example (
    a integer,
    b integer,
    c integer,
    UNIQUE (a, c)
);
```

This specifies that the combination of values in the indicated columns is unique across the whole table, though any one of the columns need not be (and ordinarily isn't) unique.

You can assign your own name for a unique constraint, in the usual way:

```
CREATE TABLE products (
    product_no integer CONSTRAINT must_be_different UNIQUE,
    name text,
    price numeric
);
```

Adding a unique constraint will automatically create a unique B-tree index on the column or group of columns listed in the constraint. A uniqueness restriction covering only some rows cannot be written as a unique constraint, but it is possible to enforce such a restriction by creating a unique partial index.

In general, a unique constraint is violated if there is more than one row in the table where the values of all of the columns included in the constraint are equal. However, two null values are never considered equal in this comparison. That means even in the presence of a unique constraint it is possible to store duplicate rows that contain a null value in at least one of the constrained columns. This behavior conforms to the SQL standard, but we have heard that other SQL databases might not follow this rule. So be careful when developing applications that are intended to be portable.

5.4.4. Primary Keys

A primary key constraint indicates that a column, or group of columns, can be used as a unique identifier for rows in the table. This requires that the values be both unique and not null. So, the following two table definitions accept the same data:

```
CREATE TABLE products (
    product_no integer UNIQUE NOT NULL,
    name text,
    price numeric
);
```

```
CREATE TABLE products (
    product_no integer PRIMARY KEY,
    name text,
    price numeric
);
```

Primary keys can span more than one column; the syntax is similar to unique constraints:

```
CREATE TABLE example (
    a integer,
    b integer,
    c integer,
    PRIMARY KEY (a, c)
);
```

Adding a primary key will automatically create a unique B-tree index on the column or group of columns listed in the primary key, and will force the column(s) to be marked `NOT NULL`.

A table can have at most one primary key. (There can be any number of unique and not-null constraints, which are functionally almost the same thing, but only one can be identified as the primary key.) Relational database theory dictates that every table must have a primary key. This rule is not enforced by Postgres Pro, but it is usually best to follow it.

Primary keys are useful both for documentation purposes and for client applications. For example, a GUI application that allows modifying row values probably needs to know the primary key of a table to be able to identify rows uniquely. There are also various ways in which the database system makes use of a primary key if one has been declared; for example, the primary key defines the default target column(s) for foreign keys referencing its table.

5.4.5. Foreign Keys

A foreign key constraint specifies that the values in a column (or a group of columns) must match the values appearing in some row of another table. We say this maintains the *referential integrity* between two related tables.

Say you have the product table that we have used several times already:

```
CREATE TABLE products (
    product_no integer PRIMARY KEY,
    name text,
    price numeric
);
```

Let's also assume you have a table storing orders of those products. We want to ensure that the orders table only contains orders of products that actually exist. So we define a foreign key constraint in the orders table that references the products table:

```
CREATE TABLE orders (
    order_id integer PRIMARY KEY,
    product_no integer REFERENCES products (product_no),
    quantity integer
);
```

Now it is impossible to create orders with non-NULL `product_no` entries that do not appear in the products table.

We say that in this situation the orders table is the *referencing* table and the products table is the *referenced* table. Similarly, there are referencing and referenced columns.

You can also shorten the above command to:

```
CREATE TABLE orders (
    order_id integer PRIMARY KEY,
    product_no integer REFERENCES products,
    quantity integer
);
```

because in absence of a column list the primary key of the referenced table is used as the referenced column(s).

You can assign your own name for a foreign key constraint, in the usual way.

A foreign key can also constrain and reference a group of columns. As usual, it then needs to be written in table constraint form. Here is a contrived syntax example:

```
CREATE TABLE t1 (
  a integer PRIMARY KEY,
  b integer,
  c integer,
  FOREIGN KEY (b, c) REFERENCES other_table (c1, c2)
);
```

Of course, the number and type of the constrained columns need to match the number and type of the referenced columns.

Sometimes it is useful for the “other table” of a foreign key constraint to be the same table; this is called a *self-referential* foreign key. For example, if you want rows of a table to represent nodes of a tree structure, you could write

```
CREATE TABLE tree (
    node_id integer PRIMARY KEY,
    parent_id integer REFERENCES tree,
    name text,
    ...
);
```

A top-level node would have NULL `parent_id`, while non-NULL `parent_id` entries would be constrained to reference valid rows of the table.

A table can have more than one foreign key constraint. This is used to implement many-to-many relationships between tables. Say you have tables about products and orders, but now you want to allow one order to contain possibly many products (which the structure above did not allow). You could use this table structure:

```
CREATE TABLE products (
```

```
    product_no integer PRIMARY KEY,
    name text,
    price numeric
);

CREATE TABLE orders (
    order_id integer PRIMARY KEY,
    shipping_address text,
    ...
);

CREATE TABLE order_items (
    product_no integer REFERENCES products,
    order_id integer REFERENCES orders,
    quantity integer,
    PRIMARY KEY (product_no, order_id)
);
```

Notice that the primary key overlaps with the foreign keys in the last table.

We know that the foreign keys disallow creation of orders that do not relate to any products. But what if a product is removed after an order is created that references it? SQL allows you to handle that as well. Intuitively, we have a few options:

- Disallow deleting a referenced product
- Delete the orders as well
- Something else?

To illustrate this, let's implement the following policy on the many-to-many relationship example above: when someone wants to remove a product that is still referenced by an order (via `order_items`), we disallow it. If someone removes an order, the order items are removed as well:

```
CREATE TABLE products (
    product_no integer PRIMARY KEY,
    name text,
    price numeric
);

CREATE TABLE orders (
    order_id integer PRIMARY KEY,
    shipping_address text,
    ...
);

CREATE TABLE order_items (
    product_no integer REFERENCES products ON DELETE RESTRICT,
    order_id integer REFERENCES orders ON DELETE CASCADE,
    quantity integer,
    PRIMARY KEY (product_no, order_id)
);
```

Restricting and cascading deletes are the two most common options. `RESTRICT` prevents deletion of a referenced row. `NO ACTION` means that if any referencing rows still exist when the constraint is checked, an error is raised; this is the default behavior if you do not specify anything. (The essential difference between these two choices is that `NO ACTION` allows the check to be deferred until later in the transaction, whereas `RESTRICT` does not.) `CASCADE` specifies that when a referenced row is deleted, row(s) referencing it should be automatically deleted as well. There are two other options: `SET NULL` and `SET DEFAULT`. These cause the referencing column(s) in the referencing row(s) to be set to nulls or their default values, respectively, when the referenced row is deleted. Note that these do not excuse you from observing any

constraints. For example, if an action specifies SET DEFAULT but the default value would not satisfy the foreign key constraint, the operation will fail.

Analogous to ON DELETE there is also ON UPDATE which is invoked when a referenced column is changed (updated). The possible actions are the same. In this case, CASCADE means that the updated values of the referenced column(s) should be copied into the referencing row(s).

Normally, a referencing row need not satisfy the foreign key constraint if any of its referencing columns are null. If MATCH FULL is added to the foreign key declaration, a referencing row escapes satisfying the constraint only if all its referencing columns are null (so a mix of null and non-null values is guaranteed to fail a MATCH FULL constraint). If you don't want referencing rows to be able to avoid satisfying the foreign key constraint, declare the referencing column(s) as NOT NULL.

A foreign key must reference columns that either are a primary key or form a unique constraint, or are columns from a non-partial unique index. This means that the referenced columns always have an index to allow efficient lookups on whether a referencing row has a match. Since a DELETE of a row from the referenced table or an UPDATE of a referenced column will require a scan of the referencing table for rows matching the old value, it is often a good idea to index the referencing columns too. Because this is not always needed, and there are many choices available on how to index, the declaration of a foreign key constraint does not automatically create an index on the referencing columns.

More information about updating and deleting data is in Chapter 6. Also see the description of foreign key constraint syntax in the reference documentation for CREATE TABLE.

5.4.6. Exclusion Constraints

Exclusion constraints ensure that if any two rows are compared on the specified columns or expressions using the specified operators, at least one of these operator comparisons will return false or null. The syntax is:

```
CREATE TABLE circles (
    c circle,
    EXCLUDE USING gist (c WITH &&)
);
```

See also CREATE TABLE ... CONSTRAINT ... EXCLUDE for details.

Adding an exclusion constraint will automatically create an index of the type specified in the constraint declaration.

5.5. System Columns

Every table has several *system columns* that are implicitly defined by the system. Therefore, these names cannot be used as names of user-defined columns. (Note that these restrictions are separate from whether the name is a key word or not; quoting a name will not allow you to escape these restrictions.) You do not really need to be concerned about these columns; just know they exist.

`tableoid`

The OID of the table containing this row. This column is particularly handy for queries that select from partitioned tables (see Section 5.11) or inheritance hierarchies (see Section 5.10), since without it, it's difficult to tell which individual table a row came from. The `tableoid` can be joined against the `oid` column of `pg_class` to obtain the table name.

`xmin`

The identity (transaction ID) of the inserting transaction for this row version. (A row version is an individual state of a row; each update of a row creates a new row version for the same logical row.)

`cmin`

The command identifier (starting at zero) within the inserting transaction.

`xmax`

The identity (transaction ID) of the deleting transaction, or zero for an undeleted row version. It is possible for this column to be nonzero in a visible row version. That usually indicates that the deleting transaction hasn't committed yet, or that an attempted deletion was rolled back.

`cmax`

The command identifier within the deleting transaction, or zero.

`ctid`

The physical location of the row version within its table. Note that although the `ctid` can be used to locate the row version very quickly, a row's `ctid` will change if it is updated or moved by `VACUUM FULL`. Therefore `ctid` is useless as a long-term row identifier. A primary key should be used to identify logical rows.

In Postgres Pro Enterprise, transaction IDs are implemented as 64-bit counters to prevent transaction ID wraparound. For details, see Section 24.1.5.

Command identifiers are 32-bit quantities. This creates a hard limit of 2^{32} (4 billion) SQL commands within a single transaction. In practice this limit is not a problem — note that the limit is on the number of SQL commands, not the number of rows processed. Also, only commands that actually modify the database contents will consume a command identifier.

5.6. Modifying Tables

When you create a table and you realize that you made a mistake, or the requirements of the application change, you can drop the table and create it again. But this is not a convenient option if the table is already filled with data, or if the table is referenced by other database objects (for instance a foreign key constraint). Therefore Postgres Pro provides a family of commands to make modifications to existing tables. Note that this is conceptually distinct from altering the data contained in the table: here we are interested in altering the definition, or structure, of the table.

You can:

- Add columns
- Remove columns
- Add constraints
- Remove constraints
- Change default values
- Change column data types
- Rename columns
- Rename tables

All these actions are performed using the ALTER TABLE command, whose reference page contains details beyond those given here.

5.6.1. Adding a Column

To add a column, use a command like:

```
ALTER TABLE products ADD COLUMN description text;
```

The new column is initially filled with whatever default value is given (null if you don't specify a `DEFAULT` clause).

> **Tip**
>
> From Postgres Pro 11, adding a column with a constant default value no longer means that each row of the table needs to be updated when the `ALTER TABLE` statement is executed. Instead, the

default value will be returned the next time the row is accessed, and applied when the table is rewritten, making the ALTER TABLE very fast even on large tables.

However, if the default value is volatile (e.g., clock_timestamp()) each row will need to be updated with the value calculated at the time ALTER TABLE is executed. To avoid a potentially lengthy update operation, particularly if you intend to fill the column with mostly nondefault values anyway, it may be preferable to add the column with no default, insert the correct values using UPDATE, and then add any desired default as described below.

You can also define constraints on the column at the same time, using the usual syntax:

```
ALTER TABLE products ADD COLUMN description text CHECK (description <> '');
```

In fact all the options that can be applied to a column description in CREATE TABLE can be used here. Keep in mind however that the default value must satisfy the given constraints, or the ADD will fail. Alternatively, you can add constraints later (see below) after you've filled in the new column correctly.

5.6.2. Removing a Column

To remove a column, use a command like:

```
ALTER TABLE products DROP COLUMN description;
```

Whatever data was in the column disappears. Table constraints involving the column are dropped, too. However, if the column is referenced by a foreign key constraint of another table, Postgres Pro will not silently drop that constraint. You can authorize dropping everything that depends on the column by adding CASCADE:

```
ALTER TABLE products DROP COLUMN description CASCADE;
```

See Section 5.14 for a description of the general mechanism behind this.

5.6.3. Adding a Constraint

To add a constraint, the table constraint syntax is used. For example:

```
ALTER TABLE products ADD CHECK (name <> '');
ALTER TABLE products ADD CONSTRAINT some_name UNIQUE (product_no);
ALTER TABLE products ADD FOREIGN KEY (product_group_id) REFERENCES product_groups;
```

To add a not-null constraint, which cannot be written as a table constraint, use this syntax:

```
ALTER TABLE products ALTER COLUMN product_no SET NOT NULL;
```

The constraint will be checked immediately, so the table data must satisfy the constraint before it can be added.

5.6.4. Removing a Constraint

To remove a constraint you need to know its name. If you gave it a name then that's easy. Otherwise the system assigned a generated name, which you need to find out. The psql command \d *tablename* can be helpful here; other interfaces might also provide a way to inspect table details. Then the command is:

```
ALTER TABLE products DROP CONSTRAINT some_name;
```

As with dropping a column, you need to add CASCADE if you want to drop a constraint that something else depends on. An example is that a foreign key constraint depends on a unique or primary key constraint on the referenced column(s).

This works the same for all constraint types except not-null constraints. To drop a not null constraint use:

```
ALTER TABLE products ALTER COLUMN product_no DROP NOT NULL;
```

(Recall that not-null constraints do not have names.)

5.6.5. Changing a Column's Default Value

To set a new default for a column, use a command like:

```
ALTER TABLE products ALTER COLUMN price SET DEFAULT 7.77;
```

Note that this doesn't affect any existing rows in the table, it just changes the default for future `INSERT` commands.

To remove any default value, use:

```
ALTER TABLE products ALTER COLUMN price DROP DEFAULT;
```

This is effectively the same as setting the default to null. As a consequence, it is not an error to drop a default where one hadn't been defined, because the default is implicitly the null value.

5.6.6. Changing a Column's Data Type

To convert a column to a different data type, use a command like:

```
ALTER TABLE products ALTER COLUMN price TYPE numeric(10,2);
```

This will succeed only if each existing entry in the column can be converted to the new type by an implicit cast. If a more complex conversion is needed, you can add a `USING` clause that specifies how to compute the new values from the old.

Postgres Pro will attempt to convert the column's default value (if any) to the new type, as well as any constraints that involve the column. But these conversions might fail, or might produce surprising results. It's often best to drop any constraints on the column before altering its type, and then add back suitably modified constraints afterwards.

5.6.7. Renaming a Column

To rename a column:

```
ALTER TABLE products RENAME COLUMN product_no TO product_number;
```

5.6.8. Renaming a Table

To rename a table:

```
ALTER TABLE products RENAME TO items;
```

5.7. Privileges

When an object is created, it is assigned an owner. The owner is normally the role that executed the creation statement. For most kinds of objects, the initial state is that only the owner (or a superuser) can do anything with the object. To allow other roles to use it, *privileges* must be granted.

There are different kinds of privileges: `SELECT`, `INSERT`, `UPDATE`, `DELETE`, `TRUNCATE`, `REFERENCES`, `TRIGGER`, `CREATE`, `CONNECT`, `TEMPORARY`, `EXECUTE`, and `USAGE`. The privileges applicable to a particular object vary depending on the object's type (table, function, etc). More detail about the meanings of these privileges appears below. The following sections and chapters will also show you how these privileges are used.

The right to modify or destroy an object is inherent in being the object's owner, and cannot be granted or revoked in itself. (However, like all privileges, that right can be inherited by members of the owning role; see Section 21.3.)

An object can be assigned to a new owner with an `ALTER` command of the appropriate kind for the object, for example

```
ALTER TABLE table_name OWNER TO new_owner;
```

Superusers can always do this; ordinary roles can only do it if they are both the current owner of the object (or a member of the owning role) and a member of the new owning role.

To assign privileges, the GRANT command is used. For example, if `joe` is an existing role, and `accounts` is an existing table, the privilege to update the table can be granted with:

```
GRANT UPDATE ON accounts TO joe;
```

Writing `ALL` in place of a specific privilege grants all privileges that are relevant for the object type.

The special "role" name `PUBLIC` can be used to grant a privilege to every role on the system. Also, "group" roles can be set up to help manage privileges when there are many users of a database — for details see Chapter 21.

To revoke a previously-granted privilege, use the fittingly named REVOKE command:

```
REVOKE ALL ON accounts FROM PUBLIC;
```

Ordinarily, only the object's owner (or a superuser) can grant or revoke privileges on an object. However, it is possible to grant a privilege "with grant option", which gives the recipient the right to grant it in turn to others. If the grant option is subsequently revoked then all who received the privilege from that recipient (directly or through a chain of grants) will lose the privilege. For details see the GRANT and REVOKE reference pages.

An object's owner can choose to revoke their own ordinary privileges, for example to make a table read-only for themselves as well as others. But owners are always treated as holding all grant options, so they can always re-grant their own privileges.

The available privileges are:

`SELECT`

Allows `SELECT` from any column, or specific column(s), of a table, view, materialized view, or other table-like object. Also allows use of `COPY TO`. This privilege is also needed to reference existing column values in `UPDATE` or `DELETE`. For sequences, this privilege also allows use of the `currval` function. For large objects, this privilege allows the object to be read.

`INSERT`

Allows `INSERT` of a new row into a table, view, etc. Can be granted on specific column(s), in which case only those columns may be assigned to in the `INSERT` command (other columns will therefore receive default values). Also allows use of `COPY FROM`.

`UPDATE`

Allows `UPDATE` of any column, or specific column(s), of a table, view, etc. (In practice, any nontrivial `UPDATE` command will require `SELECT` privilege as well, since it must reference table columns to determine which rows to update, and/or to compute new values for columns.) `SELECT ... FOR UPDATE` and `SELECT ... FOR SHARE` also require this privilege on at least one column, in addition to the `SELECT` privilege. For sequences, this privilege allows use of the `nextval` and `setval` functions. For large objects, this privilege allows writing or truncating the object.

`DELETE`

Allows `DELETE` of a row from a table, view, etc. (In practice, any nontrivial `DELETE` command will require `SELECT` privilege as well, since it must reference table columns to determine which rows to delete.)

`TRUNCATE`

Allows `TRUNCATE` on a table.

`REFERENCES`

Allows creation of a foreign key constraint referencing a table, or specific column(s) of a table.

`TRIGGER`

Allows creation of a trigger on a table, view, etc.

`CREATE`

For databases, allows new schemas and publications to be created within the database, and allows trusted extensions to be installed within the database.

For schemas, allows new objects to be created within the schema. To rename an existing object, you must own the object *and* have this privilege for the containing schema.

For tablespaces, allows tables, indexes, and temporary files to be created within the tablespace, and allows databases to be created that have the tablespace as their default tablespace.

Note that revoking this privilege will not alter the existence or location of existing objects.

`CONNECT`

Allows the grantee to connect to the database. This privilege is checked at connection startup (in addition to checking any restrictions imposed by `pg_hba.conf`).

`TEMPORARY`

Allows temporary tables to be created while using the database.

`EXECUTE`

Allows calling a function or procedure, including use of any operators that are implemented on top of the function. This is the only type of privilege that is applicable to functions and procedures.

`USAGE`

For procedural languages, allows use of the language for the creation of functions in that language. This is the only type of privilege that is applicable to procedural languages.

For schemas, allows access to objects contained in the schema (assuming that the objects' own privilege requirements are also met). Essentially this allows the grantee to “look up” objects within the schema. Without this permission, it is still possible to see the object names, e.g., by querying system catalogs. Also, after revoking this permission, existing sessions might have statements that have previously performed this lookup, so this is not a completely secure way to prevent object access.

For sequences, allows use of the `currval` and `nextval` functions.

For types and domains, allows use of the type or domain in the creation of tables, functions, and other schema objects. (Note that this privilege does not control all “usage” of the type, such as values of the type appearing in queries. It only prevents objects from being created that depend on the type. The main purpose of this privilege is controlling which users can create dependencies on a type, which could prevent the owner from changing the type later.)

For foreign-data wrappers, allows creation of new servers using the foreign-data wrapper.

For foreign servers, allows creation of foreign tables using the server. Grantees may also create, alter, or drop their own user mappings associated with that server.

The privileges required by other commands are listed on the reference page of the respective command.

Postgres Pro grants privileges on some types of objects to `PUBLIC` by default when the objects are created. No privileges are granted to `PUBLIC` by default on tables, table columns, sequences, foreign data

wrappers, foreign servers, large objects, schemas, or tablespaces. For other types of objects, the default privileges granted to PUBLIC are as follows: CONNECT and TEMPORARY (create temporary tables) privileges for databases; EXECUTE privilege for functions and procedures; and USAGE privilege for languages and data types (including domains). The object owner can, of course, REVOKE both default and expressly granted privileges. (For maximum security, issue the REVOKE in the same transaction that creates the object; then there is no window in which another user can use the object.) Also, these default privilege settings can be overridden using the ALTER DEFAULT PRIVILEGES command.

Table 5.1 shows the one-letter abbreviations that are used for these privilege types in *ACL* (Access Control List) values. You will see these letters in the output of the psql commands listed below, or when looking at ACL columns of system catalogs.

Table 5.1. ACL Privilege Abbreviations

Privilege	Abbreviation	Applicable Object Types
SELECT	r (“read”)	LARGE OBJECT, SEQUENCE, TABLE (and table-like objects), table column
INSERT	a (“append”)	TABLE, table column
UPDATE	w (“write”)	LARGE OBJECT, SEQUENCE, TABLE, table column
DELETE	d	TABLE
TRUNCATE	D	TABLE
REFERENCES	x	TABLE, table column
TRIGGER	t	TABLE
CREATE	C	DATABASE, SCHEMA, TABLESPACE
CONNECT	c	DATABASE
TEMPORARY	T	DATABASE
EXECUTE	X	FUNCTION, PROCEDURE
USAGE	U	DOMAIN, FOREIGN DATA WRAPPER, FOREIGN SERVER, LANGUAGE, SCHEMA, SEQUENCE, TYPE

Table 5.2 summarizes the privileges available for each type of SQL object, using the abbreviations shown above. It also shows the psql command that can be used to examine privilege settings for each object type.

Table 5.2. Summary of Access Privileges

Object Type	All Privileges	Default PUBLIC Privileges	psql Command
DATABASE	CTc	Tc	\l
DOMAIN	U	U	\dD+
FUNCTION or PROCEDURE	X	X	\df+
FOREIGN DATA WRAPPER	U	none	\dew+
FOREIGN SERVER	U	none	\des+
LANGUAGE	U	U	\dL+
LARGE OBJECT	rw	none	
SCHEMA	UC	none	\dn+
SEQUENCE	rwU	none	\dp
TABLE (and table-like objects)	arwdDxt	none	\dp
Table column	arwx	none	\dp

Object Type	All Privileges	Default PUBLIC Privileges	psql Command
TABLESPACE	C	none	\db+
TYPE	U	U	\dT+

The privileges that have been granted for a particular object are displayed as a list of aclitem entries, each having the format:

grantee=privilege-abbreviation[*]*.../grantor*

Each aclitem lists all the permissions of one grantee that have been granted by a particular grantor. Specific privileges are represented by one-letter abbreviations from Table 5.1, with * appended if the privilege was granted with grant option. For example, calvin=r*w/hobbes specifies that the role calvin has the privilege SELECT (r) with grant option (*) as well as the non-grantable privilege UPDATE (w), both granted by the role hobbes. If calvin also has some privileges on the same object granted by a different grantor, those would appear as a separate aclitem entry. An empty grantee field in an aclitem stands for PUBLIC.

As an example, suppose that user miriam creates table mytable and does:

```
GRANT SELECT ON mytable TO PUBLIC;
GRANT SELECT, UPDATE, INSERT ON mytable TO admin;
GRANT SELECT (col1), UPDATE (col1) ON mytable TO miriam_rw;
```

Then psql's \dp command would show:

```
=> \dp mytable
                                 Access privileges
 Schema |  Name   | Type  |   Access privileges   |   Column privileges   | Policies
--------+---------+-------+-----------------------+-----------------------+----------
 public | mytable | table | miriam=arwdDxt/miriam+| col1:                +|
        |         |       | =r/miriam            +|   miriam_rw=rw/miriam |
        |         |       | admin=arw/miriam      |                       |
(1 row)
```

If the “Access privileges” column is empty for a given object, it means the object has default privileges (that is, its privileges entry in the relevant system catalog is null). Default privileges always include all privileges for the owner, and can include some privileges for PUBLIC depending on the object type, as explained above. The first GRANT or REVOKE on an object will instantiate the default privileges (producing, for example, miriam=arwdDxt/miriam) and then modify them per the specified request. Similarly, entries are shown in “Column privileges” only for columns with nondefault privileges. (Note: for this purpose, “default privileges” always means the built-in default privileges for the object's type. An object whose privileges have been affected by an ALTER DEFAULT PRIVILEGES command will always be shown with an explicit privilege entry that includes the effects of the ALTER.)

Notice that the owner's implicit grant options are not marked in the access privileges display. A * will appear only when grant options have been explicitly granted to someone.

5.8. Row Security Policies

In addition to the SQL-standard privilege system available through GRANT, tables can have *row security policies* that restrict, on a per-user basis, which rows can be returned by normal queries or inserted, updated, or deleted by data modification commands. This feature is also known as *Row-Level Security*. By default, tables do not have any policies, so that if a user has access privileges to a table according to the SQL privilege system, all rows within it are equally available for querying or updating.

When row security is enabled on a table (with ALTER TABLE ... ENABLE ROW LEVEL SECURITY), all normal access to the table for selecting rows or modifying rows must be allowed by a row security policy.

(However, the table's owner is typically not subject to row security policies.) If no policy exists for the table, a default-deny policy is used, meaning that no rows are visible or can be modified. Operations that apply to the whole table, such as TRUNCATE and REFERENCES, are not subject to row security.

Row security policies can be specific to commands, or to roles, or to both. A policy can be specified to apply to ALL commands, or to SELECT, INSERT, UPDATE, or DELETE. Multiple roles can be assigned to a given policy, and normal role membership and inheritance rules apply.

To specify which rows are visible or modifiable according to a policy, an expression is required that returns a Boolean result. This expression will be evaluated for each row prior to any conditions or functions coming from the user's query. (The only exceptions to this rule are leakproof functions, which are guaranteed to not leak information; the optimizer may choose to apply such functions ahead of the row-security check.) Rows for which the expression does not return true will not be processed. Separate expressions may be specified to provide independent control over the rows which are visible and the rows which are allowed to be modified. Policy expressions are run as part of the query and with the privileges of the user running the query, although security-definer functions can be used to access data not available to the calling user.

Superusers and roles with the BYPASSRLS attribute always bypass the row security system when accessing a table. Table owners normally bypass row security as well, though a table owner can choose to be subject to row security with ALTER TABLE ... FORCE ROW LEVEL SECURITY.

Enabling and disabling row security, as well as adding policies to a table, is always the privilege of the table owner only.

Policies are created using the CREATE POLICY command, altered using the ALTER POLICY command, and dropped using the DROP POLICY command. To enable and disable row security for a given table, use the ALTER TABLE command.

Each policy has a name and multiple policies can be defined for a table. As policies are table-specific, each policy for a table must have a unique name. Different tables may have policies with the same name.

When multiple policies apply to a given query, they are combined using either OR (for permissive policies, which are the default) or using AND (for restrictive policies). This is similar to the rule that a given role has the privileges of all roles that they are a member of. Permissive vs. restrictive policies are discussed further below.

As a simple example, here is how to create a policy on the account relation to allow only members of the managers role to access rows, and only rows of their accounts:

```
CREATE TABLE accounts (manager text, company text, contact_email text);

ALTER TABLE accounts ENABLE ROW LEVEL SECURITY;

CREATE POLICY account_managers ON accounts TO managers
    USING (manager = current_user);
```

The policy above implicitly provides a WITH CHECK clause identical to its USING clause, so that the constraint applies both to rows selected by a command (so a manager cannot SELECT, UPDATE, or DELETE existing rows belonging to a different manager) and to rows modified by a command (so rows belonging to a different manager cannot be created via INSERT or UPDATE).

If no role is specified, or the special user name PUBLIC is used, then the policy applies to all users on the system. To allow all users to access only their own row in a users table, a simple policy can be used:

```
CREATE POLICY user_policy ON users
    USING (user_name = current_user);
```

This works similarly to the previous example.

To use a different policy for rows that are being added to the table compared to those rows that are visible, multiple policies can be combined. This pair of policies would allow all users to view all rows in the `users` table, but only modify their own:

```
CREATE POLICY user_sel_policy ON users
    FOR SELECT
    USING (true);
CREATE POLICY user_mod_policy ON users
    USING (user_name = current_user);
```

In a `SELECT` command, these two policies are combined using `OR`, with the net effect being that all rows can be selected. In other command types, only the second policy applies, so that the effects are the same as before.

Row security can also be disabled with the `ALTER TABLE` command. Disabling row security does not remove any policies that are defined on the table; they are simply ignored. Then all rows in the table are visible and modifiable, subject to the standard SQL privileges system.

Below is a larger example of how this feature can be used in production environments. The table `passwd` emulates a Unix password file:

```
-- Simple passwd-file based example
CREATE TABLE passwd (
  user_name             text UNIQUE NOT NULL,
  pwhash                text,
  uid                   int  PRIMARY KEY,
  gid                   int  NOT NULL,
  real_name             text NOT NULL,
  home_phone            text,
  extra_info            text,
  home_dir              text NOT NULL,
  shell                 text NOT NULL
);

CREATE ROLE admin;  -- Administrator
CREATE ROLE bob;    -- Normal user
CREATE ROLE alice;  -- Normal user

-- Populate the table
INSERT INTO passwd VALUES
  ('admin','xxx',0,0,'Admin','111-222-3333',null,'/root','/bin/dash');
INSERT INTO passwd VALUES
  ('bob','xxx',1,1,'Bob','123-456-7890',null,'/home/bob','/bin/zsh');
INSERT INTO passwd VALUES
  ('alice','xxx',2,1,'Alice','098-765-4321',null,'/home/alice','/bin/zsh');

-- Be sure to enable row-level security on the table
ALTER TABLE passwd ENABLE ROW LEVEL SECURITY;

-- Create policies
-- Administrator can see all rows and add any rows
CREATE POLICY admin_all ON passwd TO admin USING (true) WITH CHECK (true);
-- Normal users can view all rows
CREATE POLICY all_view ON passwd FOR SELECT USING (true);
-- Normal users can update their own records, but
-- limit which shells a normal user is allowed to set
CREATE POLICY user_mod ON passwd FOR UPDATE
  USING (current_user = user_name)
  WITH CHECK (
```

```
    current_user = user_name AND
    shell IN ('/bin/bash','/bin/sh','/bin/dash','/bin/zsh','/bin/tcsh')
  );

-- Allow admin all normal rights
GRANT SELECT, INSERT, UPDATE, DELETE ON passwd TO admin;
-- Users only get select access on public columns
GRANT SELECT
  (user_name, uid, gid, real_name, home_phone, extra_info, home_dir, shell)
  ON passwd TO public;
-- Allow users to update certain columns
GRANT UPDATE
  (pwhash, real_name, home_phone, extra_info, shell)
  ON passwd TO public;
```

As with any security settings, it's important to test and ensure that the system is behaving as expected. Using the example above, this demonstrates that the permission system is working properly.

```
-- admin can view all rows and fields
postgres=> set role admin;
SET
postgres=> table passwd;
 user_name | pwhash | uid | gid | real_name |  home_phone  | extra_info | home_dir    |
   shell
-----------+--------+-----+-----+-----------+--------------+------------+-------------
+-----------
 admin     | xxx    |   0 |   0 | Admin     | 111-222-3333 |            | /root
 | /bin/dash
 bob       | xxx    |   1 |   1 | Bob       | 123-456-7890 |            | /home/bob
 | /bin/zsh
 alice     | xxx    |   2 |   1 | Alice     | 098-765-4321 |            | /home/alice
 | /bin/zsh
(3 rows)

-- Test what Alice is able to do
postgres=> set role alice;
SET
postgres=> table passwd;
ERROR:  permission denied for table passwd
postgres=> select user_name,real_name,home_phone,extra_info,home_dir,shell from passwd;
 user_name | real_name |  home_phone  | extra_info | home_dir    |   shell
-----------+-----------+--------------+------------+-------------+-----------
 admin     | Admin     | 111-222-3333 |            | /root       | /bin/dash
 bob       | Bob       | 123-456-7890 |            | /home/bob   | /bin/zsh
 alice     | Alice     | 098-765-4321 |            | /home/alice | /bin/zsh
(3 rows)

postgres=> update passwd set user_name = 'joe';
ERROR:  permission denied for table passwd
-- Alice is allowed to change her own real_name, but no others
postgres=> update passwd set real_name = 'Alice Doe';
UPDATE 1
postgres=> update passwd set real_name = 'John Doe' where user_name = 'admin';
UPDATE 0
postgres=> update passwd set shell = '/bin/xx';
ERROR:  new row violates WITH CHECK OPTION for "passwd"
postgres=> delete from passwd;
ERROR:  permission denied for table passwd
postgres=> insert into passwd (user_name) values ('xxx');
```

```
ERROR:  permission denied for table passwd
-- Alice can change her own password; RLS silently prevents updating other rows
postgres=> update passwd set pwhash = 'abc';
UPDATE 1
```

All of the policies constructed thus far have been permissive policies, meaning that when multiple policies are applied they are combined using the "OR" Boolean operator. While permissive policies can be constructed to only allow access to rows in the intended cases, it can be simpler to combine permissive policies with restrictive policies (which the records must pass and which are combined using the "AND" Boolean operator). Building on the example above, we add a restrictive policy to require the administrator to be connected over a local Unix socket to access the records of the `passwd` table:

```
CREATE POLICY admin_local_only ON passwd AS RESTRICTIVE TO admin
    USING (pg_catalog.inet_client_addr() IS NULL);
```

We can then see that an administrator connecting over a network will not see any records, due to the restrictive policy:

```
=> SELECT current_user;
 current_user
--------------
 admin
(1 row)

=> select inet_client_addr();
 inet_client_addr
------------------
 127.0.0.1
(1 row)

=> TABLE passwd;
 user_name | pwhash | uid | gid | real_name | home_phone | extra_info | home_dir |
 shell
-----------+--------+-----+-----+-----------+------------+------------+----------
+-------
(0 rows)

=> UPDATE passwd set pwhash = NULL;
UPDATE 0
```

Referential integrity checks, such as unique or primary key constraints and foreign key references, always bypass row security to ensure that data integrity is maintained. Care must be taken when developing schemas and row level policies to avoid "covert channel" leaks of information through such referential integrity checks.

In some contexts it is important to be sure that row security is not being applied. For example, when taking a backup, it could be disastrous if row security silently caused some rows to be omitted from the backup. In such a situation, you can set the row_security configuration parameter to `off`. This does not in itself bypass row security; what it does is throw an error if any query's results would get filtered by a policy. The reason for the error can then be investigated and fixed.

In the examples above, the policy expressions consider only the current values in the row to be accessed or updated. This is the simplest and best-performing case; when possible, it's best to design row security applications to work this way. If it is necessary to consult other rows or other tables to make a policy decision, that can be accomplished using sub-`SELECT`s, or functions that contain `SELECT`s, in the policy expressions. Be aware however that such accesses can create race conditions that could allow information leakage if care is not taken. As an example, consider the following table design:

```
-- definition of privilege groups
CREATE TABLE groups (group_id int PRIMARY KEY,
```

```
                    group_name text NOT NULL);

INSERT INTO groups VALUES
  (1, 'low'),
  (2, 'medium'),
  (5, 'high');

GRANT ALL ON groups TO alice;  -- alice is the administrator
GRANT SELECT ON groups TO public;

-- definition of users' privilege levels
CREATE TABLE users (user_name text PRIMARY KEY,
                    group_id int NOT NULL REFERENCES groups);

INSERT INTO users VALUES
  ('alice', 5),
  ('bob', 2),
  ('mallory', 2);

GRANT ALL ON users TO alice;
GRANT SELECT ON users TO public;

-- table holding the information to be protected
CREATE TABLE information (info text,
                          group_id int NOT NULL REFERENCES groups);

INSERT INTO information VALUES
  ('barely secret', 1),
  ('slightly secret', 2),
  ('very secret', 5);

ALTER TABLE information ENABLE ROW LEVEL SECURITY;

-- a row should be visible to/updatable by users whose security group_id is
-- greater than or equal to the row's group_id
CREATE POLICY fp_s ON information FOR SELECT
  USING (group_id <= (SELECT group_id FROM users WHERE user_name = current_user));
CREATE POLICY fp_u ON information FOR UPDATE
  USING (group_id <= (SELECT group_id FROM users WHERE user_name = current_user));

-- we rely only on RLS to protect the information table
GRANT ALL ON information TO public;
```

Now suppose that `alice` wishes to change the “slightly secret” information, but decides that `mallory` should not be trusted with the new content of that row, so she does:

```
BEGIN;
UPDATE users SET group_id = 1 WHERE user_name = 'mallory';
UPDATE information SET info = 'secret from mallory' WHERE group_id = 2;
COMMIT;
```

That looks safe; there is no window wherein `mallory` should be able to see the “secret from mallory” string. However, there is a race condition here. If `mallory` is concurrently doing, say,

```
SELECT * FROM information WHERE group_id = 2 FOR UPDATE;
```

and her transaction is in `READ COMMITTED` mode, it is possible for her to see “secret from mallory”. That happens if her transaction reaches the `information` row just after `alice`'s does. It blocks waiting for `alice`'s transaction to commit, then fetches the updated row contents thanks to the `FOR UPDATE` clause. However, it does *not* fetch an updated row for the implicit `SELECT` from `users`, because that sub-`SELECT`

did not have FOR UPDATE; instead the users row is read with the snapshot taken at the start of the query. Therefore, the policy expression tests the old value of mallory's privilege level and allows her to see the updated row.

There are several ways around this problem. One simple answer is to use SELECT ... FOR SHARE in sub-SELECTs in row security policies. However, that requires granting UPDATE privilege on the referenced table (here users) to the affected users, which might be undesirable. (But another row security policy could be applied to prevent them from actually exercising that privilege; or the sub-SELECT could be embedded into a security definer function.) Also, heavy concurrent use of row share locks on the referenced table could pose a performance problem, especially if updates of it are frequent. Another solution, practical if updates of the referenced table are infrequent, is to take an ACCESS EXCLUSIVE lock on the referenced table when updating it, so that no concurrent transactions could be examining old row values. Or one could just wait for all concurrent transactions to end after committing an update of the referenced table and before making changes that rely on the new security situation.

For additional details see CREATE POLICY and ALTER TABLE.

5.9. Schemas

A Postgres Pro database cluster contains one or more named databases. Roles and a few other object types are shared across the entire cluster. A client connection to the server can only access data in a single database, the one specified in the connection request.

> **Note**
>
> Users of a cluster do not necessarily have the privilege to access every database in the cluster. Sharing of role names means that there cannot be different roles named, say, joe in two databases in the same cluster; but the system can be configured to allow joe access to only some of the databases.

A database contains one or more named *schemas*, which in turn contain tables. Schemas also contain other kinds of named objects, including data types, functions, and operators. The same object name can be used in different schemas without conflict; for example, both schema1 and myschema can contain tables named mytable. Unlike databases, schemas are not rigidly separated: a user can access objects in any of the schemas in the database they are connected to, if they have privileges to do so.

There are several reasons why one might want to use schemas:

- To allow many users to use one database without interfering with each other.
- To organize database objects into logical groups to make them more manageable.
- Third-party applications can be put into separate schemas so they do not collide with the names of other objects.

Schemas are analogous to directories at the operating system level, except that schemas cannot be nested.

5.9.1. Creating a Schema

To create a schema, use the CREATE SCHEMA command. Give the schema a name of your choice. For example:

```
CREATE SCHEMA myschema;
```

To create or access objects in a schema, write a *qualified name* consisting of the schema name and table name separated by a dot:

```
schema.table
```

This works anywhere a table name is expected, including the table modification commands and the data access commands discussed in the following chapters. (For brevity we will speak of tables only, but the same ideas apply to other kinds of named objects, such as types and functions.)

Actually, the even more general syntax

database.*schema*.*table*

can be used too, but at present this is just for pro forma compliance with the SQL standard. If you write a database name, it must be the same as the database you are connected to.

So to create a table in the new schema, use:

```
CREATE TABLE myschema.mytable (
 ...
);
```

To drop a schema if it's empty (all objects in it have been dropped), use:

```
DROP SCHEMA myschema;
```

To drop a schema including all contained objects, use:

```
DROP SCHEMA myschema CASCADE;
```

See Section 5.14 for a description of the general mechanism behind this.

Often you will want to create a schema owned by someone else (since this is one of the ways to restrict the activities of your users to well-defined namespaces). The syntax for that is:

```
CREATE SCHEMA schema_name AUTHORIZATION user_name;
```

You can even omit the schema name, in which case the schema name will be the same as the user name. See Section 5.9.6 for how this can be useful.

Schema names beginning with `pg_` are reserved for system purposes and cannot be created by users.

5.9.2. The Public Schema

In the previous sections we created tables without specifying any schema names. By default such tables (and other objects) are automatically put into a schema named “public”. Every new database contains such a schema. Thus, the following are equivalent:

```
CREATE TABLE products ( ... );
```

and:

```
CREATE TABLE public.products ( ... );
```

5.9.3. The Schema Search Path

Qualified names are tedious to write, and it's often best not to wire a particular schema name into applications anyway. Therefore tables are often referred to by *unqualified names*, which consist of just the table name. The system determines which table is meant by following a *search path*, which is a list of schemas to look in. The first matching table in the search path is taken to be the one wanted. If there is no match in the search path, an error is reported, even if matching table names exist in other schemas in the database.

The ability to create like-named objects in different schemas complicates writing a query that references precisely the same objects every time. It also opens up the potential for users to change the behavior of other users' queries, maliciously or accidentally. Due to the prevalence of unqualified names in queries and their use in Postgres Pro internals, adding a schema to `search_path` effectively trusts all users having `CREATE` privilege on that schema. When you run an ordinary query, a malicious user able to create

objects in a schema of your search path can take control and execute arbitrary SQL functions as though you executed them.

The first schema named in the search path is called the current schema. Aside from being the first schema searched, it is also the schema in which new tables will be created if the `CREATE TABLE` command does not specify a schema name.

To show the current search path, use the following command:

```
SHOW search_path;
```

In the default setup this returns:

```
 search_path
--------------
 "$user", public
```

The first element specifies that a schema with the same name as the current user is to be searched. If no such schema exists, the entry is ignored. The second element refers to the public schema that we have seen already.

The first schema in the search path that exists is the default location for creating new objects. That is the reason that by default objects are created in the public schema. When objects are referenced in any other context without schema qualification (table modification, data modification, or query commands) the search path is traversed until a matching object is found. Therefore, in the default configuration, any unqualified access again can only refer to the public schema.

To put our new schema in the path, we use:

```
SET search_path TO myschema,public;
```

(We omit the `$user` here because we have no immediate need for it.) And then we can access the table without schema qualification:

```
DROP TABLE mytable;
```

Also, since `myschema` is the first element in the path, new objects would by default be created in it.

We could also have written:

```
SET search_path TO myschema;
```

Then we no longer have access to the public schema without explicit qualification. There is nothing special about the public schema except that it exists by default. It can be dropped, too.

See also Section 9.26 for other ways to manipulate the schema search path.

The search path works in the same way for data type names, function names, and operator names as it does for table names. Data type and function names can be qualified in exactly the same way as table names. If you need to write a qualified operator name in an expression, there is a special provision: you must write

```
OPERATOR(schema.operator)
```

This is needed to avoid syntactic ambiguity. An example is:

```
SELECT 3 OPERATOR(pg_catalog.+) 4;
```

In practice one usually relies on the search path for operators, so as not to have to write anything so ugly as that.

5.9.4. Schemas and Privileges

By default, users cannot access any objects in schemas they do not own. To allow that, the owner of the schema must grant the `USAGE` privilege on the schema. To allow users to make use of the objects in the schema, additional privileges might need to be granted, as appropriate for the object.

A user can also be allowed to create objects in someone else's schema. To allow that, the CREATE privilege on the schema needs to be granted. Note that by default, everyone has CREATE and USAGE privileges on the schema public. This allows all users that are able to connect to a given database to create objects in its public schema. Some usage patterns call for revoking that privilege:

```
REVOKE CREATE ON SCHEMA public FROM PUBLIC;
```

(The first “public” is the schema, the second “public” means “every user”. In the first sense it is an identifier, in the second sense it is a key word, hence the different capitalization; recall the guidelines from Section 4.1.1.)

5.9.5. The System Catalog Schema

In addition to public and user-created schemas, each database contains a pg_catalog schema, which contains the system tables and all the built-in data types, functions, and operators. pg_catalog is always effectively part of the search path. If it is not named explicitly in the path then it is implicitly searched *before* searching the path's schemas. This ensures that built-in names will always be findable. However, you can explicitly place pg_catalog at the end of your search path if you prefer to have user-defined names override built-in names.

Since system table names begin with pg_, it is best to avoid such names to ensure that you won't suffer a conflict if some future version defines a system table named the same as your table. (With the default search path, an unqualified reference to your table name would then be resolved as the system table instead.) System tables will continue to follow the convention of having names beginning with pg_, so that they will not conflict with unqualified user-table names so long as users avoid the pg_ prefix.

5.9.6. Usage Patterns

Schemas can be used to organize your data in many ways. A *secure schema usage pattern* prevents untrusted users from changing the behavior of other users' queries. When a database does not use a secure schema usage pattern, users wishing to securely query that database would take protective action at the beginning of each session. Specifically, they would begin each session by setting search_path to the empty string or otherwise removing non-superuser-writable schemas from search_path. There are a few usage patterns easily supported by the default configuration:

- Constrain ordinary users to user-private schemas. To implement this, issue REVOKE CREATE ON SCHEMA public FROM PUBLIC, and create a schema for each user with the same name as that user. Recall that the default search path starts with $user, which resolves to the user name. Therefore, if each user has a separate schema, they access their own schemas by default. After adopting this pattern in a database where untrusted users had already logged in, consider auditing the public schema for objects named like objects in schema pg_catalog. This pattern is a secure schema usage pattern unless an untrusted user is the database owner or has been granted ADMIN OPTION on a relevant role, in which case no secure schema usage pattern exists.

- Remove the public schema from the default search path, by modifying postgresql.conf or by issuing ALTER ROLE ALL SET search_path = "$user". Everyone retains the ability to create objects in the public schema, but only qualified names will choose those objects. While qualified table references are fine, calls to functions in the public schema will be unsafe or unreliable. If you create functions or extensions in the public schema, use the first pattern instead. Otherwise, like the first pattern, this is secure unless an untrusted user is the database owner or has been granted ADMIN OPTION on a relevant role.

- Keep the default. All users access the public schema implicitly. This simulates the situation where schemas are not available at all, giving a smooth transition from the non-schema-aware world. However, this is never a secure pattern. It is acceptable only when the database has a single user or a few mutually-trusting users.

For any pattern, to install shared applications (tables to be used by everyone, additional functions provided by third parties, etc.), put them into separate schemas. Remember to grant appropriate privileges

to allow the other users to access them. Users can then refer to these additional objects by qualifying the names with a schema name, or they can put the additional schemas into their search path, as they choose.

5.9.7. Portability

In the SQL standard, the notion of objects in the same schema being owned by different users does not exist. Moreover, some implementations do not allow you to create schemas that have a different name than their owner. In fact, the concepts of schema and user are nearly equivalent in a database system that implements only the basic schema support specified in the standard. Therefore, many users consider qualified names to really consist of *user_name*.*table_name*. This is how Postgres Pro will effectively behave if you create a per-user schema for every user.

Also, there is no concept of a `public` schema in the SQL standard. For maximum conformance to the standard, you should not use the `public` schema.

Of course, some SQL database systems might not implement schemas at all, or provide namespace support by allowing (possibly limited) cross-database access. If you need to work with those systems, then maximum portability would be achieved by not using schemas at all.

5.10. Inheritance

Postgres Pro implements table inheritance, which can be a useful tool for database designers. (SQL:1999 and later define a type inheritance feature, which differs in many respects from the features described here.)

Let's start with an example: suppose we are trying to build a data model for cities. Each state has many cities, but only one capital. We want to be able to quickly retrieve the capital city for any particular state. This can be done by creating two tables, one for state capitals and one for cities that are not capitals. However, what happens when we want to ask for data about a city, regardless of whether it is a capital or not? The inheritance feature can help to resolve this problem. We define the `capitals` table so that it inherits from `cities`:

```
CREATE TABLE cities (
    name            text,
    population      float,
    elevation       int     -- in feet
);

CREATE TABLE capitals (
    state           char(2)
) INHERITS (cities);
```

In this case, the `capitals` table *inherits* all the columns of its parent table, `cities`. State capitals also have an extra column, `state`, that shows their state.

In Postgres Pro, a table can inherit from zero or more other tables, and a query can reference either all rows of a table or all rows of a table plus all of its descendant tables. The latter behavior is the default. For example, the following query finds the names of all cities, including state capitals, that are located at an elevation over 500 feet:

```
SELECT name, elevation
    FROM cities
    WHERE elevation > 500;
```

Given the sample data from the Postgres Pro tutorial (see Section 2.1), this returns:

```
   name    | elevation
-----------+-----------
 Las Vegas |      2174
 Mariposa  |      1953
```

```
 Madison   |       845
```

On the other hand, the following query finds all the cities that are not state capitals and are situated at an elevation over 500 feet:

```
SELECT name, elevation
    FROM ONLY cities
    WHERE elevation > 500;

   name    | elevation
-----------+-----------
 Las Vegas |      2174
 Mariposa  |      1953
```

Here the `ONLY` keyword indicates that the query should apply only to `cities`, and not any tables below `cities` in the inheritance hierarchy. Many of the commands that we have already discussed — `SELECT`, `UPDATE` and `DELETE` — support the `ONLY` keyword.

You can also write the table name with a trailing `*` to explicitly specify that descendant tables are included:

```
SELECT name, elevation
    FROM cities*
    WHERE elevation > 500;
```

Writing `*` is not necessary, since this behavior is always the default. However, this syntax is still supported for compatibility with older releases where the default could be changed.

In some cases you might wish to know which table a particular row originated from. There is a system column called `tableoid` in each table which can tell you the originating table:

```
SELECT c.tableoid, c.name, c.elevation
FROM cities c
WHERE c.elevation > 500;
```

which returns:

```
 tableoid |   name    | elevation
----------+-----------+-----------
   139793 | Las Vegas |      2174
   139793 | Mariposa  |      1953
   139798 | Madison   |       845
```

(If you try to reproduce this example, you will probably get different numeric OIDs.) By doing a join with `pg_class` you can see the actual table names:

```
SELECT p.relname, c.name, c.elevation
FROM cities c, pg_class p
WHERE c.elevation > 500 AND c.tableoid = p.oid;
```

which returns:

```
 relname  |   name    | elevation
----------+-----------+-----------
 cities   | Las Vegas |      2174
 cities   | Mariposa  |      1953
 capitals | Madison   |       845
```

Another way to get the same effect is to use the `regclass` alias type, which will print the table OID symbolically:

```
SELECT c.tableoid::regclass, c.name, c.elevation
FROM cities c
WHERE c.elevation > 500;
```

Inheritance does not automatically propagate data from INSERT or COPY commands to other tables in the inheritance hierarchy. In our example, the following INSERT statement will fail:

```
INSERT INTO cities (name, population, elevation, state)
VALUES ('Albany', NULL, NULL, 'NY');
```

We might hope that the data would somehow be routed to the capitals table, but this does not happen: INSERT always inserts into exactly the table specified. In some cases it is possible to redirect the insertion using a rule (see Chapter 43). However that does not help for the above case because the cities table does not contain the column state, and so the command will be rejected before the rule can be applied.

All check constraints and not-null constraints on a parent table are automatically inherited by its children, unless explicitly specified otherwise with NO INHERIT clauses. Other types of constraints (unique, primary key, and foreign key constraints) are not inherited.

A table can inherit from more than one parent table, in which case it has the union of the columns defined by the parent tables. Any columns declared in the child table's definition are added to these. If the same column name appears in multiple parent tables, or in both a parent table and the child's definition, then these columns are “merged” so that there is only one such column in the child table. To be merged, columns must have the same data types, else an error is raised. Inheritable check constraints and not-null constraints are merged in a similar fashion. Thus, for example, a merged column will be marked not-null if any one of the column definitions it came from is marked not-null. Check constraints are merged if they have the same name, and the merge will fail if their conditions are different.

Table inheritance is typically established when the child table is created, using the INHERITS clause of the CREATE TABLE statement. Alternatively, a table which is already defined in a compatible way can have a new parent relationship added, using the INHERIT variant of ALTER TABLE. To do this the new child table must already include columns with the same names and types as the columns of the parent. It must also include check constraints with the same names and check expressions as those of the parent. Similarly an inheritance link can be removed from a child using the NO INHERIT variant of ALTER TABLE. Dynamically adding and removing inheritance links like this can be useful when the inheritance relationship is being used for table partitioning (see Section 5.11).

One convenient way to create a compatible table that will later be made a new child is to use the LIKE clause in CREATE TABLE. This creates a new table with the same columns as the source table. If there are any CHECK constraints defined on the source table, the INCLUDING CONSTRAINTS option to LIKE should be specified, as the new child must have constraints matching the parent to be considered compatible.

A parent table cannot be dropped while any of its children remain. Neither can columns or check constraints of child tables be dropped or altered if they are inherited from any parent tables. If you wish to remove a table and all of its descendants, one easy way is to drop the parent table with the CASCADE option (see Section 5.14).

ALTER TABLE will propagate any changes in column data definitions and check constraints down the inheritance hierarchy. Again, dropping columns that are depended on by other tables is only possible when using the CASCADE option. ALTER TABLE follows the same rules for duplicate column merging and rejection that apply during CREATE TABLE.

Inherited queries perform access permission checks on the parent table only. Thus, for example, granting UPDATE permission on the cities table implies permission to update rows in the capitals table as well, when they are accessed through cities. This preserves the appearance that the data is (also) in the parent table. But the capitals table could not be updated directly without an additional grant. In a similar way, the parent table's row security policies (see Section 5.8) are applied to rows coming from child tables during an inherited query. A child table's policies, if any, are applied only when it is the table explicitly named in the query; and in that case, any policies attached to its parent(s) are ignored.

Foreign tables (see Section 5.12) can also be part of inheritance hierarchies, either as parent or child tables, just as regular tables can be. If a foreign table is part of an inheritance hierarchy then any operations not supported by the foreign table are not supported on the whole hierarchy either.

5.10.1. Caveats

Note that not all SQL commands are able to work on inheritance hierarchies. Commands that are used for data querying, data modification, or schema modification (e.g., `SELECT`, `UPDATE`, `DELETE`, most variants of `ALTER TABLE`, but not `INSERT` or `ALTER TABLE ... RENAME`) typically default to including child tables and support the `ONLY` notation to exclude them. Commands that do database maintenance and tuning (e.g., `REINDEX`, `VACUUM`) typically only work on individual, physical tables and do not support recursing over inheritance hierarchies. The respective behavior of each individual command is documented in its reference page (SQL Commands).

A serious limitation of the inheritance feature is that indexes (including unique constraints) and foreign key constraints only apply to single tables, not to their inheritance children. This is true on both the referencing and referenced sides of a foreign key constraint. Thus, in the terms of the above example:

- If we declared `cities.name` to be `UNIQUE` or a `PRIMARY KEY`, this would not stop the `capitals` table from having rows with names duplicating rows in `cities`. And those duplicate rows would by default show up in queries from `cities`. In fact, by default `capitals` would have no unique constraint at all, and so could contain multiple rows with the same name. You could add a unique constraint to `capitals`, but this would not prevent duplication compared to `cities`.
- Similarly, if we were to specify that `cities.name REFERENCES` some other table, this constraint would not automatically propagate to `capitals`. In this case you could work around it by manually adding the same `REFERENCES` constraint to `capitals`.
- Specifying that another table's column `REFERENCES cities(name)` would allow the other table to contain city names, but not capital names. There is no good workaround for this case.

Some functionality not implemented for inheritance hierarchies is implemented for declarative partitioning. Considerable care is needed in deciding whether partitioning with legacy inheritance is useful for your application.

5.11. Table Partitioning

Postgres Pro supports basic table partitioning. This section describes why and how to implement partitioning as part of your database design.

5.11.1. Overview

Partitioning refers to splitting what is logically one large table into smaller physical pieces. Partitioning can provide several benefits:

- Query performance can be improved dramatically in certain situations, particularly when most of the heavily accessed rows of the table are in a single partition or a small number of partitions. Partitioning effectively substitutes for the upper tree levels of indexes, making it more likely that the heavily-used parts of the indexes fit in memory.
- When queries or updates access a large percentage of a single partition, performance can be improved by using a sequential scan of that partition instead of using an index, which would require random-access reads scattered across the whole table.
- Bulk loads and deletes can be accomplished by adding or removing partitions, if the usage pattern is accounted for in the partitioning design. Dropping an individual partition using `DROP TABLE`, or doing `ALTER TABLE DETACH PARTITION`, is far faster than a bulk operation. These commands also entirely avoid the `VACUUM` overhead caused by a bulk `DELETE`.
- Seldom-used data can be migrated to cheaper and slower storage media.

These benefits will normally be worthwhile only when a table would otherwise be very large. The exact point at which a table will benefit from partitioning depends on the application, although a rule of thumb is that the size of the table should exceed the physical memory of the database server.

Postgres Pro offers built-in support for the following forms of partitioning:

Range Partitioning

The table is partitioned into “ranges” defined by a key column or set of columns, with no overlap between the ranges of values assigned to different partitions. For example, one might partition by date ranges, or by ranges of identifiers for particular business objects. Each range's bounds are understood as being inclusive at the lower end and exclusive at the upper end. For example, if one partition's range is from `1` to `10`, and the next one's range is from `10` to `20`, then value `10` belongs to the second partition not the first.

List Partitioning

The table is partitioned by explicitly listing which key value(s) appear in each partition.

Hash Partitioning

The table is partitioned by specifying a modulus and a remainder for each partition. Each partition will hold the rows for which the hash value of the partition key divided by the specified modulus will produce the specified remainder.

If your application needs to use other forms of partitioning not listed above, alternative methods such as inheritance and `UNION ALL` views can be used instead. Such methods offer flexibility but do not have some of the performance benefits of built-in declarative partitioning.

5.11.2. Declarative Partitioning

Postgres Pro allows you to declare that a table is divided into partitions. The table that is divided is referred to as a *partitioned table*. The declaration includes the *partitioning method* as described above, plus a list of columns or expressions to be used as the *partition key*.

The partitioned table itself is a “virtual” table having no storage of its own. Instead, the storage belongs to *partitions*, which are otherwise-ordinary tables associated with the partitioned table. Each partition stores a subset of the data as defined by its *partition bounds*. All rows inserted into a partitioned table will be routed to the appropriate one of the partitions based on the values of the partition key column(s). Updating the partition key of a row will cause it to be moved into a different partition if it no longer satisfies the partition bounds of its original partition.

Partitions may themselves be defined as partitioned tables, resulting in *sub-partitioning*. Although all partitions must have the same columns as their partitioned parent, partitions may have their own indexes, constraints and default values, distinct from those of other partitions. See CREATE TABLE for more details on creating partitioned tables and partitions.

It is not possible to turn a regular table into a partitioned table or vice versa. However, it is possible to add an existing regular or partitioned table as a partition of a partitioned table, or remove a partition from a partitioned table turning it into a standalone table; this can simplify and speed up many maintenance processes. See ALTER TABLE to learn more about the `ATTACH PARTITION` and `DETACH PARTITION` subcommands.

Partitions can also be foreign tables, although considerable care is needed because it is then the user's responsibility that the contents of the foreign table satisfy the partitioning rule. There are some other restrictions as well. See CREATE FOREIGN TABLE for more information.

5.11.2.1. Example

Suppose we are constructing a database for a large ice cream company. The company measures peak temperatures every day as well as ice cream sales in each region. Conceptually, we want a table like:

```
CREATE TABLE measurement (
    city_id         int not null,
    logdate         date not null,
    peaktemp        int,
    unitsales       int
```

```
);
```

We know that most queries will access just the last week's, month's or quarter's data, since the main use of this table will be to prepare online reports for management. To reduce the amount of old data that needs to be stored, we decide to keep only the most recent 3 years worth of data. At the beginning of each month we will remove the oldest month's data. In this situation we can use partitioning to help us meet all of our different requirements for the measurements table.

To use declarative partitioning in this case, use the following steps:

1. Create the `measurement` table as a partitioned table by specifying the `PARTITION BY` clause, which includes the partitioning method (`RANGE` in this case) and the list of column(s) to use as the partition key.

   ```
   CREATE TABLE measurement (
       city_id         int not null,
       logdate         date not null,
       peaktemp        int,
       unitsales       int
   ) PARTITION BY RANGE (logdate);
   ```

2. Create partitions. Each partition's definition must specify bounds that correspond to the partitioning method and partition key of the parent. Note that specifying bounds such that the new partition's values would overlap with those in one or more existing partitions will cause an error.

   Partitions thus created are in every way normal Postgres Pro tables (or, possibly, foreign tables). It is possible to specify a tablespace and storage parameters for each partition separately.

   For our example, each partition should hold one month's worth of data, to match the requirement of deleting one month's data at a time. So the commands might look like:

   ```
   CREATE TABLE measurement_y2006m02 PARTITION OF measurement
       FOR VALUES FROM ('2006-02-01') TO ('2006-03-01');

   CREATE TABLE measurement_y2006m03 PARTITION OF measurement
       FOR VALUES FROM ('2006-03-01') TO ('2006-04-01');

   ...
   CREATE TABLE measurement_y2007m11 PARTITION OF measurement
       FOR VALUES FROM ('2007-11-01') TO ('2007-12-01');

   CREATE TABLE measurement_y2007m12 PARTITION OF measurement
       FOR VALUES FROM ('2007-12-01') TO ('2008-01-01')
       TABLESPACE fasttablespace;

   CREATE TABLE measurement_y2008m01 PARTITION OF measurement
       FOR VALUES FROM ('2008-01-01') TO ('2008-02-01')
       WITH (parallel_workers = 4)
       TABLESPACE fasttablespace;
   ```

   (Recall that adjacent partitions can share a bound value, since range upper bounds are treated as exclusive bounds.)

   If you wish to implement sub-partitioning, again specify the `PARTITION BY` clause in the commands used to create individual partitions, for example:

   ```
   CREATE TABLE measurement_y2006m02 PARTITION OF measurement
       FOR VALUES FROM ('2006-02-01') TO ('2006-03-01')
       PARTITION BY RANGE (peaktemp);
   ```

   After creating partitions of `measurement_y2006m02`, any data inserted into `measurement` that is mapped to `measurement_y2006m02` (or data that is directly inserted into `measurement_y2006m02`, which is allowed provided its partition constraint is satisfied) will be further redirected to one of its

partitions based on the peaktemp column. The partition key specified may overlap with the parent's partition key, although care should be taken when specifying the bounds of a sub-partition such that the set of data it accepts constitutes a subset of what the partition's own bounds allow; the system does not try to check whether that's really the case.

Inserting data into the parent table that does not map to one of the existing partitions will cause an error; an appropriate partition must be added manually.

It is not necessary to manually create table constraints describing the partition boundary conditions for partitions. Such constraints will be created automatically.

3. Create an index on the key column(s), as well as any other indexes you might want, on the partitioned table. (The key index is not strictly necessary, but in most scenarios it is helpful.) This automatically creates a matching index on each partition, and any partitions you create or attach later will also have such an index. An index or unique constraint declared on a partitioned table is “virtual” in the same way that the partitioned table is: the actual data is in child indexes on the individual partition tables.

   ```
   CREATE INDEX ON measurement (logdate);
   ```

4. Ensure that the enable_partition_pruning configuration parameter is not disabled in postgresql.conf. If it is, queries will not be optimized as desired.

In the above example we would be creating a new partition each month, so it might be wise to write a script that generates the required DDL automatically.

5.11.2.2. Partition Maintenance

Normally the set of partitions established when initially defining the table is not intended to remain static. It is common to want to remove partitions holding old data and periodically add new partitions for new data. One of the most important advantages of partitioning is precisely that it allows this otherwise painful task to be executed nearly instantaneously by manipulating the partition structure, rather than physically moving large amounts of data around.

The simplest option for removing old data is to drop the partition that is no longer necessary:

```
DROP TABLE measurement_y2006m02;
```

This can very quickly delete millions of records because it doesn't have to individually delete every record. Note however that the above command requires taking an ACCESS EXCLUSIVE lock on the parent table.

Another option that is often preferable is to remove the partition from the partitioned table but retain access to it as a table in its own right. This has two forms:

```
ALTER TABLE measurement DETACH PARTITION measurement_y2006m02;
ALTER TABLE measurement DETACH PARTITION measurement_y2006m02 CONCURRENTLY;
```

These allow further operations to be performed on the data before it is dropped. For example, this is often a useful time to back up the data using COPY, pg_dump, or similar tools. It might also be a useful time to aggregate data into smaller formats, perform other data manipulations, or run reports. The first form of the command requires an ACCESS EXCLUSIVE lock on the parent table. Adding the CONCURRENTLY qualifier as in the second form allows the detach operation to require only SHARE UPDATE EXCLUSIVE lock on the parent table, but see ALTER TABLE ... DETACH PARTITION for details on the restrictions.

Similarly we can add a new partition to handle new data. We can create an empty partition in the partitioned table just as the original partitions were created above:

```
CREATE TABLE measurement_y2008m02 PARTITION OF measurement
    FOR VALUES FROM ('2008-02-01') TO ('2008-03-01')
    TABLESPACE fasttablespace;
```

As an alternative, it is sometimes more convenient to create the new table outside the partition structure, and attach it as a partition later. This allows new data to be loaded, checked, and transformed prior to it appearing in the partitioned table. Moreover, the ATTACH PARTITION operation requires only SHARE UPDATE EXCLUSIVE lock on the partitioned table, as opposed to the ACCESS EXCLUSIVE lock that

is required by CREATE TABLE ... PARTITION OF, so it is more friendly to concurrent operations on the partitioned table. The CREATE TABLE ... LIKE option is helpful to avoid tediously repeating the parent table's definition:

```
CREATE TABLE measurement_y2008m02
  (LIKE measurement INCLUDING DEFAULTS INCLUDING CONSTRAINTS)
  TABLESPACE fasttablespace;

ALTER TABLE measurement_y2008m02 ADD CONSTRAINT y2008m02
   CHECK ( logdate >= DATE '2008-02-01' AND logdate < DATE '2008-03-01' );

\copy measurement_y2008m02 from 'measurement_y2008m02'
-- possibly some other data preparation work

ALTER TABLE measurement ATTACH PARTITION measurement_y2008m02
    FOR VALUES FROM ('2008-02-01') TO ('2008-03-01' );
```

Before running the ATTACH PARTITION command, it is recommended to create a CHECK constraint on the table to be attached that matches the expected partition constraint, as illustrated above. That way, the system will be able to skip the scan which is otherwise needed to validate the implicit partition constraint. Without the CHECK constraint, the table will be scanned to validate the partition constraint while holding an ACCESS EXCLUSIVE lock on that partition. It is recommended to drop the now-redundant CHECK constraint after the ATTACH PARTITION is complete. If the table being attached is itself a partitioned table, then each of its sub-partitions will be recursively locked and scanned until either a suitable CHECK constraint is encountered or the leaf partitions are reached.

Similarly, if the partitioned table has a DEFAULT partition, it is recommended to create a CHECK constraint which excludes the to-be-attached partition's constraint. If this is not done then the DEFAULT partition will be scanned to verify that it contains no records which should be located in the partition being attached. This operation will be performed whilst holding an ACCESS EXCLUSIVE lock on the DEFAULT partition. If the DEFAULT partition is itself a partitioned table, then each of its partitions will be recursively checked in the same way as the table being attached, as mentioned above.

As explained above, it is possible to create indexes on partitioned tables so that they are applied automatically to the entire hierarchy. This is very convenient, as not only will the existing partitions become indexed, but also any partitions that are created in the future will. One limitation is that it's not possible to use the CONCURRENTLY qualifier when creating such a partitioned index. To avoid long lock times, it is possible to use CREATE INDEX ON ONLY the partitioned table; such an index is marked invalid, and the partitions do not get the index applied automatically. The indexes on partitions can be created individually using CONCURRENTLY, and then *attached* to the index on the parent using ALTER INDEX .. ATTACH PARTITION. Once indexes for all partitions are attached to the parent index, the parent index is marked valid automatically. Example:

```
CREATE INDEX measurement_usls_idx ON ONLY measurement (unitsales);

CREATE INDEX CONCURRENTLY measurement_usls_200602_idx
    ON measurement_y2006m02 (unitsales);
ALTER INDEX measurement_usls_idx
    ATTACH PARTITION measurement_usls_200602_idx;
...
```

This technique can be used with UNIQUE and PRIMARY KEY constraints too; the indexes are created implicitly when the constraint is created. Example:

```
ALTER TABLE ONLY measurement ADD UNIQUE (city_id, logdate);

ALTER TABLE measurement_y2006m02 ADD UNIQUE (city_id, logdate);
ALTER INDEX measurement_city_id_logdate_key
    ATTACH PARTITION measurement_y2006m02_city_id_logdate_key;
...
```

5.11.2.3. Limitations

The following limitations apply to partitioned tables:

- To create a unique or primary key constraint on a partitioned table, the partition keys must not include any expressions or function calls and the constraint's columns must include all of the partition key columns. This limitation exists because the individual indexes making up the constraint can only directly enforce uniqueness within their own partitions; therefore, the partition structure itself must guarantee that there are not duplicates in different partitions.
- There is no way to create an exclusion constraint spanning the whole partitioned table. It is only possible to put such a constraint on each leaf partition individually. Again, this limitation stems from not being able to enforce cross-partition restrictions.
- `BEFORE ROW` triggers on `INSERT` cannot change which partition is the final destination for a new row.
- Mixing temporary and permanent relations in the same partition tree is not allowed. Hence, if the partitioned table is permanent, so must be its partitions and likewise if the partitioned table is temporary. When using temporary relations, all members of the partition tree have to be from the same session.

Individual partitions are linked to their partitioned table using inheritance behind-the-scenes. However, it is not possible to use all of the generic features of inheritance with declaratively partitioned tables or their partitions, as discussed below. Notably, a partition cannot have any parents other than the partitioned table it is a partition of, nor can a table inherit from both a partitioned table and a regular table. That means partitioned tables and their partitions never share an inheritance hierarchy with regular tables.

Since a partition hierarchy consisting of the partitioned table and its partitions is still an inheritance hierarchy, `tableoid` and all the normal rules of inheritance apply as described in Section 5.10, with a few exceptions:

- Partitions cannot have columns that are not present in the parent. It is not possible to specify columns when creating partitions with `CREATE TABLE`, nor is it possible to add columns to partitions after-the-fact using `ALTER TABLE`. Tables may be added as a partition with `ALTER TABLE ... ATTACH PARTITION` only if their columns exactly match the parent.
- Both `CHECK` and `NOT NULL` constraints of a partitioned table are always inherited by all its partitions. `CHECK` constraints that are marked `NO INHERIT` are not allowed to be created on partitioned tables. You cannot drop a `NOT NULL` constraint on a partition's column if the same constraint is present in the parent table.
- Using `ONLY` to add or drop a constraint on only the partitioned table is supported as long as there are no partitions. Once partitions exist, using `ONLY` will result in an error for any constraints other than `UNIQUE` and `PRIMARY KEY`. Instead, constraints on the partitions themselves can be added and (if they are not present in the parent table) dropped.
- As a partitioned table does not have any data itself, attempts to use `TRUNCATE ONLY` on a partitioned table will always return an error.

5.11.3. Partitioning Using Inheritance

While the built-in declarative partitioning is suitable for most common use cases, there are some circumstances where a more flexible approach may be useful. Partitioning can be implemented using table inheritance, which allows for several features not supported by declarative partitioning, such as:

- For declarative partitioning, partitions must have exactly the same set of columns as the partitioned table, whereas with table inheritance, child tables may have extra columns not present in the parent.
- Table inheritance allows for multiple inheritance.
- Declarative partitioning only supports range, list and hash partitioning, whereas table inheritance allows data to be divided in a manner of the user's choosing. (Note, however, that if constraint exclusion is unable to prune child tables effectively, query performance might be poor.)

5.11.3.1. Example

This example builds a partitioning structure equivalent to the declarative partitioning example above. Use the following steps:

1. Create the “root” table, from which all of the “child” tables will inherit. This table will contain no data. Do not define any check constraints on this table, unless you intend them to be applied equally to all child tables. There is no point in defining any indexes or unique constraints on it, either. For our example, the root table is the `measurement` table as originally defined:

```
CREATE TABLE measurement (
    city_id         int not null,
    logdate         date not null,
    peaktemp        int,
    unitsales       int
);
```

2. Create several “child” tables that each inherit from the root table. Normally, these tables will not add any columns to the set inherited from the root. Just as with declarative partitioning, these tables are in every way normal Postgres Pro tables (or foreign tables).

```
CREATE TABLE measurement_y2006m02 () INHERITS (measurement);
CREATE TABLE measurement_y2006m03 () INHERITS (measurement);
...
CREATE TABLE measurement_y2007m11 () INHERITS (measurement);
CREATE TABLE measurement_y2007m12 () INHERITS (measurement);
CREATE TABLE measurement_y2008m01 () INHERITS (measurement);
```

3. Add non-overlapping table constraints to the child tables to define the allowed key values in each.

   Typical examples would be:

```
CHECK ( x = 1 )
CHECK ( county IN ( 'Oxfordshire', 'Buckinghamshire', 'Warwickshire' ))
CHECK ( outletID >= 100 AND outletID < 200 )
```

   Ensure that the constraints guarantee that there is no overlap between the key values permitted in different child tables. A common mistake is to set up range constraints like:

```
CHECK ( outletID BETWEEN 100 AND 200 )
CHECK ( outletID BETWEEN 200 AND 300 )
```

   This is wrong since it is not clear which child table the key value 200 belongs in. Instead, ranges should be defined in this style:

```
CREATE TABLE measurement_y2006m02 (
    CHECK ( logdate >= DATE '2006-02-01' AND logdate < DATE '2006-03-01' )
) INHERITS (measurement);

CREATE TABLE measurement_y2006m03 (
    CHECK ( logdate >= DATE '2006-03-01' AND logdate < DATE '2006-04-01' )
) INHERITS (measurement);

...
CREATE TABLE measurement_y2007m11 (
    CHECK ( logdate >= DATE '2007-11-01' AND logdate < DATE '2007-12-01' )
) INHERITS (measurement);

CREATE TABLE measurement_y2007m12 (
    CHECK ( logdate >= DATE '2007-12-01' AND logdate < DATE '2008-01-01' )
) INHERITS (measurement);

CREATE TABLE measurement_y2008m01 (
    CHECK ( logdate >= DATE '2008-01-01' AND logdate < DATE '2008-02-01' )
```

```
) INHERITS (measurement);
```

4. For each child table, create an index on the key column(s), as well as any other indexes you might want.

```
CREATE INDEX measurement_y2006m02_logdate ON measurement_y2006m02 (logdate);
CREATE INDEX measurement_y2006m03_logdate ON measurement_y2006m03 (logdate);
CREATE INDEX measurement_y2007m11_logdate ON measurement_y2007m11 (logdate);
CREATE INDEX measurement_y2007m12_logdate ON measurement_y2007m12 (logdate);
CREATE INDEX measurement_y2008m01_logdate ON measurement_y2008m01 (logdate);
```

5. We want our application to be able to say `INSERT INTO measurement ...` and have the data be redirected into the appropriate child table. We can arrange that by attaching a suitable trigger function to the root table. If data will be added only to the latest child, we can use a very simple trigger function:

```
CREATE OR REPLACE FUNCTION measurement_insert_trigger()
RETURNS TRIGGER AS $$
BEGIN
    INSERT INTO measurement_y2008m01 VALUES (NEW.*);
    RETURN NULL;
END;
$$
LANGUAGE plpgsql;
```

After creating the function, we create a trigger which calls the trigger function:

```
CREATE TRIGGER insert_measurement_trigger
    BEFORE INSERT ON measurement
    FOR EACH ROW EXECUTE FUNCTION measurement_insert_trigger();
```

We must redefine the trigger function each month so that it always inserts into the current child table. The trigger definition does not need to be updated, however.

We might want to insert data and have the server automatically locate the child table into which the row should be added. We could do this with a more complex trigger function, for example:

```
CREATE OR REPLACE FUNCTION measurement_insert_trigger()
RETURNS TRIGGER AS $$
BEGIN
    IF ( NEW.logdate >= DATE '2006-02-01' AND
         NEW.logdate < DATE '2006-03-01' ) THEN
        INSERT INTO measurement_y2006m02 VALUES (NEW.*);
    ELSIF ( NEW.logdate >= DATE '2006-03-01' AND
            NEW.logdate < DATE '2006-04-01' ) THEN
        INSERT INTO measurement_y2006m03 VALUES (NEW.*);
    ...
    ELSIF ( NEW.logdate >= DATE '2008-01-01' AND
            NEW.logdate < DATE '2008-02-01' ) THEN
        INSERT INTO measurement_y2008m01 VALUES (NEW.*);
    ELSE
        RAISE EXCEPTION 'Date out of range.  Fix the measurement_insert_trigger()
 function!';
    END IF;
    RETURN NULL;
END;
$$
LANGUAGE plpgsql;
```

The trigger definition is the same as before. Note that each `IF` test must exactly match the `CHECK` constraint for its child table.

While this function is more complex than the single-month case, it doesn't need to be updated as often, since branches can be added in advance of being needed.

> **Note**
>
> In practice, it might be best to check the newest child first, if most inserts go into that child. For simplicity, we have shown the trigger's tests in the same order as in other parts of this example.

A different approach to redirecting inserts into the appropriate child table is to set up rules, instead of a trigger, on the root table. For example:

```
CREATE RULE measurement_insert_y2006m02 AS
ON INSERT TO measurement WHERE
    ( logdate >= DATE '2006-02-01' AND logdate < DATE '2006-03-01' )
DO INSTEAD
    INSERT INTO measurement_y2006m02 VALUES (NEW.*);
...
CREATE RULE measurement_insert_y2008m01 AS
ON INSERT TO measurement WHERE
    ( logdate >= DATE '2008-01-01' AND logdate < DATE '2008-02-01' )
DO INSTEAD
    INSERT INTO measurement_y2008m01 VALUES (NEW.*);
```

A rule has significantly more overhead than a trigger, but the overhead is paid once per query rather than once per row, so this method might be advantageous for bulk-insert situations. In most cases, however, the trigger method will offer better performance.

Be aware that `COPY` ignores rules. If you want to use `COPY` to insert data, you'll need to copy into the correct child table rather than directly into the root. `COPY` does fire triggers, so you can use it normally if you use the trigger approach.

Another disadvantage of the rule approach is that there is no simple way to force an error if the set of rules doesn't cover the insertion date; the data will silently go into the root table instead.

6. Ensure that the constraint_exclusion configuration parameter is not disabled in `postgresql.conf`; otherwise child tables may be accessed unnecessarily.

As we can see, a complex table hierarchy could require a substantial amount of DDL. In the above example we would be creating a new child table each month, so it might be wise to write a script that generates the required DDL automatically.

5.11.3.2. Maintenance for Inheritance Partitioning

To remove old data quickly, simply drop the child table that is no longer necessary:

```
DROP TABLE measurement_y2006m02;
```

To remove the child table from the inheritance hierarchy table but retain access to it as a table in its own right:

```
ALTER TABLE measurement_y2006m02 NO INHERIT measurement;
```

To add a new child table to handle new data, create an empty child table just as the original children were created above:

```
CREATE TABLE measurement_y2008m02 (
    CHECK ( logdate >= DATE '2008-02-01' AND logdate < DATE '2008-03-01' )
) INHERITS (measurement);
```

Alternatively, one may want to create and populate the new child table before adding it to the table hierarchy. This could allow data to be loaded, checked, and transformed before being made visible to queries on the parent table.

```
CREATE TABLE measurement_y2008m02
  (LIKE measurement INCLUDING DEFAULTS INCLUDING CONSTRAINTS);
```

```
ALTER TABLE measurement_y2008m02 ADD CONSTRAINT y2008m02
   CHECK ( logdate >= DATE '2008-02-01' AND logdate < DATE '2008-03-01' );
\copy measurement_y2008m02 from 'measurement_y2008m02'
-- possibly some other data preparation work
ALTER TABLE measurement_y2008m02 INHERIT measurement;
```

5.11.3.3. Caveats

The following caveats apply to partitioning implemented using inheritance:

- There is no automatic way to verify that all of the `CHECK` constraints are mutually exclusive. It is safer to create code that generates child tables and creates and/or modifies associated objects than to write each by hand.
- Indexes and foreign key constraints apply to single tables and not to their inheritance children, hence they have some caveats to be aware of.
- The schemes shown here assume that the values of a row's key column(s) never change, or at least do not change enough to require it to move to another partition. An `UPDATE` that attempts to do that will fail because of the `CHECK` constraints. If you need to handle such cases, you can put suitable update triggers on the child tables, but it makes management of the structure much more complicated.
- If you are using manual `VACUUM` or `ANALYZE` commands, don't forget that you need to run them on each child table individually. A command like:

  ```
  ANALYZE measurement;
  ```

  will only process the root table.
- `INSERT` statements with `ON CONFLICT` clauses are unlikely to work as expected, as the `ON CONFLICT` action is only taken in case of unique violations on the specified target relation, not its child relations.
- Triggers or rules will be needed to route rows to the desired child table, unless the application is explicitly aware of the partitioning scheme. Triggers may be complicated to write, and will be much slower than the tuple routing performed internally by declarative partitioning.

5.11.4. Partition Pruning

Partition pruning is a query optimization technique that improves performance for declaratively partitioned tables. As an example:

```
SET enable_partition_pruning = on;                 -- the default
SELECT count(*) FROM measurement WHERE logdate >= DATE '2008-01-01';
```

Without partition pruning, the above query would scan each of the partitions of the `measurement` table. With partition pruning enabled, the planner will examine the definition of each partition and prove that the partition need not be scanned because it could not contain any rows meeting the query's `WHERE` clause. When the planner can prove this, it excludes (*prunes*) the partition from the query plan.

By using the EXPLAIN command and the enable_partition_pruning configuration parameter, it's possible to show the difference between a plan for which partitions have been pruned and one for which they have not. A typical unoptimized plan for this type of table setup is:

```
SET enable_partition_pruning = off;
EXPLAIN SELECT count(*) FROM measurement WHERE logdate >= DATE '2008-01-01';
                                     QUERY PLAN
-------------------------------------------------------------------------------------
 Aggregate  (cost=188.76..188.77 rows=1 width=8)
   ->  Append  (cost=0.00..181.05 rows=3085 width=0)
         ->  Seq Scan on measurement_y2006m02  (cost=0.00..33.12 rows=617 width=0)
               Filter: (logdate >= '2008-01-01'::date)
         ->  Seq Scan on measurement_y2006m03  (cost=0.00..33.12 rows=617 width=0)
```

```
               Filter: (logdate >= '2008-01-01'::date)
...
         ->  Seq Scan on measurement_y2007m11  (cost=0.00..33.12 rows=617 width=0)
               Filter: (logdate >= '2008-01-01'::date)
         ->  Seq Scan on measurement_y2007m12  (cost=0.00..33.12 rows=617 width=0)
               Filter: (logdate >= '2008-01-01'::date)
         ->  Seq Scan on measurement_y2008m01  (cost=0.00..33.12 rows=617 width=0)
               Filter: (logdate >= '2008-01-01'::date)
```

Some or all of the partitions might use index scans instead of full-table sequential scans, but the point here is that there is no need to scan the older partitions at all to answer this query. When we enable partition pruning, we get a significantly cheaper plan that will deliver the same answer:

```
SET enable_partition_pruning = on;
EXPLAIN SELECT count(*) FROM measurement WHERE logdate >= DATE '2008-01-01';
                                     QUERY PLAN
------------------------------------------------------------------------------------
 Aggregate  (cost=37.75..37.76 rows=1 width=8)
   ->  Seq Scan on measurement_y2008m01  (cost=0.00..33.12 rows=617 width=0)
         Filter: (logdate >= '2008-01-01'::date)
```

Note that partition pruning is driven only by the constraints defined implicitly by the partition keys, not by the presence of indexes. Therefore it isn't necessary to define indexes on the key columns. Whether an index needs to be created for a given partition depends on whether you expect that queries that scan the partition will generally scan a large part of the partition or just a small part. An index will be helpful in the latter case but not the former.

Partition pruning can be performed not only during the planning of a given query, but also during its execution. This is useful as it can allow more partitions to be pruned when clauses contain expressions whose values are not known at query planning time, for example, parameters defined in a `PREPARE` statement, using a value obtained from a subquery, or using a parameterized value on the inner side of a nested loop join. Partition pruning during execution can be performed at any of the following times:

- During initialization of the query plan. Partition pruning can be performed here for parameter values which are known during the initialization phase of execution. Partitions which are pruned during this stage will not show up in the query's `EXPLAIN` or `EXPLAIN ANALYZE`. It is possible to determine the number of partitions which were removed during this phase by observing the “Subplans Removed” property in the `EXPLAIN` output. It's important to note that any partitions removed by the partition pruning done at this stage are still locked at the beginning of execution.
- During actual execution of the query plan. Partition pruning may also be performed here to remove partitions using values which are only known during actual query execution. This includes values from subqueries and values from execution-time parameters such as those from parameterized nested loop joins. Since the value of these parameters may change many times during the execution of the query, partition pruning is performed whenever one of the execution parameters being used by partition pruning changes. Determining if partitions were pruned during this phase requires careful inspection of the `loops` property in the `EXPLAIN ANALYZE` output. Subplans corresponding to different partitions may have different values for it depending on how many times each of them was pruned during execution. Some may be shown as `(never executed)` if they were pruned every time.

Partition pruning can be disabled using the enable_partition_pruning setting.

5.11.5. Partitioning and Constraint Exclusion

Constraint exclusion is a query optimization technique similar to partition pruning. While it is primarily used for partitioning implemented using the legacy inheritance method, it can be used for other purposes, including with declarative partitioning.

Constraint exclusion works in a very similar way to partition pruning, except that it uses each table's `CHECK` constraints — which gives it its name — whereas partition pruning uses the table's partition

bounds, which exist only in the case of declarative partitioning. Another difference is that constraint exclusion is only applied at plan time; there is no attempt to remove partitions at execution time.

The fact that constraint exclusion uses `CHECK` constraints, which makes it slow compared to partition pruning, can sometimes be used as an advantage: because constraints can be defined even on declaratively-partitioned tables, in addition to their internal partition bounds, constraint exclusion may be able to elide additional partitions from the query plan.

The default (and recommended) setting of constraint_exclusion is neither `on` nor `off`, but an intermediate setting called `partition`, which causes the technique to be applied only to queries that are likely to be working on inheritance partitioned tables. The `on` setting causes the planner to examine `CHECK` constraints in all queries, even simple ones that are unlikely to benefit.

The following caveats apply to constraint exclusion:

- Constraint exclusion is only applied during query planning, unlike partition pruning, which can also be applied during query execution.
- Constraint exclusion only works when the query's `WHERE` clause contains constants (or externally supplied parameters). For example, a comparison against a non-immutable function such as `CURRENT_TIMESTAMP` cannot be optimized, since the planner cannot know which child table the function's value might fall into at run time.
- Keep the partitioning constraints simple, else the planner may not be able to prove that child tables might not need to be visited. Use simple equality conditions for list partitioning, or simple range tests for range partitioning, as illustrated in the preceding examples. A good rule of thumb is that partitioning constraints should contain only comparisons of the partitioning column(s) to constants using B-tree-indexable operators, because only B-tree-indexable column(s) are allowed in the partition key.
- All constraints on all children of the parent table are examined during constraint exclusion, so large numbers of children are likely to increase query planning time considerably. So the legacy inheritance based partitioning will work well with up to perhaps a hundred child tables; don't try to use many thousands of children.

5.11.6. Best Practices for Declarative Partitioning

The choice of how to partition a table should be made carefully, as the performance of query planning and execution can be negatively affected by poor design.

One of the most critical design decisions will be the column or columns by which you partition your data. Often the best choice will be to partition by the column or set of columns which most commonly appear in `WHERE` clauses of queries being executed on the partitioned table. `WHERE` clauses that are compatible with the partition bound constraints can be used to prune unneeded partitions. However, you may be forced into making other decisions by requirements for the `PRIMARY KEY` or a `UNIQUE` constraint. Removal of unwanted data is also a factor to consider when planning your partitioning strategy. An entire partition can be detached fairly quickly, so it may be beneficial to design the partition strategy in such a way that all data to be removed at once is located in a single partition.

Choosing the target number of partitions that the table should be divided into is also a critical decision to make. Not having enough partitions may mean that indexes remain too large and that data locality remains poor which could result in low cache hit ratios. However, dividing the table into too many partitions can also cause issues. Too many partitions can mean longer query planning times and higher memory consumption during both query planning and execution, as further described below. When choosing how to partition your table, it's also important to consider what changes may occur in the future. For example, if you choose to have one partition per customer and you currently have a small number of large customers, consider the implications if in several years you instead find yourself with a large number of small customers. In this case, it may be better to choose to partition by `HASH` and choose a reasonable number of partitions rather than trying to partition by `LIST` and hoping that the number of customers does not increase beyond what it is practical to partition the data by.

Sub-partitioning can be useful to further divide partitions that are expected to become larger than other partitions. Another option is to use range partitioning with multiple columns in the partition key. Either of these can easily lead to excessive numbers of partitions, so restraint is advisable.

It is important to consider the overhead of partitioning during query planning and execution. The query planner is generally able to handle partition hierarchies with up to a few thousand partitions fairly well, provided that typical queries allow the query planner to prune all but a small number of partitions. Planning times become longer and memory consumption becomes higher when more partitions remain after the planner performs partition pruning. Another reason to be concerned about having a large number of partitions is that the server's memory consumption may grow significantly over time, especially if many sessions touch large numbers of partitions. That's because each partition requires its metadata to be loaded into the local memory of each session that touches it.

With data warehouse type workloads, it can make sense to use a larger number of partitions than with an OLTP type workload. Generally, in data warehouses, query planning time is less of a concern as the majority of processing time is spent during query execution. With either of these two types of workload, it is important to make the right decisions early, as re-partitioning large quantities of data can be painfully slow. Simulations of the intended workload are often beneficial for optimizing the partitioning strategy. Never just assume that more partitions are better than fewer partitions, nor vice-versa.

5.12. Foreign Data

Postgres Pro implements portions of the SQL/MED specification, allowing you to access data that resides outside Postgres Pro using regular SQL queries. Such data is referred to as *foreign data*. (Note that this usage is not to be confused with foreign keys, which are a type of constraint within the database.)

Foreign data is accessed with help from a *foreign data wrapper*. A foreign data wrapper is a library that can communicate with an external data source, hiding the details of connecting to the data source and obtaining data from it. There are some foreign data wrappers available as `contrib` modules; see Appendix F. Other kinds of foreign data wrappers might be found as third party products. If none of the existing foreign data wrappers suit your needs, you can write your own; see Chapter 57.

To access foreign data, you need to create a *foreign server* object, which defines how to connect to a particular external data source according to the set of options used by its supporting foreign data wrapper. Then you need to create one or more *foreign tables*, which define the structure of the remote data. A foreign table can be used in queries just like a normal table, but a foreign table has no storage in the Postgres Pro server. Whenever it is used, Postgres Pro asks the foreign data wrapper to fetch data from the external source, or transmit data to the external source in the case of update commands.

Accessing remote data may require authenticating to the external data source. This information can be provided by a *user mapping*, which can provide additional data such as user names and passwords based on the current Postgres Pro role.

For additional information, see CREATE FOREIGN DATA WRAPPER, CREATE SERVER, CREATE USER MAPPING, CREATE FOREIGN TABLE, and IMPORT FOREIGN SCHEMA.

5.13. Other Database Objects

Tables are the central objects in a relational database structure, because they hold your data. But they are not the only objects that exist in a database. Many other kinds of objects can be created to make the use and management of the data more efficient or convenient. They are not discussed in this chapter, but we give you a list here so that you are aware of what is possible:

- Views
- Functions, procedures, and operators
- Data types and domains
- Triggers and rewrite rules

Detailed information on these topics appears in Part V.

5.14. Dependency Tracking

When you create complex database structures involving many tables with foreign key constraints, views, triggers, functions, etc. you implicitly create a net of dependencies between the objects. For instance, a table with a foreign key constraint depends on the table it references.

To ensure the integrity of the entire database structure, Postgres Pro makes sure that you cannot drop objects that other objects still depend on. For example, attempting to drop the products table we considered in Section 5.4.5, with the orders table depending on it, would result in an error message like this:

```
DROP TABLE products;

ERROR:  cannot drop table products because other objects depend on it
DETAIL:  constraint orders_product_no_fkey on table orders depends on table products
HINT:  Use DROP ... CASCADE to drop the dependent objects too.
```

The error message contains a useful hint: if you do not want to bother deleting all the dependent objects individually, you can run:

```
DROP TABLE products CASCADE;
```

and all the dependent objects will be removed, as will any objects that depend on them, recursively. In this case, it doesn't remove the orders table, it only removes the foreign key constraint. It stops there because nothing depends on the foreign key constraint. (If you want to check what `DROP ... CASCADE` will do, run `DROP` without `CASCADE` and read the `DETAIL` output.)

Almost all `DROP` commands in Postgres Pro support specifying `CASCADE`. Of course, the nature of the possible dependencies varies with the type of the object. You can also write `RESTRICT` instead of `CASCADE` to get the default behavior, which is to prevent dropping objects that any other objects depend on.

> **Note**
>
> According to the SQL standard, specifying either `RESTRICT` or `CASCADE` is required in a `DROP` command. No database system actually enforces that rule, but whether the default behavior is `RESTRICT` or `CASCADE` varies across systems.

If a `DROP` command lists multiple objects, `CASCADE` is only required when there are dependencies outside the specified group. For example, when saying `DROP TABLE tab1, tab2` the existence of a foreign key referencing `tab1` from `tab2` would not mean that `CASCADE` is needed to succeed.

For a user-defined function or procedure whose body is defined as a string literal, Postgres Pro tracks dependencies associated with the function's externally-visible properties, such as its argument and result types, but *not* dependencies that could only be known by examining the function body. As an example, consider this situation:

```
CREATE TYPE rainbow AS ENUM ('red', 'orange', 'yellow',
                             'green', 'blue', 'purple');

CREATE TABLE my_colors (color rainbow, note text);

CREATE FUNCTION get_color_note (rainbow) RETURNS text AS
  'SELECT note FROM my_colors WHERE color = $1'
  LANGUAGE SQL;
```

(See Section 40.5 for an explanation of SQL-language functions.) Postgres Pro will be aware that the `get_color_note` function depends on the `rainbow` type: dropping the type would force dropping the function, because its argument type would no longer be defined. But Postgres Pro will not consider `get_color_note` to depend on the `my_colors` table, and so will not drop the function if the table is

dropped. While there are disadvantages to this approach, there are also benefits. The function is still valid in some sense if the table is missing, though executing it would cause an error; creating a new table of the same name would allow the function to work again.

On the other hand, for a SQL-language function or procedure whose body is written in SQL-standard style, the body is parsed at function definition time and all dependencies recognized by the parser are stored. Thus, if we write the function above as

```
CREATE FUNCTION get_color_note (rainbow) RETURNS text
BEGIN ATOMIC
  SELECT note FROM my_colors WHERE color = $1;
END;
```

then the function's dependency on the `my_colors` table will be known and enforced by `DROP`.

Chapter 6. Data Manipulation

The previous chapter discussed how to create tables and other structures to hold your data. Now it is time to fill the tables with data. This chapter covers how to insert, update, and delete table data. The chapter after this will finally explain how to extract your long-lost data from the database.

6.1. Inserting Data

When a table is created, it contains no data. The first thing to do before a database can be of much use is to insert data. Data is inserted one row at a time. You can also insert more than one row in a single command, but it is not possible to insert something that is not a complete row. Even if you know only some column values, a complete row must be created.

To create a new row, use the INSERT command. The command requires the table name and column values. For example, consider the products table from Chapter 5:

```
CREATE TABLE products (
    product_no integer,
    name text,
    price numeric
);
```

An example command to insert a row would be:

```
INSERT INTO products VALUES (1, 'Cheese', 9.99);
```

The data values are listed in the order in which the columns appear in the table, separated by commas. Usually, the data values will be literals (constants), but scalar expressions are also allowed.

The above syntax has the drawback that you need to know the order of the columns in the table. To avoid this you can also list the columns explicitly. For example, both of the following commands have the same effect as the one above:

```
INSERT INTO products (product_no, name, price) VALUES (1, 'Cheese', 9.99);
INSERT INTO products (name, price, product_no) VALUES ('Cheese', 9.99, 1);
```

Many users consider it good practice to always list the column names.

If you don't have values for all the columns, you can omit some of them. In that case, the columns will be filled with their default values. For example:

```
INSERT INTO products (product_no, name) VALUES (1, 'Cheese');
INSERT INTO products VALUES (1, 'Cheese');
```

The second form is a Postgres Pro extension. It fills the columns from the left with as many values as are given, and the rest will be defaulted.

For clarity, you can also request default values explicitly, for individual columns or for the entire row:

```
INSERT INTO products (product_no, name, price) VALUES (1, 'Cheese', DEFAULT);
INSERT INTO products DEFAULT VALUES;
```

You can insert multiple rows in a single command:

```
INSERT INTO products (product_no, name, price) VALUES
    (1, 'Cheese', 9.99),
    (2, 'Bread', 1.99),
    (3, 'Milk', 2.99);
```

It is also possible to insert the result of a query (which might be no rows, one row, or many rows):

```
INSERT INTO products (product_no, name, price)
  SELECT product_no, name, price FROM new_products
    WHERE release_date = 'today';
```

This provides the full power of the SQL query mechanism (Chapter 7) for computing the rows to be inserted.

> **Tip**
>
> When inserting a lot of data at the same time, consider using the COPY command. It is not as flexible as the INSERT command, but is more efficient. Refer to Section 14.4 for more information on improving bulk loading performance.

6.2. Updating Data

The modification of data that is already in the database is referred to as updating. You can update individual rows, all the rows in a table, or a subset of all rows. Each column can be updated separately; the other columns are not affected.

To update existing rows, use the UPDATE command. This requires three pieces of information:

1. The name of the table and column to update
2. The new value of the column
3. Which row(s) to update

Recall from Chapter 5 that SQL does not, in general, provide a unique identifier for rows. Therefore it is not always possible to directly specify which row to update. Instead, you specify which conditions a row must meet in order to be updated. Only if you have a primary key in the table (independent of whether you declared it or not) can you reliably address individual rows by choosing a condition that matches the primary key. Graphical database access tools rely on this fact to allow you to update rows individually.

For example, this command updates all products that have a price of 5 to have a price of 10:

```
UPDATE products SET price = 10 WHERE price = 5;
```

This might cause zero, one, or many rows to be updated. It is not an error to attempt an update that does not match any rows.

Let's look at that command in detail. First is the key word `UPDATE` followed by the table name. As usual, the table name can be schema-qualified, otherwise it is looked up in the path. Next is the key word `SET` followed by the column name, an equal sign, and the new column value. The new column value can be any scalar expression, not just a constant. For example, if you want to raise the price of all products by 10% you could use:

```
UPDATE products SET price = price * 1.10;
```

As you see, the expression for the new value can refer to the existing value(s) in the row. We also left out the `WHERE` clause. If it is omitted, it means that all rows in the table are updated. If it is present, only those rows that match the `WHERE` condition are updated. Note that the equals sign in the `SET` clause is an assignment while the one in the `WHERE` clause is a comparison, but this does not create any ambiguity. Of course, the `WHERE` condition does not have to be an equality test. Many other operators are available (see Chapter 9). But the expression needs to evaluate to a Boolean result.

You can update more than one column in an `UPDATE` command by listing more than one assignment in the `SET` clause. For example:

```
UPDATE mytable SET a = 5, b = 3, c = 1 WHERE a > 0;
```

6.3. Deleting Data

So far we have explained how to add data to tables and how to change data. What remains is to discuss how to remove data that is no longer needed. Just as adding data is only possible in whole rows, you can only remove entire rows from a table. In the previous section we explained that SQL does not provide a way to directly address individual rows. Therefore, removing rows can only be done by specifying

conditions that the rows to be removed have to match. If you have a primary key in the table then you can specify the exact row. But you can also remove groups of rows matching a condition, or you can remove all rows in the table at once.

You use the DELETE command to remove rows; the syntax is very similar to the UPDATE command. For instance, to remove all rows from the products table that have a price of 10, use:

```
DELETE FROM products WHERE price = 10;
```

If you simply write:

```
DELETE FROM products;
```

then all rows in the table will be deleted! Caveat programmer.

6.4. Returning Data from Modified Rows

Sometimes it is useful to obtain data from modified rows while they are being manipulated. The `INSERT`, `UPDATE`, and `DELETE` commands all have an optional `RETURNING` clause that supports this. Use of `RETURNING` avoids performing an extra database query to collect the data, and is especially valuable when it would otherwise be difficult to identify the modified rows reliably.

The allowed contents of a `RETURNING` clause are the same as a `SELECT` command's output list (see Section 7.3). It can contain column names of the command's target table, or value expressions using those columns. A common shorthand is `RETURNING *`, which selects all columns of the target table in order.

In an `INSERT`, the data available to `RETURNING` is the row as it was inserted. This is not so useful in trivial inserts, since it would just repeat the data provided by the client. But it can be very handy when relying on computed default values. For example, when using a `serial` column to provide unique identifiers, `RETURNING` can return the ID assigned to a new row:

```
CREATE TABLE users (firstname text, lastname text, id serial primary key);

INSERT INTO users (firstname, lastname) VALUES ('Joe', 'Cool') RETURNING id;
```

The `RETURNING` clause is also very useful with `INSERT ... SELECT`.

In an `UPDATE`, the data available to `RETURNING` is the new content of the modified row. For example:

```
UPDATE products SET price = price * 1.10
  WHERE price <= 99.99
  RETURNING name, price AS new_price;
```

In a `DELETE`, the data available to `RETURNING` is the content of the deleted row. For example:

```
DELETE FROM products
  WHERE obsoletion_date = 'today'
  RETURNING *;
```

If there are triggers (Chapter 41) on the target table, the data available to `RETURNING` is the row as modified by the triggers. Thus, inspecting columns computed by triggers is another common use-case for `RETURNING`.

Chapter 7. Queries

The previous chapters explained how to create tables, how to fill them with data, and how to manipulate that data. Now we finally discuss how to retrieve the data from the database.

7.1. Overview

The process of retrieving or the command to retrieve data from a database is called a *query*. In SQL the SELECT command is used to specify queries. The general syntax of the SELECT command is

```
[WITH with_queries] SELECT select_list FROM table_expression [sort_specification]
```

The following sections describe the details of the select list, the table expression, and the sort specification. WITH queries are treated last since they are an advanced feature.

A simple kind of query has the form:

```
SELECT * FROM table1;
```

Assuming that there is a table called table1, this command would retrieve all rows and all user-defined columns from table1. (The method of retrieval depends on the client application. For example, the psql program will display an ASCII-art table on the screen, while client libraries will offer functions to extract individual values from the query result.) The select list specification * means all columns that the table expression happens to provide. A select list can also select a subset of the available columns or make calculations using the columns. For example, if table1 has columns named a, b, and c (and perhaps others) you can make the following query:

```
SELECT a, b + c FROM table1;
```

(assuming that b and c are of a numerical data type). See Section 7.3 for more details.

FROM table1 is a simple kind of table expression: it reads just one table. In general, table expressions can be complex constructs of base tables, joins, and subqueries. But you can also omit the table expression entirely and use the SELECT command as a calculator:

```
SELECT 3 * 4;
```

This is more useful if the expressions in the select list return varying results. For example, you could call a function this way:

```
SELECT random();
```

7.2. Table Expressions

A *table expression* computes a table. The table expression contains a FROM clause that is optionally followed by WHERE, GROUP BY, and HAVING clauses. Trivial table expressions simply refer to a table on disk, a so-called base table, but more complex expressions can be used to modify or combine base tables in various ways.

The optional WHERE, GROUP BY, and HAVING clauses in the table expression specify a pipeline of successive transformations performed on the table derived in the FROM clause. All these transformations produce a virtual table that provides the rows that are passed to the select list to compute the output rows of the query.

7.2.1. The FROM Clause

The FROM clause derives a table from one or more other tables given in a comma-separated table reference list.

```
FROM table_reference [, table_reference [, ...]]
```

A table reference can be a table name (possibly schema-qualified), or a derived table such as a subquery, a JOIN construct, or complex combinations of these. If more than one table reference is listed in the FROM

clause, the tables are cross-joined (that is, the Cartesian product of their rows is formed; see below). The result of the FROM list is an intermediate virtual table that can then be subject to transformations by the WHERE, GROUP BY, and HAVING clauses and is finally the result of the overall table expression.

When a table reference names a table that is the parent of a table inheritance hierarchy, the table reference produces rows of not only that table but all of its descendant tables, unless the key word ONLY precedes the table name. However, the reference produces only the columns that appear in the named table — any columns added in subtables are ignored.

Instead of writing ONLY before the table name, you can write * after the table name to explicitly specify that descendant tables are included. There is no real reason to use this syntax any more, because searching descendant tables is now always the default behavior. However, it is supported for compatibility with older releases.

7.2.1.1. Joined Tables

A joined table is a table derived from two other (real or derived) tables according to the rules of the particular join type. Inner, outer, and cross-joins are available. The general syntax of a joined table is

```
T1 join_type T2 [ join_condition ]
```

Joins of all types can be chained together, or nested: either or both *T1* and *T2* can be joined tables. Parentheses can be used around JOIN clauses to control the join order. In the absence of parentheses, JOIN clauses nest left-to-right.

Join Types

Cross join

```
T1 CROSS JOIN T2
```

For every possible combination of rows from *T1* and *T2* (i.e., a Cartesian product), the joined table will contain a row consisting of all columns in *T1* followed by all columns in *T2*. If the tables have N and M rows respectively, the joined table will have N * M rows.

FROM *T1* CROSS JOIN *T2* is equivalent to FROM *T1* INNER JOIN *T2* ON TRUE (see below). It is also equivalent to FROM *T1*, *T2*.

> **Note**
>
> This latter equivalence does not hold exactly when more than two tables appear, because JOIN binds more tightly than comma. For example FROM *T1* CROSS JOIN *T2* INNER JOIN *T3* ON *condition* is not the same as FROM *T1*, *T2* INNER JOIN *T3* ON *condition* because the *condition* can reference *T1* in the first case but not the second.

Qualified joins

```
T1 { [INNER] | { LEFT | RIGHT | FULL } [OUTER] } JOIN T2 ON boolean_expression
T1 { [INNER] | { LEFT | RIGHT | FULL } [OUTER] } JOIN T2 USING ( join column list )
T1 NATURAL { [INNER] | { LEFT | RIGHT | FULL } [OUTER] } JOIN T2
```

The words INNER and OUTER are optional in all forms. INNER is the default; LEFT, RIGHT, and FULL imply an outer join.

The *join condition* is specified in the ON or USING clause, or implicitly by the word NATURAL. The join condition determines which rows from the two source tables are considered to “match”, as explained in detail below.

The possible types of qualified join are:

`INNER JOIN`

For each row R1 of T1, the joined table has a row for each row in T2 that satisfies the join condition with R1.

`LEFT OUTER JOIN`

First, an inner join is performed. Then, for each row in T1 that does not satisfy the join condition with any row in T2, a joined row is added with null values in columns of T2. Thus, the joined table always has at least one row for each row in T1.

`RIGHT OUTER JOIN`

First, an inner join is performed. Then, for each row in T2 that does not satisfy the join condition with any row in T1, a joined row is added with null values in columns of T1. This is the converse of a left join: the result table will always have a row for each row in T2.

`FULL OUTER JOIN`

First, an inner join is performed. Then, for each row in T1 that does not satisfy the join condition with any row in T2, a joined row is added with null values in columns of T2. Also, for each row of T2 that does not satisfy the join condition with any row in T1, a joined row with null values in the columns of T1 is added.

The `ON` clause is the most general kind of join condition: it takes a Boolean value expression of the same kind as is used in a `WHERE` clause. A pair of rows from *`T1`* and *`T2`* match if the `ON` expression evaluates to true.

The `USING` clause is a shorthand that allows you to take advantage of the specific situation where both sides of the join use the same name for the joining column(s). It takes a comma-separated list of the shared column names and forms a join condition that includes an equality comparison for each one. For example, joining *`T1`* and *`T2`* with `USING (a, b)` produces the join condition `ON` *`T1`*`.a = `*`T2`*`.a AND` *`T1`*`.b = `*`T2`*`.b`.

Furthermore, the output of `JOIN USING` suppresses redundant columns: there is no need to print both of the matched columns, since they must have equal values. While `JOIN ON` produces all columns from *`T1`* followed by all columns from *`T2`*, `JOIN USING` produces one output column for each of the listed column pairs (in the listed order), followed by any remaining columns from *`T1`*, followed by any remaining columns from *`T2`*.

Finally, `NATURAL` is a shorthand form of `USING`: it forms a `USING` list consisting of all column names that appear in both input tables. As with `USING`, these columns appear only once in the output table. If there are no common column names, `NATURAL JOIN` behaves like `JOIN ... ON TRUE`, producing a cross-product join.

> **Note**
>
> `USING` is reasonably safe from column changes in the joined relations since only the listed columns are combined. `NATURAL` is considerably more risky since any schema changes to either relation that cause a new matching column name to be present will cause the join to combine that new column as well.

To put this together, assume we have tables `t1`:

```
 num | name
-----+------
   1 | a
   2 | b
   3 | c
```

and `t2`:

```
 num | value
-----+-------
   1 | xxx
   3 | yyy
   5 | zzz
```

then we get the following results for the various joins:

```
=> SELECT * FROM t1 CROSS JOIN t2;
 num | name | num | value
-----+------+-----+-------
   1 | a    |   1 | xxx
   1 | a    |   3 | yyy
   1 | a    |   5 | zzz
   2 | b    |   1 | xxx
   2 | b    |   3 | yyy
   2 | b    |   5 | zzz
   3 | c    |   1 | xxx
   3 | c    |   3 | yyy
   3 | c    |   5 | zzz
(9 rows)

=> SELECT * FROM t1 INNER JOIN t2 ON t1.num = t2.num;
 num | name | num | value
-----+------+-----+-------
   1 | a    |   1 | xxx
   3 | c    |   3 | yyy
(2 rows)

=> SELECT * FROM t1 INNER JOIN t2 USING (num);
 num | name | value
-----+------+-------
   1 | a    | xxx
   3 | c    | yyy
(2 rows)

=> SELECT * FROM t1 NATURAL INNER JOIN t2;
 num | name | value
-----+------+-------
   1 | a    | xxx
   3 | c    | yyy
(2 rows)

=> SELECT * FROM t1 LEFT JOIN t2 ON t1.num = t2.num;
 num | name | num | value
-----+------+-----+-------
   1 | a    |   1 | xxx
   2 | b    |     |
   3 | c    |   3 | yyy
(3 rows)

=> SELECT * FROM t1 LEFT JOIN t2 USING (num);
 num | name | value
-----+------+-------
   1 | a    | xxx
   2 | b    |
   3 | c    | yyy
(3 rows)
```

```
=> SELECT * FROM t1 RIGHT JOIN t2 ON t1.num = t2.num;
 num | name | num | value
-----+------+-----+-------
   1 | a    |   1 | xxx
   3 | c    |   3 | yyy
     |      |   5 | zzz
(3 rows)

=> SELECT * FROM t1 FULL JOIN t2 ON t1.num = t2.num;
 num | name | num | value
-----+------+-----+-------
   1 | a    |   1 | xxx
   2 | b    |     |
   3 | c    |   3 | yyy
     |      |   5 | zzz
(4 rows)
```

The join condition specified with `ON` can also contain conditions that do not relate directly to the join. This can prove useful for some queries but needs to be thought out carefully. For example:

```
=> SELECT * FROM t1 LEFT JOIN t2 ON t1.num = t2.num AND t2.value = 'xxx';
 num | name | num | value
-----+------+-----+-------
   1 | a    |   1 | xxx
   2 | b    |     |
   3 | c    |     |
(3 rows)
```

Notice that placing the restriction in the `WHERE` clause produces a different result:

```
=> SELECT * FROM t1 LEFT JOIN t2 ON t1.num = t2.num WHERE t2.value = 'xxx';
 num | name | num | value
-----+------+-----+-------
   1 | a    |   1 | xxx
(1 row)
```

This is because a restriction placed in the `ON` clause is processed *before* the join, while a restriction placed in the `WHERE` clause is processed *after* the join. That does not matter with inner joins, but it matters a lot with outer joins.

7.2.1.2. Table and Column Aliases

A temporary name can be given to tables and complex table references to be used for references to the derived table in the rest of the query. This is called a *table alias*.

To create a table alias, write

```
FROM table_reference AS alias
```

or

```
FROM table_reference alias
```

The `AS` key word is optional noise. *`alias`* can be any identifier.

A typical application of table aliases is to assign short identifiers to long table names to keep the join clauses readable. For example:

```
SELECT * FROM some_very_long_table_name s JOIN another_fairly_long_name a ON s.id =
 a.num;
```

The alias becomes the new name of the table reference so far as the current query is concerned — it is not allowed to refer to the table by the original name elsewhere in the query. Thus, this is not valid:

```
SELECT * FROM my_table AS m WHERE my_table.a > 5;    -- wrong
```

Table aliases are mainly for notational convenience, but it is necessary to use them when joining a table to itself, e.g.:

```
SELECT * FROM people AS mother JOIN people AS child ON mother.id = child.mother_id;
```

Additionally, an alias is required if the table reference is a subquery (see Section 7.2.1.3).

Parentheses are used to resolve ambiguities. In the following example, the first statement assigns the alias `b` to the second instance of `my_table`, but the second statement assigns the alias to the result of the join:

```
SELECT * FROM my_table AS a CROSS JOIN my_table AS b ...
SELECT * FROM (my_table AS a CROSS JOIN my_table) AS b ...
```

Another form of table aliasing gives temporary names to the columns of the table, as well as the table itself:

```
FROM table_reference [AS] alias ( column1 [, column2 [, ...]] )
```

If fewer column aliases are specified than the actual table has columns, the remaining columns are not renamed. This syntax is especially useful for self-joins or subqueries.

When an alias is applied to the output of a `JOIN` clause, the alias hides the original name(s) within the `JOIN`. For example:

```
SELECT a.* FROM my_table AS a JOIN your_table AS b ON ...
```

is valid SQL, but:

```
SELECT a.* FROM (my_table AS a JOIN your_table AS b ON ...) AS c
```

is not valid; the table alias `a` is not visible outside the alias `c`.

7.2.1.3. Subqueries

Subqueries specifying a derived table must be enclosed in parentheses and *must* be assigned a table alias name (as in Section 7.2.1.2). For example:

```
FROM (SELECT * FROM table1) AS alias_name
```

This example is equivalent to `FROM table1 AS alias_name`. More interesting cases, which cannot be reduced to a plain join, arise when the subquery involves grouping or aggregation.

A subquery can also be a `VALUES` list:

```
FROM (VALUES ('anne', 'smith'), ('bob', 'jones'), ('joe', 'blow'))
     AS names(first, last)
```

Again, a table alias is required. Assigning alias names to the columns of the `VALUES` list is optional, but is good practice. For more information see Section 7.7.

7.2.1.4. Table Functions

Table functions are functions that produce a set of rows, made up of either base data types (scalar types) or composite data types (table rows). They are used like a table, view, or subquery in the `FROM` clause of a query. Columns returned by table functions can be included in `SELECT`, `JOIN`, or `WHERE` clauses in the same manner as columns of a table, view, or subquery.

Table functions may also be combined using the `ROWS FROM` syntax, with the results returned in parallel columns; the number of result rows in this case is that of the largest function result, with smaller results padded with null values to match.

```
function_call [WITH ORDINALITY] [[AS] table_alias [(column_alias [, ... ])]]
ROWS FROM( function_call [, ... ] ) [WITH ORDINALITY] [[AS] table_alias [(column_alias
 [, ... ])]]
```

If the WITH ORDINALITY clause is specified, an additional column of type bigint will be added to the function result columns. This column numbers the rows of the function result set, starting from 1. (This is a generalization of the SQL-standard syntax for UNNEST ... WITH ORDINALITY.) By default, the ordinal column is called ordinality, but a different column name can be assigned to it using an AS clause.

The special table function UNNEST may be called with any number of array parameters, and it returns a corresponding number of columns, as if UNNEST (Section 9.19) had been called on each parameter separately and combined using the ROWS FROM construct.

```
UNNEST( array_expression [, ... ] ) [WITH ORDINALITY] [[AS] table_alias [(column_alias
 [, ... ])]]
```

If no *table_alias* is specified, the function name is used as the table name; in the case of a ROWS FROM() construct, the first function's name is used.

If column aliases are not supplied, then for a function returning a base data type, the column name is also the same as the function name. For a function returning a composite type, the result columns get the names of the individual attributes of the type.

Some examples:

```
CREATE TABLE foo (fooid int, foosubid int, fooname text);

CREATE FUNCTION getfoo(int) RETURNS SETOF foo AS $$
    SELECT * FROM foo WHERE fooid = $1;
$$ LANGUAGE SQL;

SELECT * FROM getfoo(1) AS t1;

SELECT * FROM foo
    WHERE foosubid IN (
                        SELECT foosubid
                        FROM getfoo(foo.fooid) z
                        WHERE z.fooid = foo.fooid
                      );

CREATE VIEW vw_getfoo AS SELECT * FROM getfoo(1);

SELECT * FROM vw_getfoo;
```

In some cases it is useful to define table functions that can return different column sets depending on how they are invoked. To support this, the table function can be declared as returning the pseudo-type record with no OUT parameters. When such a function is used in a query, the expected row structure must be specified in the query itself, so that the system can know how to parse and plan the query. This syntax looks like:

```
function_call [AS] alias (column_definition [, ... ])
function_call AS [alias] (column_definition [, ... ])
ROWS FROM( ... function_call AS (column_definition [, ... ]) [, ... ] )
```

When not using the ROWS FROM() syntax, the *column_definition* list replaces the column alias list that could otherwise be attached to the FROM item; the names in the column definitions serve as column aliases. When using the ROWS FROM() syntax, a *column_definition* list can be attached to each member function separately; or if there is only one member function and no WITH ORDINALITY clause, a *column_definition* list can be written in place of a column alias list following ROWS FROM().

Consider this example:

```
SELECT *
    FROM dblink('dbname=mydb', 'SELECT proname, prosrc FROM pg_proc')
      AS t1(proname name, prosrc text)
```

```
    WHERE proname LIKE 'bytea%';
```

The dblink function (part of the dblink module) executes a remote query. It is declared to return `record` since it might be used for any kind of query. The actual column set must be specified in the calling query so that the parser knows, for example, what `*` should expand to.

This example uses `ROWS FROM`:

```
SELECT *
FROM ROWS FROM
    (
        json_to_recordset('[{"a":40,"b":"foo"},{"a":"100","b":"bar"}]')
            AS (a INTEGER, b TEXT),
        generate_series(1, 3)
    ) AS x (p, q, s)
ORDER BY p;

  p  |  q  | s
-----+-----+---
  40 | foo | 1
 100 | bar | 2
     |     | 3
```

It joins two functions into a single `FROM` target. `json_to_recordset()` is instructed to return two columns, the first `integer` and the second `text`. The result of `generate_series()` is used directly. The `ORDER BY` clause sorts the column values as integers.

7.2.1.5. `LATERAL` Subqueries

Subqueries appearing in `FROM` can be preceded by the key word `LATERAL`. This allows them to reference columns provided by preceding `FROM` items. (Without `LATERAL`, each subquery is evaluated independently and so cannot cross-reference any other `FROM` item.)

Table functions appearing in `FROM` can also be preceded by the key word `LATERAL`, but for functions the key word is optional; the function's arguments can contain references to columns provided by preceding `FROM` items in any case.

A `LATERAL` item can appear at the top level in the `FROM` list, or within a `JOIN` tree. In the latter case it can also refer to any items that are on the left-hand side of a `JOIN` that it is on the right-hand side of.

When a `FROM` item contains `LATERAL` cross-references, evaluation proceeds as follows: for each row of the `FROM` item providing the cross-referenced column(s), or set of rows of multiple `FROM` items providing the columns, the `LATERAL` item is evaluated using that row or row set's values of the columns. The resulting row(s) are joined as usual with the rows they were computed from. This is repeated for each row or set of rows from the column source table(s).

A trivial example of `LATERAL` is

```
SELECT * FROM foo, LATERAL (SELECT * FROM bar WHERE bar.id = foo.bar_id) ss;
```

This is not especially useful since it has exactly the same result as the more conventional

```
SELECT * FROM foo, bar WHERE bar.id = foo.bar_id;
```

`LATERAL` is primarily useful when the cross-referenced column is necessary for computing the row(s) to be joined. A common application is providing an argument value for a set-returning function. For example, supposing that `vertices(polygon)` returns the set of vertices of a polygon, we could identify close-together vertices of polygons stored in a table with:

```
SELECT p1.id, p2.id, v1, v2
FROM polygons p1, polygons p2,
     LATERAL vertices(p1.poly) v1,
     LATERAL vertices(p2.poly) v2
```

```
WHERE (v1 <-> v2) < 10 AND p1.id != p2.id;
```

This query could also be written

```
SELECT p1.id, p2.id, v1, v2
FROM polygons p1 CROSS JOIN LATERAL vertices(p1.poly) v1,
     polygons p2 CROSS JOIN LATERAL vertices(p2.poly) v2
WHERE (v1 <-> v2) < 10 AND p1.id != p2.id;
```

or in several other equivalent formulations. (As already mentioned, the `LATERAL` key word is unnecessary in this example, but we use it for clarity.)

It is often particularly handy to `LEFT JOIN` to a `LATERAL` subquery, so that source rows will appear in the result even if the `LATERAL` subquery produces no rows for them. For example, if `get_product_names()` returns the names of products made by a manufacturer, but some manufacturers in our table currently produce no products, we could find out which ones those are like this:

```
SELECT m.name
FROM manufacturers m LEFT JOIN LATERAL get_product_names(m.id) pname ON true
WHERE pname IS NULL;
```

7.2.2. The `WHERE` Clause

The syntax of the `WHERE` clause is

```
WHERE search_condition
```

where *search_condition* is any value expression (see Section 4.2) that returns a value of type `boolean`.

After the processing of the `FROM` clause is done, each row of the derived virtual table is checked against the search condition. If the result of the condition is true, the row is kept in the output table, otherwise (i.e., if the result is false or null) it is discarded. The search condition typically references at least one column of the table generated in the `FROM` clause; this is not required, but otherwise the `WHERE` clause will be fairly useless.

> **Note**
>
> The join condition of an inner join can be written either in the `WHERE` clause or in the `JOIN` clause. For example, these table expressions are equivalent:
>
> ```
> FROM a, b WHERE a.id = b.id AND b.val > 5
> ```
>
> and:
>
> ```
> FROM a INNER JOIN b ON (a.id = b.id) WHERE b.val > 5
> ```
>
> or perhaps even:
>
> ```
> FROM a NATURAL JOIN b WHERE b.val > 5
> ```
>
> Which one of these you use is mainly a matter of style. The `JOIN` syntax in the `FROM` clause is probably not as portable to other SQL database management systems, even though it is in the SQL standard. For outer joins there is no choice: they must be done in the `FROM` clause. The `ON` or `USING` clause of an outer join is *not* equivalent to a `WHERE` condition, because it results in the addition of rows (for unmatched input rows) as well as the removal of rows in the final result.

Here are some examples of `WHERE` clauses:

```
SELECT ... FROM fdt WHERE c1 > 5

SELECT ... FROM fdt WHERE c1 IN (1, 2, 3)

SELECT ... FROM fdt WHERE c1 IN (SELECT c1 FROM t2)
```

```
SELECT ... FROM fdt WHERE c1 IN (SELECT c3 FROM t2 WHERE c2 = fdt.c1 + 10)

SELECT ... FROM fdt WHERE c1 BETWEEN (SELECT c3 FROM t2 WHERE c2 = fdt.c1 + 10) AND 100

SELECT ... FROM fdt WHERE EXISTS (SELECT c1 FROM t2 WHERE c2 > fdt.c1)
```

`fdt` is the table derived in the `FROM` clause. Rows that do not meet the search condition of the `WHERE` clause are eliminated from `fdt`. Notice the use of scalar subqueries as value expressions. Just like any other query, the subqueries can employ complex table expressions. Notice also how `fdt` is referenced in the subqueries. Qualifying `c1` as `fdt.c1` is only necessary if `c1` is also the name of a column in the derived input table of the subquery. But qualifying the column name adds clarity even when it is not needed. This example shows how the column naming scope of an outer query extends into its inner queries.

7.2.3. The `GROUP BY` and `HAVING` Clauses

After passing the `WHERE` filter, the derived input table might be subject to grouping, using the `GROUP BY` clause, and elimination of group rows using the `HAVING` clause.

```
SELECT select_list
    FROM ...
    [WHERE ...]
    GROUP BY grouping_column_reference [, grouping_column_reference]...
```

The `GROUP BY` clause is used to group together those rows in a table that have the same values in all the columns listed. The order in which the columns are listed does not matter. The effect is to combine each set of rows having common values into one group row that represents all rows in the group. This is done to eliminate redundancy in the output and/or compute aggregates that apply to these groups. For instance:

```
=> SELECT * FROM test1;
 x | y
---+---
 a | 3
 c | 2
 b | 5
 a | 1
(4 rows)

=> SELECT x FROM test1 GROUP BY x;
 x
---
 a
 b
 c
(3 rows)
```

In the second query, we could not have written `SELECT * FROM test1 GROUP BY x`, because there is no single value for the column `y` that could be associated with each group. The grouped-by columns can be referenced in the select list since they have a single value in each group.

In general, if a table is grouped, columns that are not listed in `GROUP BY` cannot be referenced except in aggregate expressions. An example with aggregate expressions is:

```
=> SELECT x, sum(y) FROM test1 GROUP BY x;
 x | sum
---+-----
 a |   4
 b |   5
 c |   2
(3 rows)
```

Here `sum` is an aggregate function that computes a single value over the entire group. More information about the available aggregate functions can be found in Section 9.21.

> **Tip**
>
> Grouping without aggregate expressions effectively calculates the set of distinct values in a column. This can also be achieved using the `DISTINCT` clause (see Section 7.3.3).

Here is another example: it calculates the total sales for each product (rather than the total sales of all products):

```
SELECT product_id, p.name, (sum(s.units) * p.price) AS sales
    FROM products p LEFT JOIN sales s USING (product_id)
    GROUP BY product_id, p.name, p.price;
```

In this example, the columns `product_id`, `p.name`, and `p.price` must be in the `GROUP BY` clause since they are referenced in the query select list (but see below). The column `s.units` does not have to be in the `GROUP BY` list since it is only used in an aggregate expression (`sum(...)`), which represents the sales of a product. For each product, the query returns a summary row about all sales of the product.

If the products table is set up so that, say, `product_id` is the primary key, then it would be enough to group by `product_id` in the above example, since name and price would be *functionally dependent* on the product ID, and so there would be no ambiguity about which name and price value to return for each product ID group.

In strict SQL, `GROUP BY` can only group by columns of the source table but Postgres Pro extends this to also allow `GROUP BY` to group by columns in the select list. Grouping by value expressions instead of simple column names is also allowed.

If a table has been grouped using `GROUP BY`, but only certain groups are of interest, the `HAVING` clause can be used, much like a `WHERE` clause, to eliminate groups from the result. The syntax is:

```
SELECT select_list FROM ... [WHERE ...] GROUP BY ... HAVING boolean_expression
```

Expressions in the `HAVING` clause can refer both to grouped expressions and to ungrouped expressions (which necessarily involve an aggregate function).

Example:

```
=> SELECT x, sum(y) FROM test1 GROUP BY x HAVING sum(y) > 3;
 x | sum
---+-----
 a |   4
 b |   5
(2 rows)

=> SELECT x, sum(y) FROM test1 GROUP BY x HAVING x < 'c';
 x | sum
---+-----
 a |   4
 b |   5
(2 rows)
```

Again, a more realistic example:

```
SELECT product_id, p.name, (sum(s.units) * (p.price - p.cost)) AS profit
    FROM products p LEFT JOIN sales s USING (product_id)
    WHERE s.date > CURRENT_DATE - INTERVAL '4 weeks'
    GROUP BY product_id, p.name, p.price, p.cost
```

```
    HAVING sum(p.price * s.units) > 5000;
```

In the example above, the WHERE clause is selecting rows by a column that is not grouped (the expression is only true for sales during the last four weeks), while the HAVING clause restricts the output to groups with total gross sales over 5000. Note that the aggregate expressions do not necessarily need to be the same in all parts of the query.

If a query contains aggregate function calls, but no GROUP BY clause, grouping still occurs: the result is a single group row (or perhaps no rows at all, if the single row is then eliminated by HAVING). The same is true if it contains a HAVING clause, even without any aggregate function calls or GROUP BY clause.

7.2.4. GROUPING SETS, CUBE, and ROLLUP

More complex grouping operations than those described above are possible using the concept of *grouping sets*. The data selected by the FROM and WHERE clauses is grouped separately by each specified grouping set, aggregates computed for each group just as for simple GROUP BY clauses, and then the results returned. For example:

```
=> SELECT * FROM items_sold;
 brand | size | sales
-------+------+-------
 Foo   | L    |  10
 Foo   | M    |  20
 Bar   | M    |  15
 Bar   | L    |  5
(4 rows)

=> SELECT brand, size, sum(sales) FROM items_sold GROUP BY GROUPING SETS ((brand),
 (size), ());
 brand | size | sum
-------+------+-----
 Foo   |      |  30
 Bar   |      |  20
       | L    |  15
       | M    |  35
       |      |  50
(5 rows)
```

Each sublist of GROUPING SETS may specify zero or more columns or expressions and is interpreted the same way as though it were directly in the GROUP BY clause. An empty grouping set means that all rows are aggregated down to a single group (which is output even if no input rows were present), as described above for the case of aggregate functions with no GROUP BY clause.

References to the grouping columns or expressions are replaced by null values in result rows for grouping sets in which those columns do not appear. To distinguish which grouping a particular output row resulted from, see Table 9.61.

A shorthand notation is provided for specifying two common types of grouping set. A clause of the form

```
ROLLUP ( e1, e2, e3, ... )
```

represents the given list of expressions and all prefixes of the list including the empty list; thus it is equivalent to

```
GROUPING SETS (
    ( e1, e2, e3, ... ),
    ...
    ( e1, e2 ),
    ( e1 ),
    ( )
)
```

This is commonly used for analysis over hierarchical data; e.g., total salary by department, division, and company-wide total.

A clause of the form

```
CUBE ( e1, e2, ... )
```

represents the given list and all of its possible subsets (i.e., the power set). Thus

```
CUBE ( a, b, c )
```

is equivalent to

```
GROUPING SETS (
    ( a, b, c ),
    ( a, b    ),
    ( a,    c ),
    ( a       ),
    (    b, c ),
    (    b    ),
    (       c ),
    (         )
)
```

The individual elements of a `CUBE` or `ROLLUP` clause may be either individual expressions, or sublists of elements in parentheses. In the latter case, the sublists are treated as single units for the purposes of generating the individual grouping sets. For example:

```
CUBE ( (a, b), (c, d) )
```

is equivalent to

```
GROUPING SETS (
    ( a, b, c, d ),
    ( a, b       ),
    (       c, d ),
    (            )
)
```

and

```
ROLLUP ( a, (b, c), d )
```

is equivalent to

```
GROUPING SETS (
    ( a, b, c, d ),
    ( a, b, c    ),
    ( a          ),
    (            )
)
```

The `CUBE` and `ROLLUP` constructs can be used either directly in the `GROUP BY` clause, or nested inside a `GROUPING SETS` clause. If one `GROUPING SETS` clause is nested inside another, the effect is the same as if all the elements of the inner clause had been written directly in the outer clause.

If multiple grouping items are specified in a single `GROUP BY` clause, then the final list of grouping sets is the cross product of the individual items. For example:

```
GROUP BY a, CUBE (b, c), GROUPING SETS ((d), (e))
```

is equivalent to

```
GROUP BY GROUPING SETS (
    (a, b, c, d), (a, b, c, e),
    (a, b, d),    (a, b, e),
```

```
    (a, c, d),    (a, c, e),
    (a, d),       (a, e)
)
```

When specifying multiple grouping items together, the final set of grouping sets might contain duplicates. For example:

```
GROUP BY ROLLUP (a, b), ROLLUP (a, c)
```

is equivalent to

```
GROUP BY GROUPING SETS (
    (a, b, c),
    (a, b),
    (a, b),
    (a, c),
    (a),
    (a),
    (a, c),
    (a),
    ()
)
```

If these duplicates are undesirable, they can be removed using the `DISTINCT` clause directly on the `GROUP BY`. Therefore:

```
GROUP BY DISTINCT ROLLUP (a, b), ROLLUP (a, c)
```

is equivalent to

```
GROUP BY GROUPING SETS (
    (a, b, c),
    (a, b),
    (a, c),
    (a),
    ()
)
```

This is not the same as using `SELECT DISTINCT` because the output rows may still contain duplicates. If any of the ungrouped columns contains NULL, it will be indistinguishable from the NULL used when that same column is grouped.

> **Note**
>
> The construct `(a, b)` is normally recognized in expressions as a row constructor. Within the `GROUP BY` clause, this does not apply at the top levels of expressions, and `(a, b)` is parsed as a list of expressions as described above. If for some reason you *need* a row constructor in a grouping expression, use `ROW(a, b)`.

7.2.5. Window Function Processing

If the query contains any window functions (see Section 3.5, Section 9.22 and Section 4.2.8), these functions are evaluated after any grouping, aggregation, and `HAVING` filtering is performed. That is, if the query uses any aggregates, `GROUP BY`, or `HAVING`, then the rows seen by the window functions are the group rows instead of the original table rows from `FROM`/`WHERE`.

When multiple window functions are used, all the window functions having equivalent `PARTITION BY` and `ORDER BY` clauses in their window definitions are guaranteed to see the same ordering of the input rows, even if the `ORDER BY` does not uniquely determine the ordering. However, no guarantees are made about the evaluation of functions having different `PARTITION BY` or `ORDER BY` specifications. (In such

cases a sort step is typically required between the passes of window function evaluations, and the sort is not guaranteed to preserve ordering of rows that its ORDER BY sees as equivalent.)

Currently, window functions always require presorted data, and so the query output will be ordered according to one or another of the window functions' PARTITION BY/ORDER BY clauses. It is not recommended to rely on this, however. Use an explicit top-level ORDER BY clause if you want to be sure the results are sorted in a particular way.

7.3. Select Lists

As shown in the previous section, the table expression in the SELECT command constructs an intermediate virtual table by possibly combining tables, views, eliminating rows, grouping, etc. This table is finally passed on to processing by the *select list*. The select list determines which *columns* of the intermediate table are actually output.

7.3.1. Select-List Items

The simplest kind of select list is * which emits all columns that the table expression produces. Otherwise, a select list is a comma-separated list of value expressions (as defined in Section 4.2). For instance, it could be a list of column names:

```
SELECT a, b, c FROM ...
```

The columns names a, b, and c are either the actual names of the columns of tables referenced in the FROM clause, or the aliases given to them as explained in Section 7.2.1.2. The name space available in the select list is the same as in the WHERE clause, unless grouping is used, in which case it is the same as in the HAVING clause.

If more than one table has a column of the same name, the table name must also be given, as in:

```
SELECT tbl1.a, tbl2.a, tbl1.b FROM ...
```

When working with multiple tables, it can also be useful to ask for all the columns of a particular table:

```
SELECT tbl1.*, tbl2.a FROM ...
```

See Section 8.16.5 for more about the *table_name*.* notation.

If an arbitrary value expression is used in the select list, it conceptually adds a new virtual column to the returned table. The value expression is evaluated once for each result row, with the row's values substituted for any column references. But the expressions in the select list do not have to reference any columns in the table expression of the FROM clause; they can be constant arithmetic expressions, for instance.

7.3.2. Column Labels

The entries in the select list can be assigned names for subsequent processing, such as for use in an ORDER BY clause or for display by the client application. For example:

```
SELECT a AS value, b + c AS sum FROM ...
```

If no output column name is specified using AS, the system assigns a default column name. For simple column references, this is the name of the referenced column. For function calls, this is the name of the function. For complex expressions, the system will generate a generic name.

The AS key word is usually optional, but in some cases where the desired column name matches a Postgres Pro key word, you must write AS or double-quote the column name in order to avoid ambiguity. (Appendix C shows which key words require AS to be used as a column label.) For example, FROM is one such key word, so this does not work:

```
SELECT a from, b + c AS sum FROM ...
```

but either of these do:

```
SELECT a AS from, b + c AS sum FROM ...
```

```
SELECT a "from", b + c AS sum FROM ...
```

For greatest safety against possible future key word additions, it is recommended that you always either write AS or double-quote the output column name.

> **Note**
>
> The naming of output columns here is different from that done in the FROM clause (see Section 7.2.1.2). It is possible to rename the same column twice, but the name assigned in the select list is the one that will be passed on.

7.3.3. DISTINCT

After the select list has been processed, the result table can optionally be subject to the elimination of duplicate rows. The DISTINCT key word is written directly after SELECT to specify this:

```
SELECT DISTINCT select_list ...
```

(Instead of DISTINCT the key word ALL can be used to specify the default behavior of retaining all rows.)

Obviously, two rows are considered distinct if they differ in at least one column value. Null values are considered equal in this comparison.

Alternatively, an arbitrary expression can determine what rows are to be considered distinct:

```
SELECT DISTINCT ON (expression [, expression ...]) select_list ...
```

Here *expression* is an arbitrary value expression that is evaluated for all rows. A set of rows for which all the expressions are equal are considered duplicates, and only the first row of the set is kept in the output. Note that the "first row" of a set is unpredictable unless the query is sorted on enough columns to guarantee a unique ordering of the rows arriving at the DISTINCT filter. (DISTINCT ON processing occurs after ORDER BY sorting.)

The DISTINCT ON clause is not part of the SQL standard and is sometimes considered bad style because of the potentially indeterminate nature of its results. With judicious use of GROUP BY and subqueries in FROM, this construct can be avoided, but it is often the most convenient alternative.

7.4. Combining Queries (UNION, INTERSECT, EXCEPT)

The results of two queries can be combined using the set operations union, intersection, and difference. The syntax is

```
query1 UNION [ALL] query2
query1 INTERSECT [ALL] query2
query1 EXCEPT [ALL] query2
```

where *query1* and *query2* are queries that can use any of the features discussed up to this point.

UNION effectively appends the result of *query2* to the result of *query1* (although there is no guarantee that this is the order in which the rows are actually returned). Furthermore, it eliminates duplicate rows from its result, in the same way as DISTINCT, unless UNION ALL is used.

INTERSECT returns all rows that are both in the result of *query1* and in the result of *query2*. Duplicate rows are eliminated unless INTERSECT ALL is used.

EXCEPT returns all rows that are in the result of *query1* but not in the result of *query2*. (This is sometimes called the *difference* between two queries.) Again, duplicates are eliminated unless EXCEPT ALL is used.

In order to calculate the union, intersection, or difference of two queries, the two queries must be "union compatible", which means that they return the same number of columns and the corresponding columns have compatible data types, as described in Section 10.5.

Set operations can be combined, for example

query1 UNION *query2* EXCEPT *query3*

which is equivalent to

(*query1* UNION *query2*) EXCEPT *query3*

As shown here, you can use parentheses to control the order of evaluation. Without parentheses, UNION and EXCEPT associate left-to-right, but INTERSECT binds more tightly than those two operators. Thus

query1 UNION *query2* INTERSECT *query3*

means

query1 UNION (*query2* INTERSECT *query3*)

You can also surround an individual *query* with parentheses. This is important if the *query* needs to use any of the clauses discussed in following sections, such as LIMIT. Without parentheses, you'll get a syntax error, or else the clause will be understood as applying to the output of the set operation rather than one of its inputs. For example,

```
SELECT a FROM b UNION SELECT x FROM y LIMIT 10
```

is accepted, but it means

```
(SELECT a FROM b UNION SELECT x FROM y) LIMIT 10
```

not

```
SELECT a FROM b UNION (SELECT x FROM y LIMIT 10)
```

7.5. Sorting Rows (ORDER BY)

After a query has produced an output table (after the select list has been processed) it can optionally be sorted. If sorting is not chosen, the rows will be returned in an unspecified order. The actual order in that case will depend on the scan and join plan types and the order on disk, but it must not be relied on. A particular output ordering can only be guaranteed if the sort step is explicitly chosen.

The ORDER BY clause specifies the sort order:

```
SELECT select_list
    FROM table_expression
    ORDER BY sort_expression1 [ASC | DESC] [NULLS { FIRST | LAST }]
             [, sort_expression2 [ASC | DESC] [NULLS { FIRST | LAST }] ...]
```

The sort expression(s) can be any expression that would be valid in the query's select list. An example is:

```
SELECT a, b FROM table1 ORDER BY a + b, c;
```

When more than one expression is specified, the later values are used to sort rows that are equal according to the earlier values. Each expression can be followed by an optional ASC or DESC keyword to set the sort direction to ascending or descending. ASC order is the default. Ascending order puts smaller values first, where “smaller” is defined in terms of the < operator. Similarly, descending order is determined with the > operator. [1]

The NULLS FIRST and NULLS LAST options can be used to determine whether nulls appear before or after non-null values in the sort ordering. By default, null values sort as if larger than any non-null value; that is, NULLS FIRST is the default for DESC order, and NULLS LAST otherwise.

Note that the ordering options are considered independently for each sort column. For example ORDER BY x, y DESC means ORDER BY x ASC, y DESC, which is not the same as ORDER BY x DESC, y DESC.

A *sort_expression* can also be the column label or number of an output column, as in:

[1] Actually, Postgres Pro uses the *default B-tree operator class* for the expression's data type to determine the sort ordering for ASC and DESC. Conventionally, data types will be set up so that the < and > operators correspond to this sort ordering, but a user-defined data type's designer could choose to do something different.

```
SELECT a + b AS sum, c FROM table1 ORDER BY sum;
SELECT a, max(b) FROM table1 GROUP BY a ORDER BY 1;
```

both of which sort by the first output column. Note that an output column name has to stand alone, that is, it cannot be used in an expression — for example, this is *not* correct:

```
SELECT a + b AS sum, c FROM table1 ORDER BY sum + c;          -- wrong
```

This restriction is made to reduce ambiguity. There is still ambiguity if an `ORDER BY` item is a simple name that could match either an output column name or a column from the table expression. The output column is used in such cases. This would only cause confusion if you use `AS` to rename an output column to match some other table column's name.

`ORDER BY` can be applied to the result of a `UNION`, `INTERSECT`, or `EXCEPT` combination, but in this case it is only permitted to sort by output column names or numbers, not by expressions.

7.6. `LIMIT` and `OFFSET`

`LIMIT` and `OFFSET` allow you to retrieve just a portion of the rows that are generated by the rest of the query:

```
SELECT select_list
    FROM table_expression
    [ ORDER BY ... ]
    [ LIMIT { number | ALL } ] [ OFFSET number ]
```

If a limit count is given, no more than that many rows will be returned (but possibly fewer, if the query itself yields fewer rows). `LIMIT ALL` is the same as omitting the `LIMIT` clause, as is `LIMIT` with a NULL argument.

`OFFSET` says to skip that many rows before beginning to return rows. `OFFSET 0` is the same as omitting the `OFFSET` clause, as is `OFFSET` with a NULL argument.

If both `OFFSET` and `LIMIT` appear, then `OFFSET` rows are skipped before starting to count the `LIMIT` rows that are returned.

When using `LIMIT`, it is important to use an `ORDER BY` clause that constrains the result rows into a unique order. Otherwise you will get an unpredictable subset of the query's rows. You might be asking for the tenth through twentieth rows, but tenth through twentieth in what ordering? The ordering is unknown, unless you specified `ORDER BY`.

The query optimizer takes `LIMIT` into account when generating query plans, so you are very likely to get different plans (yielding different row orders) depending on what you give for `LIMIT` and `OFFSET`. Thus, using different `LIMIT`/`OFFSET` values to select different subsets of a query result *will give inconsistent results* unless you enforce a predictable result ordering with `ORDER BY`. This is not a bug; it is an inherent consequence of the fact that SQL does not promise to deliver the results of a query in any particular order unless `ORDER BY` is used to constrain the order.

The rows skipped by an `OFFSET` clause still have to be computed inside the server; therefore a large `OFFSET` might be inefficient.

7.7. `VALUES` Lists

`VALUES` provides a way to generate a “constant table” that can be used in a query without having to actually create and populate a table on-disk. The syntax is

```
VALUES ( expression [, ...] ) [, ...]
```

Each parenthesized list of expressions generates a row in the table. The lists must all have the same number of elements (i.e., the number of columns in the table), and corresponding entries in each list must have compatible data types. The actual data type assigned to each column of the result is determined using the same rules as for `UNION` (see Section 10.5).

As an example:

```
VALUES (1, 'one'), (2, 'two'), (3, 'three');
```

will return a table of two columns and three rows. It's effectively equivalent to:

```
SELECT 1 AS column1, 'one' AS column2
UNION ALL
SELECT 2, 'two'
UNION ALL
SELECT 3, 'three';
```

By default, Postgres Pro assigns the names `column1`, `column2`, etc. to the columns of a `VALUES` table. The column names are not specified by the SQL standard and different database systems do it differently, so it's usually better to override the default names with a table alias list, like this:

```
=> SELECT * FROM (VALUES (1, 'one'), (2, 'two'), (3, 'three')) AS t (num,letter);
 num | letter
-----+--------
   1 | one
   2 | two
   3 | three
(3 rows)
```

Syntactically, `VALUES` followed by expression lists is treated as equivalent to:

```
SELECT select_list FROM table_expression
```

and can appear anywhere a `SELECT` can. For example, you can use it as part of a `UNION`, or attach a *sort_specification* (`ORDER BY`, `LIMIT`, and/or `OFFSET`) to it. `VALUES` is most commonly used as the data source in an `INSERT` command, and next most commonly as a subquery.

For more information see VALUES.

7.8. `WITH` Queries (Common Table Expressions)

`WITH` provides a way to write auxiliary statements for use in a larger query. These statements, which are often referred to as Common Table Expressions or CTEs, can be thought of as defining temporary tables that exist just for one query. Each auxiliary statement in a `WITH` clause can be a `SELECT`, `INSERT`, `UPDATE`, or `DELETE`; and the `WITH` clause itself is attached to a primary statement that can also be a `SELECT`, `INSERT`, `UPDATE`, or `DELETE`.

7.8.1. `SELECT` in `WITH`

The basic value of `SELECT` in `WITH` is to break down complicated queries into simpler parts. An example is:

```
WITH regional_sales AS (
    SELECT region, SUM(amount) AS total_sales
    FROM orders
    GROUP BY region
), top_regions AS (
    SELECT region
    FROM regional_sales
    WHERE total_sales > (SELECT SUM(total_sales)/10 FROM regional_sales)
)
SELECT region,
       product,
       SUM(quantity) AS product_units,
       SUM(amount) AS product_sales
FROM orders
WHERE region IN (SELECT region FROM top_regions)
GROUP BY region, product;
```

which displays per-product sales totals in only the top sales regions. The WITH clause defines two auxiliary statements named regional_sales and top_regions, where the output of regional_sales is used in top_regions and the output of top_regions is used in the primary SELECT query. This example could have been written without WITH, but we'd have needed two levels of nested sub-SELECTs. It's a bit easier to follow this way.

7.8.2. Recursive Queries

The optional RECURSIVE modifier changes WITH from a mere syntactic convenience into a feature that accomplishes things not otherwise possible in standard SQL. Using RECURSIVE, a WITH query can refer to its own output. A very simple example is this query to sum the integers from 1 through 100:

```
WITH RECURSIVE t(n) AS (
    VALUES (1)
  UNION ALL
    SELECT n+1 FROM t WHERE n < 100
)
SELECT sum(n) FROM t;
```

The general form of a recursive WITH query is always a *non-recursive term*, then UNION (or UNION ALL), then a *recursive term*, where only the recursive term can contain a reference to the query's own output. Such a query is executed as follows:

Recursive Query Evaluation

1. Evaluate the non-recursive term. For UNION (but not UNION ALL), discard duplicate rows. Include all remaining rows in the result of the recursive query, and also place them in a temporary *working table*.
2. So long as the working table is not empty, repeat these steps:
   a. Evaluate the recursive term, substituting the current contents of the working table for the recursive self-reference. For UNION (but not UNION ALL), discard duplicate rows and rows that duplicate any previous result row. Include all remaining rows in the result of the recursive query, and also place them in a temporary *intermediate table*.
   b. Replace the contents of the working table with the contents of the intermediate table, then empty the intermediate table.

> **Note**
>
> While RECURSIVE allows queries to be specified recursively, internally such queries are evaluated iteratively.

In the example above, the working table has just a single row in each step, and it takes on the values from 1 through 100 in successive steps. In the 100th step, there is no output because of the WHERE clause, and so the query terminates.

Recursive queries are typically used to deal with hierarchical or tree-structured data. A useful example is this query to find all the direct and indirect sub-parts of a product, given only a table that shows immediate inclusions:

```
WITH RECURSIVE included_parts(sub_part, part, quantity) AS (
    SELECT sub_part, part, quantity FROM parts WHERE part = 'our_product'
  UNION ALL
    SELECT p.sub_part, p.part, p.quantity * pr.quantity
    FROM included_parts pr, parts p
    WHERE p.part = pr.sub_part
)
SELECT sub_part, SUM(quantity) as total_quantity
FROM included_parts
```

```
GROUP BY sub_part
```

7.8.2.1. Search Order

When computing a tree traversal using a recursive query, you might want to order the results in either depth-first or breadth-first order. This can be done by computing an ordering column alongside the other data columns and using that to sort the results at the end. Note that this does not actually control in which order the query evaluation visits the rows; that is as always in SQL implementation-dependent. This approach merely provides a convenient way to order the results afterwards.

To create a depth-first order, we compute for each result row an array of rows that we have visited so far. For example, consider the following query that searches a table `tree` using a `link` field:

```
WITH RECURSIVE search_tree(id, link, data) AS (
    SELECT t.id, t.link, t.data
    FROM tree t
  UNION ALL
    SELECT t.id, t.link, t.data
    FROM tree t, search_tree st
    WHERE t.id = st.link
)
SELECT * FROM search_tree;
```

To add depth-first ordering information, you can write this:

```
WITH RECURSIVE search_tree(id, link, data, path) AS (
    SELECT t.id, t.link, t.data, ARRAY[t.id]
    FROM tree t
  UNION ALL
    SELECT t.id, t.link, t.data, path || t.id
    FROM tree t, search_tree st
    WHERE t.id = st.link
)
SELECT * FROM search_tree ORDER BY path;
```

In the general case where more than one field needs to be used to identify a row, use an array of rows. For example, if we needed to track fields `f1` and `f2`:

```
WITH RECURSIVE search_tree(id, link, data, path) AS (
    SELECT t.id, t.link, t.data, ARRAY[ROW(t.f1, t.f2)]
    FROM tree t
  UNION ALL
    SELECT t.id, t.link, t.data, path || ROW(t.f1, t.f2)
    FROM tree t, search_tree st
    WHERE t.id = st.link
)
SELECT * FROM search_tree ORDER BY path;
```

> **Tip**
>
> Omit the `ROW()` syntax in the common case where only one field needs to be tracked. This allows a simple array rather than a composite-type array to be used, gaining efficiency.

To create a breadth-first order, you can add a column that tracks the depth of the search, for example:

```
WITH RECURSIVE search_tree(id, link, data, depth) AS (
    SELECT t.id, t.link, t.data, 0
    FROM tree t
  UNION ALL
    SELECT t.id, t.link, t.data, depth + 1
```

```
    FROM tree t, search_tree st
    WHERE t.id = st.link
)
SELECT * FROM search_tree ORDER BY depth;
```

To get a stable sort, add data columns as secondary sorting columns.

> **Tip**
>
> The recursive query evaluation algorithm produces its output in breadth-first search order. However, this is an implementation detail and it is perhaps unsound to rely on it. The order of the rows within each level is certainly undefined, so some explicit ordering might be desired in any case.

There is built-in syntax to compute a depth- or breadth-first sort column. For example:

```
WITH RECURSIVE search_tree(id, link, data) AS (
    SELECT t.id, t.link, t.data
    FROM tree t
  UNION ALL
    SELECT t.id, t.link, t.data
    FROM tree t, search_tree st
    WHERE t.id = st.link
) SEARCH DEPTH FIRST BY id SET ordercol
SELECT * FROM search_tree ORDER BY ordercol;

WITH RECURSIVE search_tree(id, link, data) AS (
    SELECT t.id, t.link, t.data
    FROM tree t
  UNION ALL
    SELECT t.id, t.link, t.data
    FROM tree t, search_tree st
    WHERE t.id = st.link
) SEARCH BREADTH FIRST BY id SET ordercol
SELECT * FROM search_tree ORDER BY ordercol;
```

This syntax is internally expanded to something similar to the above hand-written forms. The `SEARCH` clause specifies whether depth- or breadth first search is wanted, the list of columns to track for sorting, and a column name that will contain the result data that can be used for sorting. That column will implicitly be added to the output rows of the CTE.

7.8.2.2. Cycle Detection

When working with recursive queries it is important to be sure that the recursive part of the query will eventually return no tuples, or else the query will loop indefinitely. Sometimes, using `UNION` instead of `UNION ALL` can accomplish this by discarding rows that duplicate previous output rows. However, often a cycle does not involve output rows that are completely duplicate: it may be necessary to check just one or a few fields to see if the same point has been reached before. The standard method for handling such situations is to compute an array of the already-visited values. For example, consider again the following query that searches a table `graph` using a `link` field:

```
WITH RECURSIVE search_graph(id, link, data, depth) AS (
    SELECT g.id, g.link, g.data, 0
    FROM graph g
  UNION ALL
    SELECT g.id, g.link, g.data, sg.depth + 1
    FROM graph g, search_graph sg
    WHERE g.id = sg.link
)
SELECT * FROM search_graph;
```

This query will loop if the `link` relationships contain cycles. Because we require a “depth” output, just changing `UNION ALL` to `UNION` would not eliminate the looping. Instead we need to recognize whether we have reached the same row again while following a particular path of links. We add two columns `is_cycle` and `path` to the loop-prone query:

```
WITH RECURSIVE search_graph(id, link, data, depth, is_cycle, path) AS (
    SELECT g.id, g.link, g.data, 0,
      false,
      ARRAY[g.id]
    FROM graph g
  UNION ALL
    SELECT g.id, g.link, g.data, sg.depth + 1,
      g.id = ANY(path),
      path || g.id
    FROM graph g, search_graph sg
    WHERE g.id = sg.link AND NOT is_cycle
)
SELECT * FROM search_graph;
```

Aside from preventing cycles, the array value is often useful in its own right as representing the “path” taken to reach any particular row.

In the general case where more than one field needs to be checked to recognize a cycle, use an array of rows. For example, if we needed to compare fields `f1` and `f2`:

```
WITH RECURSIVE search_graph(id, link, data, depth, is_cycle, path) AS (
    SELECT g.id, g.link, g.data, 0,
      false,
      ARRAY[ROW(g.f1, g.f2)]
    FROM graph g
  UNION ALL
    SELECT g.id, g.link, g.data, sg.depth + 1,
      ROW(g.f1, g.f2) = ANY(path),
      path || ROW(g.f1, g.f2)
    FROM graph g, search_graph sg
    WHERE g.id = sg.link AND NOT is_cycle
)
SELECT * FROM search_graph;
```

> **Tip**
>
> Omit the `ROW()` syntax in the common case where only one field needs to be checked to recognize a cycle. This allows a simple array rather than a composite-type array to be used, gaining efficiency.

There is built-in syntax to simplify cycle detection. The above query can also be written like this:

```
WITH RECURSIVE search_graph(id, link, data, depth) AS (
    SELECT g.id, g.link, g.data, 1
    FROM graph g
  UNION ALL
    SELECT g.id, g.link, g.data, sg.depth + 1
    FROM graph g, search_graph sg
    WHERE g.id = sg.link
) CYCLE id SET is_cycle USING path
SELECT * FROM search_graph;
```

and it will be internally rewritten to the above form. The `CYCLE` clause specifies first the list of columns to track for cycle detection, then a column name that will show whether a cycle has been detected, and finally the name of another column that will track the path. The cycle and path columns will implicitly be added to the output rows of the CTE.

> **Tip**
>
> The cycle path column is computed in the same way as the depth-first ordering column show in the previous section. A query can have both a SEARCH and a CYCLE clause, but a depth-first search specification and a cycle detection specification would create redundant computations, so it's more efficient to just use the CYCLE clause and order by the path column. If breadth-first ordering is wanted, then specifying both SEARCH and CYCLE can be useful.

A helpful trick for testing queries when you are not certain if they might loop is to place a LIMIT in the parent query. For example, this query would loop forever without the LIMIT:

```
WITH RECURSIVE t(n) AS (
    SELECT 1
  UNION ALL
    SELECT n+1 FROM t
)
SELECT n FROM t LIMIT 100;
```

This works because Postgres Pro's implementation evaluates only as many rows of a WITH query as are actually fetched by the parent query. Using this trick in production is not recommended, because other systems might work differently. Also, it usually won't work if you make the outer query sort the recursive query's results or join them to some other table, because in such cases the outer query will usually try to fetch all of the WITH query's output anyway.

7.8.3. Common Table Expression Materialization

A useful property of WITH queries is that they are normally evaluated only once per execution of the parent query, even if they are referred to more than once by the parent query or sibling WITH queries. Thus, expensive calculations that are needed in multiple places can be placed within a WITH query to avoid redundant work. Another possible application is to prevent unwanted multiple evaluations of functions with side-effects. However, the other side of this coin is that the optimizer is not able to push restrictions from the parent query down into a multiply-referenced WITH query, since that might affect all uses of the WITH query's output when it should affect only one. The multiply-referenced WITH query will be evaluated as written, without suppression of rows that the parent query might discard afterwards. (But, as mentioned above, evaluation might stop early if the reference(s) to the query demand only a limited number of rows.)

However, if a WITH query is non-recursive and side-effect-free (that is, it is a SELECT containing no volatile functions) then it can be folded into the parent query, allowing joint optimization of the two query levels. By default, this happens if the parent query references the WITH query just once, but not if it references the WITH query more than once. You can override that decision by specifying MATERIALIZED to force separate calculation of the WITH query, or by specifying NOT MATERIALIZED to force it to be merged into the parent query. The latter choice risks duplicate computation of the WITH query, but it can still give a net savings if each usage of the WITH query needs only a small part of the WITH query's full output.

A simple example of these rules is

```
WITH w AS (
    SELECT * FROM big_table
)
SELECT * FROM w WHERE key = 123;
```

This WITH query will be folded, producing the same execution plan as

```
SELECT * FROM big_table WHERE key = 123;
```

In particular, if there's an index on key, it will probably be used to fetch just the rows having key = 123. On the other hand, in

```
WITH w AS (
```

```
    SELECT * FROM big_table
)
SELECT * FROM w AS w1 JOIN w AS w2 ON w1.key = w2.ref
WHERE w2.key = 123;
```

the WITH query will be materialized, producing a temporary copy of big_table that is then joined with itself — without benefit of any index. This query will be executed much more efficiently if written as

```
WITH w AS NOT MATERIALIZED (
    SELECT * FROM big_table
)
SELECT * FROM w AS w1 JOIN w AS w2 ON w1.key = w2.ref
WHERE w2.key = 123;
```

so that the parent query's restrictions can be applied directly to scans of big_table.

An example where NOT MATERIALIZED could be undesirable is

```
WITH w AS (
    SELECT key, very_expensive_function(val) as f FROM some_table
)
SELECT * FROM w AS w1 JOIN w AS w2 ON w1.f = w2.f;
```

Here, materialization of the WITH query ensures that very_expensive_function is evaluated only once per table row, not twice.

The examples above only show WITH being used with SELECT, but it can be attached in the same way to INSERT, UPDATE, or DELETE. In each case it effectively provides temporary table(s) that can be referred to in the main command.

7.8.4. Data-Modifying Statements in WITH

You can use data-modifying statements (INSERT, UPDATE, or DELETE) in WITH. This allows you to perform several different operations in the same query. An example is:

```
WITH moved_rows AS (
    DELETE FROM products
    WHERE
        "date" >= '2010-10-01' AND
        "date" < '2010-11-01'
    RETURNING *
)
INSERT INTO products_log
SELECT * FROM moved_rows;
```

This query effectively moves rows from products to products_log. The DELETE in WITH deletes the specified rows from products, returning their contents by means of its RETURNING clause; and then the primary query reads that output and inserts it into products_log.

A fine point of the above example is that the WITH clause is attached to the INSERT, not the sub-SELECT within the INSERT. This is necessary because data-modifying statements are only allowed in WITH clauses that are attached to the top-level statement. However, normal WITH visibility rules apply, so it is possible to refer to the WITH statement's output from the sub-SELECT.

Data-modifying statements in WITH usually have RETURNING clauses (see Section 6.4), as shown in the example above. It is the output of the RETURNING clause, *not* the target table of the data-modifying statement, that forms the temporary table that can be referred to by the rest of the query. If a data-modifying statement in WITH lacks a RETURNING clause, then it forms no temporary table and cannot be referred to in the rest of the query. Such a statement will be executed nonetheless. A not-particularly-useful example is:

```
WITH t AS (
    DELETE FROM foo
```

```
)
DELETE FROM bar;
```

This example would remove all rows from tables `foo` and `bar`. The number of affected rows reported to the client would only include rows removed from `bar`.

Recursive self-references in data-modifying statements are not allowed. In some cases it is possible to work around this limitation by referring to the output of a recursive `WITH`, for example:

```
WITH RECURSIVE included_parts(sub_part, part) AS (
    SELECT sub_part, part FROM parts WHERE part = 'our_product'
  UNION ALL
    SELECT p.sub_part, p.part
    FROM included_parts pr, parts p
    WHERE p.part = pr.sub_part
)
DELETE FROM parts
  WHERE part IN (SELECT part FROM included_parts);
```

This query would remove all direct and indirect subparts of a product.

Data-modifying statements in `WITH` are executed exactly once, and always to completion, independently of whether the primary query reads all (or indeed any) of their output. Notice that this is different from the rule for `SELECT` in `WITH`: as stated in the previous section, execution of a `SELECT` is carried only as far as the primary query demands its output.

The sub-statements in `WITH` are executed concurrently with each other and with the main query. Therefore, when using data-modifying statements in `WITH`, the order in which the specified updates actually happen is unpredictable. All the statements are executed with the same *snapshot* (see Chapter 13), so they cannot “see” one another's effects on the target tables. This alleviates the effects of the unpredictability of the actual order of row updates, and means that `RETURNING` data is the only way to communicate changes between different `WITH` sub-statements and the main query. An example of this is that in

```
WITH t AS (
    UPDATE products SET price = price * 1.05
    RETURNING *
)
SELECT * FROM products;
```

the outer `SELECT` would return the original prices before the action of the `UPDATE`, while in

```
WITH t AS (
    UPDATE products SET price = price * 1.05
    RETURNING *
)
SELECT * FROM t;
```

the outer `SELECT` would return the updated data.

Trying to update the same row twice in a single statement is not supported. Only one of the modifications takes place, but it is not easy (and sometimes not possible) to reliably predict which one. This also applies to deleting a row that was already updated in the same statement: only the update is performed. Therefore you should generally avoid trying to modify a single row twice in a single statement. In particular avoid writing `WITH` sub-statements that could affect the same rows changed by the main statement or a sibling sub-statement. The effects of such a statement will not be predictable.

At present, any table used as the target of a data-modifying statement in `WITH` must not have a conditional rule, nor an `ALSO` rule, nor an `INSTEAD` rule that expands to multiple statements.

Chapter 8. Data Types

Postgres Pro has a rich set of native data types available to users. Users can add new types to Postgres Pro using the CREATE TYPE command.

Table 8.1 shows all the built-in general-purpose data types. Most of the alternative names listed in the "Aliases" column are the names used internally by Postgres Pro for historical reasons. In addition, some internally used or deprecated types are available, but are not listed here.

Table 8.1. Data Types

Name	Aliases	Description
bigint	int8	signed eight-byte integer
bigserial	serial8	autoincrementing eight-byte integer
bit [(*n*)]		fixed-length bit string
bit varying [(*n*)]	varbit [(*n*)]	variable-length bit string
boolean	bool	logical Boolean (true/false)
box		rectangular box on a plane
bytea		binary data ("byte array")
character [(*n*)]	char [(*n*)]	fixed-length character string
character varying [(*n*)]	varchar [(*n*)]	variable-length character string
cidr		IPv4 or IPv6 network address
circle		circle on a plane
date		calendar date (year, month, day)
double precision	float8	double precision floating-point number (8 bytes)
inet		IPv4 or IPv6 host address
integer	int, int4	signed four-byte integer
interval [*fields*] [(*p*)]		time span
json		textual JSON data
jsonb		binary JSON data, decomposed
line		infinite line on a plane
lseg		line segment on a plane
macaddr		MAC (Media Access Control) address
macaddr8		MAC (Media Access Control) address (EUI-64 format)
money		currency amount
numeric [(*p*, *s*)]	decimal [(*p*, *s*)]	exact numeric of selectable precision
path		geometric path on a plane
pg_lsn		Postgres Pro Log Sequence Number
pg_snapshot		user-level transaction ID snapshot
point		geometric point on a plane
polygon		closed geometric path on a plane
real	float4	single precision floating-point number (4 bytes)

Name	Aliases	Description
smallint	int2	signed two-byte integer
smallserial	serial2	autoincrementing two-byte integer
serial	serial4	autoincrementing four-byte integer
text		variable-length character string
time [(*p*)] [without time zone]		time of day (no time zone)
time [(*p*)] with time zone	timetz	time of day, including time zone
timestamp [(*p*)] [without time zone]		date and time (no time zone)
timestamp [(*p*)] with time zone	timestamptz	date and time, including time zone
tsquery		text search query
tsvector		text search document
txid_snapshot		user-level transaction ID snapshot (deprecated; see pg_snapshot)
uuid		universally unique identifier
xml		XML data

Compatibility

The following types (or spellings thereof) are specified by SQL: bigint, bit, bit varying, boolean, char, character varying, character, varchar, date, double precision, integer, interval, numeric, decimal, real, smallint, time (with or without time zone), timestamp (with or without time zone), xml.

Each data type has an external representation determined by its input and output functions. Many of the built-in types have obvious external formats. However, several types are either unique to Postgres Pro, such as geometric paths, or have several possible formats, such as the date and time types. Some of the input and output functions are not invertible, i.e., the result of an output function might lose accuracy when compared to the original input.

8.1. Numeric Types

Numeric types consist of two-, four-, and eight-byte integers, four- and eight-byte floating-point numbers, and selectable-precision decimals. Table 8.2 lists the available types.

Table 8.2. Numeric Types

Name	Storage Size	Description	Range
smallint	2 bytes	small-range integer	-32768 to +32767
integer	4 bytes	typical choice for integer	-2147483648 to +2147483647
bigint	8 bytes	large-range integer	-9223372036854775808 to +9223372036854775807
decimal	variable	user-specified precision, exact	up to 131072 digits before the decimal point; up to 16383 digits after the decimal point
numeric	variable	user-specified precision, exact	up to 131072 digits before the decimal point; up to

Name	Storage Size	Description	Range
			16383 digits after the decimal point
`real`	4 bytes	variable-precision, inexact	6 decimal digits precision
`double precision`	8 bytes	variable-precision, inexact	15 decimal digits precision
`smallserial`	2 bytes	small autoincrementing integer	1 to 32767
`serial`	4 bytes	autoincrementing integer	1 to 2147483647
`bigserial`	8 bytes	large autoincrementing integer	1 to 9223372036854775807

The syntax of constants for the numeric types is described in Section 4.1.2. The numeric types have a full set of corresponding arithmetic operators and functions. Refer to Chapter 9 for more information. The following sections describe the types in detail.

8.1.1. Integer Types

The types `smallint`, `integer`, and `bigint` store whole numbers, that is, numbers without fractional components, of various ranges. Attempts to store values outside of the allowed range will result in an error.

The type `integer` is the common choice, as it offers the best balance between range, storage size, and performance. The `smallint` type is generally only used if disk space is at a premium. The `bigint` type is designed to be used when the range of the `integer` type is insufficient.

SQL only specifies the integer types `integer` (or `int`), `smallint`, and `bigint`. The type names `int2`, `int4`, and `int8` are extensions, which are also used by some other SQL database systems.

8.1.2. Arbitrary Precision Numbers

The type `numeric` can store numbers with a very large number of digits. It is especially recommended for storing monetary amounts and other quantities where exactness is required. Calculations with `numeric` values yield exact results where possible, e.g., addition, subtraction, multiplication. However, calculations on `numeric` values are very slow compared to the integer types, or to the floating-point types described in the next section.

We use the following terms below: The *precision* of a `numeric` is the total count of significant digits in the whole number, that is, the number of digits to both sides of the decimal point. The *scale* of a `numeric` is the count of decimal digits in the fractional part, to the right of the decimal point. So the number 23.5141 has a precision of 6 and a scale of 4. Integers can be considered to have a scale of zero.

Both the maximum precision and the maximum scale of a `numeric` column can be configured. To declare a column of type `numeric` use the syntax:

`NUMERIC(`*`precision`*`, `*`scale`*`)`

The precision must be positive, the scale zero or positive. Alternatively:

`NUMERIC(`*`precision`*`)`

selects a scale of 0. Specifying:

`NUMERIC`

without any precision or scale creates an “unconstrained numeric” column in which numeric values of any length can be stored, up to the implementation limits. A column of this kind will not coerce input values to any particular scale, whereas `numeric` columns with a declared scale will coerce input values to that scale. (The SQL standard requires a default scale of 0, i.e., coercion to integer precision. We find this a bit useless. If you're concerned about portability, always specify the precision and scale explicitly.)

> **Note**
>
> The maximum precision that can be explicitly specified in a `NUMERIC` type declaration is 1000. An unconstrained `NUMERIC` column is subject to the limits described in Table 8.2.

If the scale of a value to be stored is greater than the declared scale of the column, the system will round the value to the specified number of fractional digits. Then, if the number of digits to the left of the decimal point exceeds the declared precision minus the declared scale, an error is raised.

Numeric values are physically stored without any extra leading or trailing zeroes. Thus, the declared precision and scale of a column are maximums, not fixed allocations. (In this sense the `numeric` type is more akin to `varchar(n)` than to `char(n)`.) The actual storage requirement is two bytes for each group of four decimal digits, plus three to eight bytes overhead.

In addition to ordinary numeric values, the `numeric` type has several special values:

```
Infinity
-Infinity
NaN
```

These are adapted from the IEEE 754 standard, and represent “infinity”, “negative infinity”, and “not-a-number”, respectively. When writing these values as constants in an SQL command, you must put quotes around them, for example `UPDATE table SET x = '-Infinity'`. On input, these strings are recognized in a case-insensitive manner. The infinity values can alternatively be spelled `inf` and `-inf`.

The infinity values behave as per mathematical expectations. For example, `Infinity` plus any finite value equals `Infinity`, as does `Infinity` plus `Infinity`; but `Infinity` minus `Infinity` yields `NaN` (not a number), because it has no well-defined interpretation. Note that an infinity can only be stored in an unconstrained `numeric` column, because it notionally exceeds any finite precision limit.

The `NaN` (not a number) value is used to represent undefined calculational results. In general, any operation with a `NaN` input yields another `NaN`. The only exception is when the operation's other inputs are such that the same output would be obtained if the `NaN` were to be replaced by any finite or infinite numeric value; then, that output value is used for `NaN` too. (An example of this principle is that `NaN` raised to the zero power yields one.)

> **Note**
>
> In most implementations of the “not-a-number” concept, `NaN` is not considered equal to any other numeric value (including `NaN`). In order to allow `numeric` values to be sorted and used in tree-based indexes, Postgres Pro treats `NaN` values as equal, and greater than all non-`NaN` values.

The types `decimal` and `numeric` are equivalent. Both types are part of the SQL standard.

When rounding values, the `numeric` type rounds ties away from zero, while (on most machines) the `real` and `double precision` types round ties to the nearest even number. For example:

```
SELECT x,
  round(x::numeric) AS num_round,
  round(x::double precision) AS dbl_round
FROM generate_series(-3.5, 3.5, 1) as x;
  x   | num_round | dbl_round
------+-----------+-----------
 -3.5 |        -4 |        -4
 -2.5 |        -3 |        -2
 -1.5 |        -2 |        -2
 -0.5 |        -1 |        -0
```

```
   0.5 |          1 |          0
   1.5 |          2 |          2
   2.5 |          3 |          2
   3.5 |          4 |          4
(8 rows)
```

8.1.3. Floating-Point Types

The data types `real` and `double precision` are inexact, variable-precision numeric types. On all currently supported platforms, these types are implementations of IEEE Standard 754 for Binary Floating-Point Arithmetic (single and double precision, respectively), to the extent that the underlying processor, operating system, and compiler support it.

Inexact means that some values cannot be converted exactly to the internal format and are stored as approximations, so that storing and retrieving a value might show slight discrepancies. Managing these errors and how they propagate through calculations is the subject of an entire branch of mathematics and computer science and will not be discussed here, except for the following points:

- If you require exact storage and calculations (such as for monetary amounts), use the `numeric` type instead.
- If you want to do complicated calculations with these types for anything important, especially if you rely on certain behavior in boundary cases (infinity, underflow), you should evaluate the implementation carefully.
- Comparing two floating-point values for equality might not always work as expected.

On all currently supported platforms, the `real` type has a range of around 1E-37 to 1E+37 with a precision of at least 6 decimal digits. The `double precision` type has a range of around 1E-307 to 1E+308 with a precision of at least 15 digits. Values that are too large or too small will cause an error. Rounding might take place if the precision of an input number is too high. Numbers too close to zero that are not representable as distinct from zero will cause an underflow error.

By default, floating point values are output in text form in their shortest precise decimal representation; the decimal value produced is closer to the true stored binary value than to any other value representable in the same binary precision. (However, the output value is currently never *exactly* midway between two representable values, in order to avoid a widespread bug where input routines do not properly respect the round-to-nearest-even rule.) This value will use at most 17 significant decimal digits for `float8` values, and at most 9 digits for `float4` values.

> **Note**
>
> This shortest-precise output format is much faster to generate than the historical rounded format.

For compatibility with output generated by older versions of Postgres Pro, and to allow the output precision to be reduced, the extra_float_digits parameter can be used to select rounded decimal output instead. Setting a value of 0 restores the previous default of rounding the value to 6 (for `float4`) or 15 (for `float8`) significant decimal digits. Setting a negative value reduces the number of digits further; for example -2 would round output to 4 or 13 digits respectively.

Any value of extra_float_digits greater than 0 selects the shortest-precise format.

> **Note**
>
> Applications that wanted precise values have historically had to set extra_float_digits to 3 to obtain them. For maximum compatibility between versions, they should continue to do so.

In addition to ordinary numeric values, the floating-point types have several special values:

```
Infinity
-Infinity
NaN
```

These represent the IEEE 754 special values “infinity”, “negative infinity”, and “not-a-number”, respectively. When writing these values as constants in an SQL command, you must put quotes around them, for example `UPDATE table SET x = '-Infinity'`. On input, these strings are recognized in a case-insensitive manner. The infinity values can alternatively be spelled `inf` and `-inf`.

> **Note**
>
> IEEE 754 specifies that `NaN` should not compare equal to any other floating-point value (including `NaN`). In order to allow floating-point values to be sorted and used in tree-based indexes, Postgres Pro treats `NaN` values as equal, and greater than all non-`NaN` values.

Postgres Pro also supports the SQL-standard notations `float` and `float(`*p*`)` for specifying inexact numeric types. Here, *p* specifies the minimum acceptable precision in *binary* digits. Postgres Pro accepts `float(1)` to `float(24)` as selecting the `real` type, while `float(25)` to `float(53)` select `double precision`. Values of *p* outside the allowed range draw an error. `float` with no precision specified is taken to mean `double precision`.

8.1.4. Serial Types

> **Note**
>
> This section describes a Postgres Pro-specific way to create an autoincrementing column. Another way is to use the SQL-standard identity column feature, described at CREATE TABLE.

The data types `smallserial`, `serial` and `bigserial` are not true types, but merely a notational convenience for creating unique identifier columns (similar to the `AUTO_INCREMENT` property supported by some other databases). In the current implementation, specifying:

```
CREATE TABLE tablename (
    colname SERIAL
);
```

is equivalent to specifying:

```
CREATE SEQUENCE tablename_colname_seq AS integer;
CREATE TABLE tablename (
    colname integer NOT NULL DEFAULT nextval('tablename_colname_seq')
);
ALTER SEQUENCE tablename_colname_seq OWNED BY tablename.colname;
```

Thus, we have created an integer column and arranged for its default values to be assigned from a sequence generator. A `NOT NULL` constraint is applied to ensure that a null value cannot be inserted. (In most cases you would also want to attach a `UNIQUE` or `PRIMARY KEY` constraint to prevent duplicate values from being inserted by accident, but this is not automatic.) Lastly, the sequence is marked as “owned by” the column, so that it will be dropped if the column or table is dropped.

> **Note**
>
> Because `smallserial`, `serial` and `bigserial` are implemented using sequences, there may be "holes" or gaps in the sequence of values which appears in the column, even if no rows are ever deleted. A value allocated from the sequence is still "used up" even if a row containing that value is never successfully inserted into the table column. This may happen, for example, if the inserting transaction rolls back. See `nextval()` in Section 9.17 for details.

To insert the next value of the sequence into the `serial` column, specify that the `serial` column should be assigned its default value. This can be done either by excluding the column from the list of columns in the `INSERT` statement, or through the use of the `DEFAULT` key word.

The type names `serial` and `serial4` are equivalent: both create `integer` columns. The type names `bigserial` and `serial8` work the same way, except that they create a `bigint` column. `bigserial` should be used if you anticipate the use of more than 2^{31} identifiers over the lifetime of the table. The type names `smallserial` and `serial2` also work the same way, except that they create a `smallint` column.

The sequence created for a `serial` column is automatically dropped when the owning column is dropped. You can drop the sequence without dropping the column, but this will force removal of the column default expression.

8.2. Monetary Types

The `money` type stores a currency amount with a fixed fractional precision; see Table 8.3. The fractional precision is determined by the database's lc_monetary setting. The range shown in the table assumes there are two fractional digits. Input is accepted in a variety of formats, including integer and floating-point literals, as well as typical currency formatting, such as `'$1,000.00'`. Output is generally in the latter form but depends on the locale.

Table 8.3. Monetary Types

Name	Storage Size	Description	Range
`money`	8 bytes	currency amount	-92233720368547758.08 to +92233720368547758.07

Since the output of this data type is locale-sensitive, it might not work to load `money` data into a database that has a different setting of `lc_monetary`. To avoid problems, before restoring a dump into a new database make sure `lc_monetary` has the same or equivalent value as in the database that was dumped.

Values of the `numeric`, `int`, and `bigint` data types can be cast to `money`. Conversion from the `real` and `double precision` data types can be done by casting to `numeric` first, for example:

```
SELECT '12.34'::float8::numeric::money;
```

However, this is not recommended. Floating point numbers should not be used to handle money due to the potential for rounding errors.

A `money` value can be cast to `numeric` without loss of precision. Conversion to other types could potentially lose precision, and must also be done in two stages:

```
SELECT '52093.89'::money::numeric::float8;
```

Division of a `money` value by an integer value is performed with truncation of the fractional part towards zero. To get a rounded result, divide by a floating-point value, or cast the `money` value to `numeric` before dividing and back to `money` afterwards. (The latter is preferable to avoid risking precision loss.) When a `money` value is divided by another `money` value, the result is `double precision` (i.e., a pure number, not money); the currency units cancel each other out in the division.

8.3. Character Types

Table 8.4. Character Types

Name	Description
`character varying( n), varchar( n)`	variable-length with limit
`character( n), char( n)`	fixed-length, blank padded
`text`	variable unlimited length

Table 8.4 shows the general-purpose character types available in Postgres Pro.

SQL defines two primary character types: `character varying(n)` and `character(n)`, where *n* is a positive integer. Both of these types can store strings up to *n* characters (not bytes) in length. An attempt to store a longer string into a column of these types will result in an error, unless the excess characters are all spaces, in which case the string will be truncated to the maximum length. (This somewhat bizarre exception is required by the SQL standard.) If the string to be stored is shorter than the declared length, values of type `character` will be space-padded; values of type `character varying` will simply store the shorter string.

If one explicitly casts a value to `character varying(n)` or `character(n)`, then an over-length value will be truncated to *n* characters without raising an error. (This too is required by the SQL standard.)

The notations `varchar(n)` and `char(n)` are aliases for `character varying(n)` and `character(n)`, respectively. If specified, the length must be greater than zero and cannot exceed 10485760. `character` without length specifier is equivalent to `character(1)`. If `character varying` is used without length specifier, the type accepts strings of any size. The latter is a Postgres Pro extension.

In addition, Postgres Pro provides the `text` type, which stores strings of any length. Although the type `text` is not in the SQL standard, several other SQL database management systems have it as well.

Values of type `character` are physically padded with spaces to the specified width *n*, and are stored and displayed that way. However, trailing spaces are treated as semantically insignificant and disregarded when comparing two values of type `character`. In collations where whitespace is significant, this behavior can produce unexpected results; for example `SELECT 'a '::CHAR(2) collate "C" < E'a \n'::CHAR(2)` returns true, even though `C` locale would consider a space to be greater than a newline. Trailing spaces are removed when converting a `character` value to one of the other string types. Note that trailing spaces *are* semantically significant in `character varying` and `text` values, and when using pattern matching, that is `LIKE` and regular expressions.

The characters that can be stored in any of these data types are determined by the database character set, which is selected when the database is created. Regardless of the specific character set, the character with code zero (sometimes called NUL) cannot be stored. For more information refer to Section 23.3.

The storage requirement for a short string (up to 126 bytes) is 1 byte plus the actual string, which includes the space padding in the case of `character`. Longer strings have 4 bytes of overhead instead of 1. Long strings are compressed by the system automatically, so the physical requirement on disk might be less. Very long values are also stored in background tables so that they do not interfere with rapid access to shorter column values. In any case, the longest possible character string that can be stored is about 1 GB. (The maximum value that will be allowed for *n* in the data type declaration is less than that. It wouldn't be useful to change this because with multibyte character encodings the number of characters and bytes can be quite different. If you desire to store long strings with no specific upper limit, use `text` or `character varying` without a length specifier, rather than making up an arbitrary length limit.)

> **Tip**
>
> There is no performance difference among these three types, apart from increased storage space when using the blank-padded type, and a few extra CPU cycles to check the length when storing into a length-constrained column. While `character(n)` has performance advantages in some other database systems, there is no such advantage in Postgres Pro; in fact `character(n)` is usually the slowest of the three because of its additional storage costs. In most situations `text` or `character varying` should be used instead.

Refer to Section 4.1.2.1 for information about the syntax of string literals, and to Chapter 9 for information about available operators and functions.

Example 8.1. Using the Character Types

```
CREATE TABLE test1 (a character(4));
INSERT INTO test1 VALUES ('ok');
```

```
SELECT a, char_length(a) FROM test1; -- 1

  a   | char_length
------+-------------
 ok   |           2


CREATE TABLE test2 (b varchar(5));
INSERT INTO test2 VALUES ('ok');
INSERT INTO test2 VALUES ('good      ');
INSERT INTO test2 VALUES ('too long');
ERROR:  value too long for type character varying(5)
INSERT INTO test2 VALUES ('too long'::varchar(5)); -- explicit truncation
SELECT b, char_length(b) FROM test2;

   b   | char_length
-------+-------------
 ok    |           2
 good  |           5
 too l |           5
```

1 The `char_length` function is discussed in Section 9.4.

There are two other fixed-length character types in Postgres Pro, shown in Table 8.5. The `name` type exists *only* for the storage of identifiers in the internal system catalogs and is not intended for use by the general user. Its length is currently defined as 64 bytes (63 usable characters plus terminator) but should be referenced using the constant `NAMEDATALEN` in `C` source code. The length is set at compile time (and is therefore adjustable for special uses); the default maximum length might change in a future release. The type `"char"` (note the quotes) is different from `char(1)` in that it only uses one byte of storage. It is internally used in the system catalogs as a simplistic enumeration type.

Table 8.5. Special Character Types

Name	Storage Size	Description
`"char"`	1 byte	single-byte internal type
`name`	64 bytes	internal type for object names

8.4. Binary Data Types

The `bytea` data type allows storage of binary strings; see Table 8.6.

Table 8.6. Binary Data Types

Name	Storage Size	Description
`bytea`	1 or 4 bytes plus the actual binary string	variable-length binary string

A binary string is a sequence of octets (or bytes). Binary strings are distinguished from character strings in two ways. First, binary strings specifically allow storing octets of value zero and other “non-printable” octets (usually, octets outside the decimal range 32 to 126). Character strings disallow zero octets, and also disallow any other octet values and sequences of octet values that are invalid according to the database's selected character set encoding. Second, operations on binary strings process the actual bytes, whereas the processing of character strings depends on locale settings. In short, binary strings are appropriate for storing data that the programmer thinks of as “raw bytes”, whereas character strings are appropriate for storing text.

The `bytea` type supports two formats for input and output: “hex” format and PostgreSQL's historical “escape” format. Both of these are always accepted on input. The output format depends on the config-

uration parameter bytea_output; the default is hex. (Note that the hex format was introduced in PostgreSQL 9.0; earlier versions and some tools don't understand it.)

The SQL standard defines a different binary string type, called `BLOB` or `BINARY LARGE OBJECT`. The input format is different from `bytea`, but the provided functions and operators are mostly the same.

8.4.1. `bytea` Hex Format

The "hex" format encodes binary data as 2 hexadecimal digits per byte, most significant nibble first. The entire string is preceded by the sequence `\x` (to distinguish it from the escape format). In some contexts, the initial backslash may need to be escaped by doubling it (see Section 4.1.2.1). For input, the hexadecimal digits can be either upper or lower case, and whitespace is permitted between digit pairs (but not within a digit pair nor in the starting `\x` sequence). The hex format is compatible with a wide range of external applications and protocols, and it tends to be faster to convert than the escape format, so its use is preferred.

Example:

```
SET bytea_output = 'hex';

SELECT '\xDEADBEEF'::bytea;
   bytea
------------
 \xdeadbeef
```

8.4.2. `bytea` Escape Format

The "escape" format is the traditional Postgres Pro format for the `bytea` type. It takes the approach of representing a binary string as a sequence of ASCII characters, while converting those bytes that cannot be represented as an ASCII character into special escape sequences. If, from the point of view of the application, representing bytes as characters makes sense, then this representation can be convenient. But in practice it is usually confusing because it fuzzes up the distinction between binary strings and character strings, and also the particular escape mechanism that was chosen is somewhat unwieldy. Therefore, this format should probably be avoided for most new applications.

When entering `bytea` values in escape format, octets of certain values *must* be escaped, while all octet values *can* be escaped. In general, to escape an octet, convert it into its three-digit octal value and precede it by a backslash. Backslash itself (octet decimal value 92) can alternatively be represented by double backslashes. Table 8.7 shows the characters that must be escaped, and gives the alternative escape sequences where applicable.

Table 8.7. `bytea` Literal Escaped Octets

Decimal Octet Value	Description	Escaped Input Representation	Example	Hex Representation
0	zero octet	`'\000'`	`'\000'::bytea`	`\x00`
39	single quote	`''''` or `'\047'`	`''''::bytea`	`\x27`
92	backslash	`'\\'` or `'\134'`	`'\\'::bytea`	`\x5c`
0 to 31 and 127 to 255	"non-printable" octets	`'\`*xxx*`'` (octal value)	`'\001'::bytea`	`\x01`

The requirement to escape *non-printable* octets varies depending on locale settings. In some instances you can get away with leaving them unescaped.

The reason that single quotes must be doubled, as shown in Table 8.7, is that this is true for any string literal in an SQL command. The generic string-literal parser consumes the outermost single quotes and reduces any pair of single quotes to one data character. What the `bytea` input function sees is just one single quote, which it treats as a plain data character. However, the `bytea` input function treats backslashes as special, and the other behaviors shown in Table 8.7 are implemented by that function.

In some contexts, backslashes must be doubled compared to what is shown above, because the generic string-literal parser will also reduce pairs of backslashes to one data character; see Section 4.1.2.1.

`Bytea` octets are output in `hex` format by default. If you change bytea_output to `escape`, "non-printable" octets are converted to their equivalent three-digit octal value and preceded by one backslash. Most "printable" octets are output by their standard representation in the client character set, e.g.:

```
SET bytea_output = 'escape';

SELECT 'abc \153\154\155 \052\251\124'::bytea;
     bytea
----------------
 abc klm *\251T
```

The octet with decimal value 92 (backslash) is doubled in the output. Details are in Table 8.8.

Table 8.8. `bytea` Output Escaped Octets

Decimal Octet Value	Description	Escaped Output Representation	Example	Output Result
92	backslash	`\\`	`'\134'::bytea`	`\\`
0 to 31 and 127 to 255	"non-printable" octets	`\`*xxx* (octal value)	`'\001'::bytea`	`\001`
32 to 126	"printable" octets	client character set representation	`'\176'::bytea`	~

Depending on the front end to Postgres Pro you use, you might have additional work to do in terms of escaping and unescaping `bytea` strings. For example, you might also have to escape line feeds and carriage returns if your interface automatically translates these.

8.5. Date/Time Types

Postgres Pro supports the full set of SQL date and time types, shown in Table 8.9. The operations available on these data types are described in Section 9.9. Dates are counted according to the Gregorian calendar, even in years before that calendar was introduced (see Section B.6 for more information).

Table 8.9. Date/Time Types

Name	Storage Size	Description	Low Value	High Value	Resolution
`timestamp [ (`*p*`) ] [ without time zone ]`	8 bytes	both date and time (no time zone)	4713 BC	294276 AD	1 microsecond
`timestamp [ (`*p*`) ] with time zone`	8 bytes	both date and time, with time zone	4713 BC	294276 AD	1 microsecond
`date`	4 bytes	date (no time of day)	4713 BC	5874897 AD	1 day
`time [ (`*p*`) ] [ without time zone ]`	8 bytes	time of day (no date)	00:00:00	24:00:00	1 microsecond
`time [ (`*p*`) ] with time zone`	12 bytes	time of day (no date), with time zone	00:00:00+1559	24:00:00-1559	1 microsecond
`interval [`*fields*`] [ (`*p*`) ]`	16 bytes	time interval	-178000000 years	178000000 years	1 microsecond

> **Note**
>
> The SQL standard requires that writing just `timestamp` be equivalent to `timestamp without time zone`, and Postgres Pro honors that behavior. `timestamptz` is accepted as an abbreviation for `timestamp with time zone`; this is a Postgres Pro extension.

`time`, `timestamp`, and `interval` accept an optional precision value *p* which specifies the number of fractional digits retained in the seconds field. By default, there is no explicit bound on precision. The allowed range of *p* is from 0 to 6.

The `interval` type has an additional option, which is to restrict the set of stored fields by writing one of these phrases:

```
YEAR
MONTH
DAY
HOUR
MINUTE
SECOND
YEAR TO MONTH
DAY TO HOUR
DAY TO MINUTE
DAY TO SECOND
HOUR TO MINUTE
HOUR TO SECOND
MINUTE TO SECOND
```

Note that if both *fields* and *p* are specified, the *fields* must include `SECOND`, since the precision applies only to the seconds.

The type `time with time zone` is defined by the SQL standard, but the definition exhibits properties which lead to questionable usefulness. In most cases, a combination of `date`, `time`, `timestamp without time zone`, and `timestamp with time zone` should provide a complete range of date/time functionality required by any application.

8.5.1. Date/Time Input

Date and time input is accepted in almost any reasonable format, including ISO 8601, SQL-compatible, traditional POSTGRES, and others. For some formats, ordering of day, month, and year in date input is ambiguous and there is support for specifying the expected ordering of these fields. Set the DateStyle parameter to `MDY` to select month-day-year interpretation, `DMY` to select day-month-year interpretation, or `YMD` to select year-month-day interpretation.

Postgres Pro is more flexible in handling date/time input than the SQL standard requires. See Appendix B for the exact parsing rules of date/time input and for the recognized text fields including months, days of the week, and time zones.

Remember that any date or time literal input needs to be enclosed in single quotes, like text strings. Refer to Section 4.1.2.7 for more information. SQL requires the following syntax

```
type [ (p) ] 'value'
```

where *p* is an optional precision specification giving the number of fractional digits in the seconds field. Precision can be specified for `time`, `timestamp`, and `interval` types, and can range from 0 to 6. If no precision is specified in a constant specification, it defaults to the precision of the literal value (but not more than 6 digits).

8.5.1.1. Dates

Table 8.10 shows some possible inputs for the `date` type.

Table 8.10. Date Input

Example	Description
1999-01-08	ISO 8601; January 8 in any mode (recommended format)
January 8, 1999	unambiguous in any `datestyle` input mode
1/8/1999	January 8 in `MDY` mode; August 1 in `DMY` mode
1/18/1999	January 18 in `MDY` mode; rejected in other modes
01/02/03	January 2, 2003 in `MDY` mode; February 1, 2003 in `DMY` mode; February 3, 2001 in `YMD` mode
1999-Jan-08	January 8 in any mode
Jan-08-1999	January 8 in any mode
08-Jan-1999	January 8 in any mode
99-Jan-08	January 8 in `YMD` mode, else error
08-Jan-99	January 8, except error in `YMD` mode
Jan-08-99	January 8, except error in `YMD` mode
19990108	ISO 8601; January 8, 1999 in any mode
990108	ISO 8601; January 8, 1999 in any mode
1999.008	year and day of year
J2451187	Julian date
January 8, 99 BC	year 99 BC

8.5.1.2. Times

The time-of-day types are `time [ (p) ] without time zone` and `time [ (p) ] with time zone`. `time` alone is equivalent to `time without time zone`.

Valid input for these types consists of a time of day followed by an optional time zone. (See Table 8.11 and Table 8.12.) If a time zone is specified in the input for `time without time zone`, it is silently ignored. You can also specify a date but it will be ignored, except when you use a time zone name that involves a daylight-savings rule, such as `America/New_York`. In this case specifying the date is required in order to determine whether standard or daylight-savings time applies. The appropriate time zone offset is recorded in the `time with time zone` value and is output as stored; it is not adjusted to the active time zone.

Table 8.11. Time Input

Example	Description
`04:05:06.789`	ISO 8601
`04:05:06`	ISO 8601
`04:05`	ISO 8601
`040506`	ISO 8601
`04:05 AM`	same as 04:05; AM does not affect value
`04:05 PM`	same as 16:05; input hour must be <= 12
`04:05:06.789-8`	ISO 8601, with time zone as UTC offset
`04:05:06-08:00`	ISO 8601, with time zone as UTC offset
`04:05-08:00`	ISO 8601, with time zone as UTC offset

Example	Description
040506-08	ISO 8601, with time zone as UTC offset
040506+0730	ISO 8601, with fractional-hour time zone as UTC offset
040506+07:30:00	UTC offset specified to seconds (not allowed in ISO 8601)
04:05:06 PST	time zone specified by abbreviation
2003-04-12 04:05:06 America/New_York	time zone specified by full name

Table 8.12. Time Zone Input

Example	Description
PST	Abbreviation (for Pacific Standard Time)
America/New_York	Full time zone name
PST8PDT	POSIX-style time zone specification
-8:00:00	UTC offset for PST
-8:00	UTC offset for PST (ISO 8601 extended format)
-800	UTC offset for PST (ISO 8601 basic format)
-8	UTC offset for PST (ISO 8601 basic format)
zulu	Military abbreviation for UTC
z	Short form of zulu (also in ISO 8601)

Refer to Section 8.5.3 for more information on how to specify time zones.

8.5.1.3. Time Stamps

Valid input for the time stamp types consists of the concatenation of a date and a time, followed by an optional time zone, followed by an optional AD or BC. (Alternatively, AD/BC can appear before the time zone, but this is not the preferred ordering.) Thus:

```
1999-01-08 04:05:06
```

and:

```
1999-01-08 04:05:06 -8:00
```

are valid values, which follow the ISO 8601 standard. In addition, the common format:

```
January 8 04:05:06 1999 PST
```

is supported.

The SQL standard differentiates `timestamp without time zone` and `timestamp with time zone` literals by the presence of a "+" or "-" symbol and time zone offset after the time. Hence, according to the standard,

```
TIMESTAMP '2004-10-19 10:23:54'
```

is a `timestamp without time zone`, while

```
TIMESTAMP '2004-10-19 10:23:54+02'
```

is a `timestamp with time zone`. Postgres Pro never examines the content of a literal string before determining its type, and therefore will treat both of the above as `timestamp without time zone`. To ensure that a literal is treated as `timestamp with time zone`, give it the correct explicit type:

```
TIMESTAMP WITH TIME ZONE '2004-10-19 10:23:54+02'
```

In a value that has been determined to be `timestamp without time zone`, Postgres Pro will silently ignore any time zone indication. That is, the resulting value is derived from the date/time fields in the input string, and is not adjusted for time zone.

For `timestamp with time zone` values, an input string that includes an explicit time zone will be converted to UTC (*Universal Coordinated Time*) using the appropriate offset for that time zone. If no time zone is stated in the input string, then it is assumed to be in the time zone indicated by the system's TimeZone parameter, and is converted to UTC using the offset for the `timezone` zone. In either case, the value is stored internally as UTC, and the originally stated or assumed time zone is not retained.

When a `timestamp with time zone` value is output, it is always converted from UTC to the current `timezone` zone, and displayed as local time in that zone. To see the time in another time zone, either change `timezone` or use the `AT TIME ZONE` construct (see Section 9.9.4).

Conversions between `timestamp without time zone` and `timestamp with time zone` normally assume that the `timestamp without time zone` value should be taken or given as `timezone` local time. A different time zone can be specified for the conversion using `AT TIME ZONE`.

8.5.1.4. Special Values

Postgres Pro supports several special date/time input values for convenience, as shown in Table 8.13. The values `infinity` and `-infinity` are specially represented inside the system and will be displayed unchanged; but the others are simply notational shorthands that will be converted to ordinary date/time values when read. (In particular, `now` and related strings are converted to a specific time value as soon as they are read.) All of these values need to be enclosed in single quotes when used as constants in SQL commands.

Table 8.13. Special Date/Time Inputs

Input String	Valid Types	Description
`epoch`	`date`, `timestamp`	1970-01-01 00:00:00+00 (Unix system time zero)
`infinity`	`date`, `timestamp`	later than all other time stamps
`-infinity`	`date`, `timestamp`	earlier than all other time stamps
`now`	`date`, `time`, `timestamp`	current transaction's start time
`today`	`date`, `timestamp`	midnight (`00:00`) today
`tomorrow`	`date`, `timestamp`	midnight (`00:00`) tomorrow
`yesterday`	`date`, `timestamp`	midnight (`00:00`) yesterday
`allballs`	`time`	00:00:00.00 UTC

The following SQL-compatible functions can also be used to obtain the current time value for the corresponding data type: `CURRENT_DATE`, `CURRENT_TIME`, `CURRENT_TIMESTAMP`, `LOCALTIME`, `LOCALTIMESTAMP`. (See Section 9.9.5.) Note that these are SQL functions and are *not* recognized in data input strings.

> **Caution**
>
> While the input strings `now`, `today`, `tomorrow`, and `yesterday` are fine to use in interactive SQL commands, they can have surprising behavior when the command is saved to be executed later, for example in prepared statements, views, and function definitions. The string can be converted to a specific time value that continues to be used long after it becomes stale. Use one of the SQL functions instead in such contexts. For example, `CURRENT_DATE + 1` is safer than `'tomorrow'::date`.

8.5.2. Date/Time Output

The output format of the date/time types can be set to one of the four styles ISO 8601, SQL (Ingres), traditional POSTGRES (Unix date format), or German. The default is the ISO format. (The SQL standard requires the use of the ISO 8601 format. The name of the "SQL" output format is a historical accident.) Table 8.14 shows examples of each output style. The output of the `date` and `time` types is generally only the date or time part in accordance with the given examples. However, the POSTGRES style outputs date-only values in ISO format.

Table 8.14. Date/Time Output Styles

Style Specification	Description	Example
`ISO`	ISO 8601, SQL standard	`1997-12-17 07:37:16-08`
`SQL`	traditional style	`12/17/1997 07:37:16.00 PST`
`Postgres`	original style	`Wed Dec 17 07:37:16 1997 PST`
`German`	regional style	`17.12.1997 07:37:16.00 PST`

> **Note**
>
> ISO 8601 specifies the use of uppercase letter `T` to separate the date and time. Postgres Pro accepts that format on input, but on output it uses a space rather than `T`, as shown above. This is for readability and for consistency with *RFC 3339* as well as some other database systems.

In the SQL and POSTGRES styles, day appears before month if DMY field ordering has been specified, otherwise month appears before day. (See Section 8.5.1 for how this setting also affects interpretation of input values.) Table 8.15 shows examples.

Table 8.15. Date Order Conventions

`datestyle` Setting	Input Ordering	Example Output
`SQL, DMY`	*day*/*month*/*year*	`17/12/1997 15:37:16.00 CET`
`SQL, MDY`	*month*/*day*/*year*	`12/17/1997 07:37:16.00 PST`
`Postgres, DMY`	*day*/*month*/*year*	`Wed 17 Dec 07:37:16 1997 PST`

In the ISO style, the time zone is always shown as a signed numeric offset from UTC, with positive sign used for zones east of Greenwich. The offset will be shown as *hh* (hours only) if it is an integral number of hours, else as *hh*:*mm* if it is an integral number of minutes, else as *hh*:*mm*:*ss*. (The third case is not possible with any modern time zone standard, but it can appear when working with timestamps that predate the adoption of standardized time zones.) In the other date styles, the time zone is shown as an alphabetic abbreviation if one is in common use in the current zone. Otherwise it appears as a signed numeric offset in ISO 8601 basic format (*hh* or *hhmm*).

The date/time style can be selected by the user using the `SET datestyle` command, the DateStyle parameter in the `postgresql.conf` configuration file, or the `PGDATESTYLE` environment variable on the server or client.

The formatting function `to_char` (see Section 9.8) is also available as a more flexible way to format date/time output.

8.5.3. Time Zones

Time zones, and time-zone conventions, are influenced by political decisions, not just earth geometry. Time zones around the world became somewhat standardized during the 1900s, but continue to be prone to arbitrary changes, particularly with respect to daylight-savings rules. Postgres Pro uses the widely-used IANA (Olson) time zone database for information about historical time zone rules. For times in the future, the assumption is that the latest known rules for a given time zone will continue to be observed indefinitely far into the future.

Postgres Pro endeavors to be compatible with the SQL standard definitions for typical usage. However, the SQL standard has an odd mix of date and time types and capabilities. Two obvious problems are:

- Although the `date` type cannot have an associated time zone, the `time` type can. Time zones in the real world have little meaning unless associated with a date as well as a time, since the offset can vary through the year with daylight-saving time boundaries.
- The default time zone is specified as a constant numeric offset from UTC. It is therefore impossible to adapt to daylight-saving time when doing date/time arithmetic across DST boundaries.

To address these difficulties, we recommend using date/time types that contain both date and time when using time zones. We do *not* recommend using the type `time with time zone` (though it is supported by Postgres Pro for legacy applications and for compliance with the SQL standard). Postgres Pro assumes your local time zone for any type containing only date or time.

All timezone-aware dates and times are stored internally in UTC. They are converted to local time in the zone specified by the TimeZone configuration parameter before being displayed to the client.

Postgres Pro allows you to specify time zones in three different forms:

- A full time zone name, for example `America/New_York`. The recognized time zone names are listed in the `pg_timezone_names` view (see Section 54.97). Postgres Pro uses the widely-used IANA time zone data for this purpose, so the same time zone names are also recognized by other software.
- A time zone abbreviation, for example `PST`. Such a specification merely defines a particular offset from UTC, in contrast to full time zone names which can imply a set of daylight savings transition rules as well. The recognized abbreviations are listed in the `pg_timezone_abbrevs` view (see Section 54.96). You cannot set the configuration parameters TimeZone or log_timezone to a time zone abbreviation, but you can use abbreviations in date/time input values and with the `AT TIME ZONE` operator.
- In addition to the timezone names and abbreviations, Postgres Pro will accept POSIX-style time zone specifications, as described in Section B.5. This option is not normally preferable to using a named time zone, but it may be necessary if no suitable IANA time zone entry is available.

In short, this is the difference between abbreviations and full names: abbreviations represent a specific offset from UTC, whereas many of the full names imply a local daylight-savings time rule, and so have two possible UTC offsets. As an example, `2014-06-04 12:00 America/New_York` represents noon local time in New York, which for this particular date was Eastern Daylight Time (UTC-4). So `2014-06-04 12:00 EDT` specifies that same time instant. But `2014-06-04 12:00 EST` specifies noon Eastern Standard Time (UTC-5), regardless of whether daylight savings was nominally in effect on that date.

To complicate matters, some jurisdictions have used the same timezone abbreviation to mean different UTC offsets at different times; for example, in Moscow `MSK` has meant UTC+3 in some years and UTC+4 in others. Postgres Pro interprets such abbreviations according to whatever they meant (or had most recently meant) on the specified date; but, as with the `EST` example above, this is not necessarily the same as local civil time on that date.

In all cases, timezone names and abbreviations are recognized case-insensitively. (This is a change from PostgreSQL versions prior to 8.2, which were case-sensitive in some contexts but not others.)

Neither timezone names nor abbreviations are hard-wired into the server; they are obtained from configuration files stored under `.../share/timezone/` and `.../share/timezonesets/` of the installation directory (see Section B.4).

The TimeZone configuration parameter can be set in the file `postgresql.conf`, or in any of the other standard ways described in Chapter 19. There are also some special ways to set it:

- The SQL command `SET TIME ZONE` sets the time zone for the session. This is an alternative spelling of `SET TIMEZONE TO` with a more SQL-spec-compatible syntax.
- The `PGTZ` environment variable is used by libpq clients to send a `SET TIME ZONE` command to the server upon connection.

8.5.4. Interval Input

`interval` values can be written using the following verbose syntax:

```
[@] quantity unit [quantity unit...] [direction]
```

where *quantity* is a number (possibly signed); *unit* is `microsecond`, `millisecond`, `second`, `minute`, `hour`, `day`, `week`, `month`, `year`, `decade`, `century`, `millennium`, or abbreviations or plurals of these units; *direction* can be `ago` or empty. The at sign (`@`) is optional noise. The amounts of the different units are implicitly added with appropriate sign accounting. `ago` negates all the fields. This syntax is also used for interval output, if IntervalStyle is set to `postgres_verbose`.

Quantities of days, hours, minutes, and seconds can be specified without explicit unit markings. For example, `'1 12:59:10'` is read the same as `'1 day 12 hours 59 min 10 sec'`. Also, a combination of years and months can be specified with a dash; for example `'200-10'` is read the same as `'200 years 10 months'`. (These shorter forms are in fact the only ones allowed by the SQL standard, and are used for output when `IntervalStyle` is set to `sql_standard`.)

Interval values can also be written as ISO 8601 time intervals, using either the “format with designators” of the standard's section 4.4.3.2 or the “alternative format” of section 4.4.3.3. The format with designators looks like this:

```
P quantity unit [ quantity unit ...] [ T [ quantity unit ...]]
```

The string must start with a `P`, and may include a `T` that introduces the time-of-day units. The available unit abbreviations are given in Table 8.16. Units may be omitted, and may be specified in any order, but units smaller than a day must appear after `T`. In particular, the meaning of `M` depends on whether it is before or after `T`.

Table 8.16. ISO 8601 Interval Unit Abbreviations

Abbreviation	Meaning
Y	Years
M	Months (in the date part)
W	Weeks
D	Days
H	Hours
M	Minutes (in the time part)
S	Seconds

In the alternative format:

```
P [ years-months-days ] [ T hours:minutes:seconds ]
```

the string must begin with `P`, and a `T` separates the date and time parts of the interval. The values are given as numbers similar to ISO 8601 dates.

When writing an interval constant with a *fields* specification, or when assigning a string to an interval column that was defined with a *fields* specification, the interpretation of unmarked quantities depends on the *fields*. For example `INTERVAL '1' YEAR` is read as 1 year, whereas `INTERVAL '1'` means 1 second. Also, field values “to the right” of the least significant field allowed by the *fields* specification are silently discarded. For example, writing `INTERVAL '1 day 2:03:04' HOUR TO MINUTE` results in dropping the seconds field, but not the day field.

According to the SQL standard all fields of an interval value must have the same sign, so a leading negative sign applies to all fields; for example the negative sign in the interval literal `'-1 2:03:04'` applies to both the days and hour/minute/second parts. Postgres Pro allows the fields to have different signs, and traditionally treats each field in the textual representation as independently signed, so that the hour/minute/second part is considered positive in this example. If `IntervalStyle` is set to `sql_standard`

then a leading sign is considered to apply to all fields (but only if no additional signs appear). Otherwise the traditional Postgres Pro interpretation is used. To avoid ambiguity, it's recommended to attach an explicit sign to each field if any field is negative.

Internally, `interval` values are stored as three integral fields: months, days, and microseconds. These fields are kept separate because the number of days in a month varies, while a day can have 23 or 25 hours if a daylight savings time transition is involved. An interval input string that uses other units is normalized into this format, and then reconstructed in a standardized way for output, for example:

```
SELECT '2 years 15 months 100 weeks 99 hours 123456789 milliseconds'::interval;
               interval
----------------------------------------
 3 years 3 mons 700 days 133:17:36.789
```

Here weeks, which are understood as “7 days”, have been kept separate, while the smaller and larger time units were combined and normalized.

Input field values can have fractional parts, for example `'1.5 weeks'` or `'01:02:03.45'`. However, because `interval` internally stores only integral fields, fractional values must be converted into smaller units. Fractional parts of units greater than months are truncated to be an integer number of months, e.g. `'1.5 years'` becomes `'1 year 6 mons'`. Fractional parts of weeks and days are computed to be an integer number of days and microseconds, assuming 30 days per month and 24 hours per day, e.g., `'1.75 months'` becomes `1 mon 22 days 12:00:00`. Only seconds will ever be shown as fractional on output.

Table 8.17 shows some examples of valid `interval` input.

Table 8.17. Interval Input

Example	Description
`1-2`	SQL standard format: 1 year 2 months
`3 4:05:06`	SQL standard format: 3 days 4 hours 5 minutes 6 seconds
`1 year 2 months 3 days 4 hours 5 minutes 6 seconds`	Traditional Postgres format: 1 year 2 months 3 days 4 hours 5 minutes 6 seconds
`P1Y2M3DT4H5M6S`	ISO 8601 “format with designators”: same meaning as above
`P0001-02-03T04:05:06`	ISO 8601 “alternative format”: same meaning as above

8.5.5. Interval Output

As previously explained, PostgreSQL stores `interval` values as months, days, and microseconds. For output, the months field is converted to years and months by dividing by 12. The days field is shown as-is. The microseconds field is converted to hours, minutes, seconds, and fractional seconds. Thus months, minutes, and seconds will never be shown as exceeding the ranges 0–11, 0–59, and 0–59 respectively, while the displayed years, days, and hours fields can be quite large. (The `justify_days` and `justify_hours` functions can be used if it is desirable to transpose large days or hours values into the next higher field.)

The output format of the interval type can be set to one of the four styles `sql_standard`, `postgres`, `postgres_verbose`, or `iso_8601`, using the command `SET intervalstyle`. The default is the `postgres` format. Table 8.18 shows examples of each output style.

The `sql_standard` style produces output that conforms to the SQL standard's specification for interval literal strings, if the interval value meets the standard's restrictions (either year-month only or day-time only, with no mixing of positive and negative components). Otherwise the output looks like a standard year-month literal string followed by a day-time literal string, with explicit signs added to disambiguate mixed-sign intervals.

The output of the `postgres` style matches the output of PostgreSQL releases prior to 8.4 when the DateStyle parameter was set to `ISO`.

The output of the `postgres_verbose` style matches the output of PostgreSQL releases prior to 8.4 when the `DateStyle` parameter was set to non-`ISO` output.

The output of the `iso_8601` style matches the “format with designators” described in section 4.4.3.2 of the ISO 8601 standard.

Table 8.18. Interval Output Style Examples

Style Specification	Year-Month Interval	Day-Time Interval	Mixed Interval
`sql_standard`	1-2	3 4:05:06	-1-2 +3 -4:05:06
`postgres`	1 year 2 mons	3 days 04:05:06	-1 year -2 mons +3 days -04:05:06
`postgres_verbose`	@ 1 year 2 mons	@ 3 days 4 hours 5 mins 6 secs	@ 1 year 2 mons -3 days 4 hours 5 mins 6 secs ago
`iso_8601`	P1Y2M	P3DT4H5M6S	P-1Y-2M3DT-4H-5M-6S

8.6. Boolean Type

Postgres Pro provides the standard SQL type `boolean`; see Table 8.19. The `boolean` type can have several states: “true”, “false”, and a third state, “unknown”, which is represented by the SQL null value.

Table 8.19. Boolean Data Type

Name	Storage Size	Description
`boolean`	1 byte	state of true or false

Boolean constants can be represented in SQL queries by the SQL key words `TRUE`, `FALSE`, and `NULL`.

The datatype input function for type `boolean` accepts these string representations for the “true” state:

```
true
yes
on
1
```

and these representations for the “false” state:

```
false
no
off
0
```

Unique prefixes of these strings are also accepted, for example `t` or `n`. Leading or trailing whitespace is ignored, and case does not matter.

The datatype output function for type `boolean` always emits either `t` or `f`, as shown in Example 8.2.

Example 8.2. Using the `boolean` Type

```
CREATE TABLE test1 (a boolean, b text);
INSERT INTO test1 VALUES (TRUE, 'sic est');
INSERT INTO test1 VALUES (FALSE, 'non est');
SELECT * FROM test1;
 a |    b
---+---------
 t | sic est
```

```
 f | non est

SELECT * FROM test1 WHERE a;
 a |    b
---+---------
 t | sic est
```

The key words `TRUE` and `FALSE` are the preferred (SQL-compliant) method for writing Boolean constants in SQL queries. But you can also use the string representations by following the generic string-literal constant syntax described in Section 4.1.2.7, for example `'yes'::boolean`.

Note that the parser automatically understands that `TRUE` and `FALSE` are of type `boolean`, but this is not so for `NULL` because that can have any type. So in some contexts you might have to cast `NULL` to `boolean` explicitly, for example `NULL::boolean`. Conversely, the cast can be omitted from a string-literal Boolean value in contexts where the parser can deduce that the literal must be of type `boolean`.

8.7. Enumerated Types

Enumerated (enum) types are data types that comprise a static, ordered set of values. They are equivalent to the `enum` types supported in a number of programming languages. An example of an enum type might be the days of the week, or a set of status values for a piece of data.

8.7.1. Declaration of Enumerated Types

Enum types are created using the CREATE TYPE command, for example:

```
CREATE TYPE mood AS ENUM ('sad', 'ok', 'happy');
```

Once created, the enum type can be used in table and function definitions much like any other type:

```
CREATE TYPE mood AS ENUM ('sad', 'ok', 'happy');
CREATE TABLE person (
    name text,
    current_mood mood
);
INSERT INTO person VALUES ('Moe', 'happy');
SELECT * FROM person WHERE current_mood = 'happy';
 name | current_mood
------+--------------
 Moe  | happy
(1 row)
```

8.7.2. Ordering

The ordering of the values in an enum type is the order in which the values were listed when the type was created. All standard comparison operators and related aggregate functions are supported for enums. For example:

```
INSERT INTO person VALUES ('Larry', 'sad');
INSERT INTO person VALUES ('Curly', 'ok');
SELECT * FROM person WHERE current_mood > 'sad';
 name  | current_mood
-------+--------------
 Moe   | happy
 Curly | ok
(2 rows)

SELECT * FROM person WHERE current_mood > 'sad' ORDER BY current_mood;
 name  | current_mood
-------+--------------
 Curly | ok
```

```
 Moe   | happy
(2 rows)

SELECT name
FROM person
WHERE current_mood = (SELECT MIN(current_mood) FROM person);
 name
-------
 Larry
(1 row)
```

8.7.3. Type Safety

Each enumerated data type is separate and cannot be compared with other enumerated types. See this example:

```
CREATE TYPE happiness AS ENUM ('happy', 'very happy', 'ecstatic');
CREATE TABLE holidays (
    num_weeks integer,
    happiness happiness
);
INSERT INTO holidays(num_weeks,happiness) VALUES (4, 'happy');
INSERT INTO holidays(num_weeks,happiness) VALUES (6, 'very happy');
INSERT INTO holidays(num_weeks,happiness) VALUES (8, 'ecstatic');
INSERT INTO holidays(num_weeks,happiness) VALUES (2, 'sad');
ERROR:  invalid input value for enum happiness: "sad"
SELECT person.name, holidays.num_weeks FROM person, holidays
  WHERE person.current_mood = holidays.happiness;
ERROR:  operator does not exist: mood = happiness
```

If you really need to do something like that, you can either write a custom operator or add explicit casts to your query:

```
SELECT person.name, holidays.num_weeks FROM person, holidays
  WHERE person.current_mood::text = holidays.happiness::text;
 name | num_weeks
------+-----------
 Moe  |         4
(1 row)
```

8.7.4. Implementation Details

Enum labels are case sensitive, so `'happy'` is not the same as `'HAPPY'`. White space in the labels is significant too.

Although enum types are primarily intended for static sets of values, there is support for adding new values to an existing enum type, and for renaming values (see ALTER TYPE). Existing values cannot be removed from an enum type, nor can the sort ordering of such values be changed, short of dropping and re-creating the enum type.

An enum value occupies four bytes on disk. The length of an enum value's textual label is limited by the `NAMEDATALEN` setting compiled into Postgres Pro; in standard builds this means at most 63 bytes.

The translations from internal enum values to textual labels are kept in the system catalog `pg_enum`. Querying this catalog directly can be useful.

8.8. Geometric Types

Geometric data types represent two-dimensional spatial objects. Table 8.20 shows the geometric types available in Postgres Pro.

Table 8.20. Geometric Types

Name	Storage Size	Description	Representation
`point`	16 bytes	Point on a plane	(x,y)
`line`	24 bytes	Infinite line	{A,B,C}
`lseg`	32 bytes	Finite line segment	((x1,y1),(x2,y2))
`box`	32 bytes	Rectangular box	((x1,y1),(x2,y2))
`path`	16+16n bytes	Closed path (similar to polygon)	((x1,y1),...)
`path`	16+16n bytes	Open path	[(x1,y1),...]
`polygon`	40+16n bytes	Polygon (similar to closed path)	((x1,y1),...)
`circle`	24 bytes	Circle	<(x,y),r> (center point and radius)

In all these types, the individual coordinates are stored as `double precision` (`float8`) numbers.

A rich set of functions and operators is available to perform various geometric operations such as scaling, translation, rotation, and determining intersections. They are explained in Section 9.11.

8.8.1. Points

Points are the fundamental two-dimensional building block for geometric types. Values of type `point` are specified using either of the following syntaxes:

```
( x , y )
  x , y
```

where *x* and *y* are the respective coordinates, as floating-point numbers.

Points are output using the first syntax.

8.8.2. Lines

Lines are represented by the linear equation $Ax + By + C = 0$, where *A* and *B* are not both zero. Values of type `line` are input and output in the following form:

```
{ A, B, C }
```

Alternatively, any of the following forms can be used for input:

```
[ ( x1 , y1 ) , ( x2 , y2 ) ]
( ( x1 , y1 ) , ( x2 , y2 ) )
  ( x1 , y1 ) , ( x2 , y2 )
    x1 , y1   ,   x2 , y2
```

where `(x1,y1)` and `(x2,y2)` are two different points on the line.

8.8.3. Line Segments

Line segments are represented by pairs of points that are the endpoints of the segment. Values of type `lseg` are specified using any of the following syntaxes:

```
[ ( x1 , y1 ) , ( x2 , y2 ) ]
( ( x1 , y1 ) , ( x2 , y2 ) )
  ( x1 , y1 ) , ( x2 , y2 )
    x1 , y1   ,   x2 , y2
```

where `(x1,y1)` and `(x2,y2)` are the end points of the line segment.

Line segments are output using the first syntax.

8.8.4. Boxes

Boxes are represented by pairs of points that are opposite corners of the box. Values of type `box` are specified using any of the following syntaxes:

```
( ( x1 , y1 ) , ( x2 , y2 ) )
  ( x1 , y1 ) , ( x2 , y2 )
    x1 , y1   ,   x2 , y2
```

where `(x1,y1)` and `(x2,y2)` are any two opposite corners of the box.

Boxes are output using the second syntax.

Any two opposite corners can be supplied on input, but the values will be reordered as needed to store the upper right and lower left corners, in that order.

8.8.5. Paths

Paths are represented by lists of connected points. Paths can be *open*, where the first and last points in the list are considered not connected, or *closed*, where the first and last points are considered connected.

Values of type `path` are specified using any of the following syntaxes:

```
[ ( x1 , y1 ) , ... , ( xn , yn ) ]
( ( x1 , y1 ) , ... , ( xn , yn ) )
  ( x1 , y1 ) , ... , ( xn , yn )
  ( x1 , y1   , ... ,   xn , yn )
    x1 , y1   , ... ,   xn , yn
```

where the points are the end points of the line segments comprising the path. Square brackets (`[]`) indicate an open path, while parentheses (`()`) indicate a closed path. When the outermost parentheses are omitted, as in the third through fifth syntaxes, a closed path is assumed.

Paths are output using the first or second syntax, as appropriate.

8.8.6. Polygons

Polygons are represented by lists of points (the vertexes of the polygon). Polygons are very similar to closed paths; the essential semantic difference is that a polygon is considered to include the area within it, while a path is not.

An important implementation difference between polygons and paths is that the stored representation of a polygon includes its smallest bounding box. This speeds up certain search operations, although computing the bounding box adds overhead while constructing new polygons.

Values of type `polygon` are specified using any of the following syntaxes:

```
( ( x1 , y1 ) , ... , ( xn , yn ) )
  ( x1 , y1 ) , ... , ( xn , yn )
  ( x1 , y1   , ... ,   xn , yn )
    x1 , y1   , ... ,   xn , yn
```

where the points are the end points of the line segments comprising the boundary of the polygon.

Polygons are output using the first syntax.

8.8.7. Circles

Circles are represented by a center point and radius. Values of type `circle` are specified using any of the following syntaxes:

```
< ( x , y ) , r >
( ( x , y ) , r )
  ( x , y ) , r
    x , y   , r
```

where `(x,y)` is the center point and `r` is the radius of the circle.

Circles are output using the first syntax.

8.9. Network Address Types

Postgres Pro offers data types to store IPv4, IPv6, and MAC addresses, as shown in Table 8.21. It is better to use these types instead of plain text types to store network addresses, because these types offer input error checking and specialized operators and functions (see Section 9.12).

Table 8.21. Network Address Types

Name	Storage Size	Description
`cidr`	7 or 19 bytes	IPv4 and IPv6 networks
`inet`	7 or 19 bytes	IPv4 and IPv6 hosts and networks
`macaddr`	6 bytes	MAC addresses
`macaddr8`	8 bytes	MAC addresses (EUI-64 format)

When sorting `inet` or `cidr` data types, IPv4 addresses will always sort before IPv6 addresses, including IPv4 addresses encapsulated or mapped to IPv6 addresses, such as ::10.2.3.4 or ::ffff:10.4.3.2.

8.9.1. `inet`

The `inet` type holds an IPv4 or IPv6 host address, and optionally its subnet, all in one field. The subnet is represented by the number of network address bits present in the host address (the “netmask”). If the netmask is 32 and the address is IPv4, then the value does not indicate a subnet, only a single host. In IPv6, the address length is 128 bits, so 128 bits specify a unique host address. Note that if you want to accept only networks, you should use the `cidr` type rather than `inet`.

The input format for this type is *`address/y`* where *`address`* is an IPv4 or IPv6 address and *`y`* is the number of bits in the netmask. If the *`/y`* portion is omitted, the netmask is taken to be 32 for IPv4 or 128 for IPv6, so the value represents just a single host. On display, the *`/y`* portion is suppressed if the netmask specifies a single host.

8.9.2. `cidr`

The `cidr` type holds an IPv4 or IPv6 network specification. Input and output formats follow Classless Internet Domain Routing conventions. The format for specifying networks is *`address/y`* where *`address`* is the network's lowest address represented as an IPv4 or IPv6 address, and *`y`* is the number of bits in the netmask. If *`y`* is omitted, it is calculated using assumptions from the older classful network numbering system, except it will be at least large enough to include all of the octets written in the input. It is an error to specify a network address that has bits set to the right of the specified netmask.

Table 8.22 shows some examples.

Table 8.22. `cidr` Type Input Examples

`cidr` Input	`cidr` Output	`abbrev( cidr)`
192.168.100.128/25	192.168.100.128/25	192.168.100.128/25
192.168/24	192.168.0.0/24	192.168.0/24
192.168/25	192.168.0.0/25	192.168.0.0/25
192.168.1	192.168.1.0/24	192.168.1/24
192.168	192.168.0.0/24	192.168.0/24
128.1	128.1.0.0/16	128.1/16
128	128.0.0.0/16	128.0/16

cidr Input	**cidr Output**	abbrev(cidr)
128.1.2	128.1.2.0/24	128.1.2/24
10.1.2	10.1.2.0/24	10.1.2/24
10.1	10.1.0.0/16	10.1/16
10	10.0.0.0/8	10/8
10.1.2.3/32	10.1.2.3/32	10.1.2.3/32
2001:4f8:3:ba::/64	2001:4f8:3:ba::/64	2001:4f8:3:ba/64
2001:4f8:3:ba:2e0:81f-f:fe22:d1f1/128	2001:4f8:3:ba:2e0:81f-f:fe22:d1f1/128	2001:4f8:3:ba:2e0:81f-f:fe22:d1f1/128
::ffff:1.2.3.0/120	::ffff:1.2.3.0/120	::ffff:1.2.3/120
::ffff:1.2.3.0/128	::ffff:1.2.3.0/128	::ffff:1.2.3.0/128

8.9.3. inet vs. cidr

The essential difference between `inet` and `cidr` data types is that `inet` accepts values with nonzero bits to the right of the netmask, whereas `cidr` does not. For example, `192.168.0.1/24` is valid for `inet` but not for `cidr`.

> **Tip**
>
> If you do not like the output format for `inet` or `cidr` values, try the functions `host`, `text`, and `abbrev`.

8.9.4. macaddr

The `macaddr` type stores MAC addresses, known for example from Ethernet card hardware addresses (although MAC addresses are used for other purposes as well). Input is accepted in the following formats:

```
'08:00:2b:01:02:03'
'08-00-2b-01-02-03'
'08002b:010203'
'08002b-010203'
'0800.2b01.0203'
'0800-2b01-0203'
'08002b010203'
```

These examples all specify the same address. Upper and lower case is accepted for the digits `a` through `f`. Output is always in the first of the forms shown.

IEEE Standard 802-2001 specifies the second form shown (with hyphens) as the canonical form for MAC addresses, and specifies the first form (with colons) as used with bit-reversed, MSB-first notation, so that 08-00-2b-01-02-03 = 10:00:D4:80:40:C0. This convention is widely ignored nowadays, and it is relevant only for obsolete network protocols (such as Token Ring). Postgres Pro makes no provisions for bit reversal; all accepted formats use the canonical LSB order.

The remaining five input formats are not part of any standard.

8.9.5. macaddr8

The `macaddr8` type stores MAC addresses in EUI-64 format, known for example from Ethernet card hardware addresses (although MAC addresses are used for other purposes as well). This type can accept both 6 and 8 byte length MAC addresses and stores them in 8 byte length format. MAC addresses given in 6 byte format will be stored in 8 byte length format with the 4th and 5th bytes set to FF and FE, respectively. Note that IPv6 uses a modified EUI-64 format where the 7th bit should be set to one after

the conversion from EUI-48. The function `macaddr8_set7bit` is provided to make this change. Generally speaking, any input which is comprised of pairs of hex digits (on byte boundaries), optionally separated consistently by one of `':'`, `'-'` or `'.'`, is accepted. The number of hex digits must be either 16 (8 bytes) or 12 (6 bytes). Leading and trailing whitespace is ignored. The following are examples of input formats that are accepted:

```
'08:00:2b:01:02:03:04:05'
'08-00-2b-01-02-03-04-05'
'08002b:0102030405'
'08002b-0102030405'
'0800.2b01.0203.0405'
'0800-2b01-0203-0405'
'08002b01:02030405'
'08002b0102030405'
```

These examples all specify the same address. Upper and lower case is accepted for the digits `a` through `f`. Output is always in the first of the forms shown.

The last six input formats shown above are not part of any standard.

To convert a traditional 48 bit MAC address in EUI-48 format to modified EUI-64 format to be included as the host portion of an IPv6 address, use `macaddr8_set7bit` as shown:

```
SELECT macaddr8_set7bit('08:00:2b:01:02:03');

    macaddr8_set7bit
-------------------------
 0a:00:2b:ff:fe:01:02:03
(1 row)
```

8.10. Bit String Types

Bit strings are strings of 1's and 0's. They can be used to store or visualize bit masks. There are two SQL bit types: `bit(n)` and `bit varying(n)`, where *n* is a positive integer.

`bit` type data must match the length *n* exactly; it is an error to attempt to store shorter or longer bit strings. `bit varying` data is of variable length up to the maximum length *n*; longer strings will be rejected. Writing `bit` without a length is equivalent to `bit(1)`, while `bit varying` without a length specification means unlimited length.

> **Note**
>
> If one explicitly casts a bit-string value to `bit(n)`, it will be truncated or zero-padded on the right to be exactly *n* bits, without raising an error. Similarly, if one explicitly casts a bit-string value to `bit varying(n)`, it will be truncated on the right if it is more than *n* bits.

Refer to Section 4.1.2.5 for information about the syntax of bit string constants. Bit-logical operators and string manipulation functions are available; see Section 9.6.

Example 8.3. Using the Bit String Types

```
CREATE TABLE test (a BIT(3), b BIT VARYING(5));
INSERT INTO test VALUES (B'101', B'00');
INSERT INTO test VALUES (B'10', B'101');

ERROR:  bit string length 2 does not match type bit(3)

INSERT INTO test VALUES (B'10'::bit(3), B'101');
```

```
SELECT * FROM test;

  a   |  b
------+-----
 101  | 00
 100  | 101
```

A bit string value requires 1 byte for each group of 8 bits, plus 5 or 8 bytes overhead depending on the length of the string (but long values may be compressed or moved out-of-line, as explained in Section 8.3 for character strings).

8.11. Text Search Types

Postgres Pro provides two data types that are designed to support full text search, which is the activity of searching through a collection of natural-language *documents* to locate those that best match a *query*. The `tsvector` type represents a document in a form optimized for text search; the `tsquery` type similarly represents a text query. Chapter 12 provides a detailed explanation of this facility, and Section 9.13 summarizes the related functions and operators.

8.11.1. `tsvector`

A `tsvector` value is a sorted list of distinct *lexemes*, which are words that have been *normalized* to merge different variants of the same word (see Chapter 12 for details). Sorting and duplicate-elimination are done automatically during input, as shown in this example:

```
SELECT 'a fat cat sat on a mat and ate a fat rat'::tsvector;
                      tsvector
----------------------------------------------------
 'a' 'and' 'ate' 'cat' 'fat' 'mat' 'on' 'rat' 'sat'
```

To represent lexemes containing whitespace or punctuation, surround them with quotes:

```
SELECT $$the lexeme '    ' contains spaces$$::tsvector;
                 tsvector
-------------------------------------------
 '    ' 'contains' 'lexeme' 'spaces' 'the'
```

(We use dollar-quoted string literals in this example and the next one to avoid the confusion of having to double quote marks within the literals.) Embedded quotes and backslashes must be doubled:

```
SELECT $$the lexeme 'Joe''s' contains a quote$$::tsvector;
                    tsvector
-----------------------------------------------
 'Joe''s' 'a' 'contains' 'lexeme' 'quote' 'the'
```

Optionally, integer *positions* can be attached to lexemes:

```
SELECT 'a:1 fat:2 cat:3 sat:4 on:5 a:6 mat:7 and:8 ate:9 a:10 fat:11 rat:12'::tsvector;
                                  tsvector
-------------------------------------------------------------------------------
 'a':1,6,10 'and':8 'ate':9 'cat':3 'fat':2,11 'mat':7 'on':5 'rat':12 'sat':4
```

A position normally indicates the source word's location in the document. Positional information can be used for *proximity ranking*. Position values can range from 1 to 16383; larger numbers are silently set to 16383. Duplicate positions for the same lexeme are discarded.

Lexemes that have positions can further be labeled with a *weight*, which can be `A`, `B`, `C`, or `D`. `D` is the default and hence is not shown on output:

```
SELECT 'a:1A fat:2B,4C cat:5D'::tsvector;
          tsvector
----------------------------
```

```
 'a':1A 'cat':5 'fat':2B,4C
```

Weights are typically used to reflect document structure, for example by marking title words differently from body words. Text search ranking functions can assign different priorities to the different weight markers.

It is important to understand that the `tsvector` type itself does not perform any word normalization; it assumes the words it is given are normalized appropriately for the application. For example,

```
SELECT 'The Fat Rats'::tsvector;
      tsvector
--------------------
 'Fat' 'Rats' 'The'
```

For most English-text-searching applications the above words would be considered non-normalized, but `tsvector` doesn't care. Raw document text should usually be passed through `to_tsvector` to normalize the words appropriately for searching:

```
SELECT to_tsvector('english', 'The Fat Rats');
   to_tsvector
-----------------
 'fat':2 'rat':3
```

Again, see Chapter 12 for more detail.

8.11.2. `tsquery`

A `tsquery` value stores lexemes that are to be searched for, and can combine them using the Boolean operators `&` (AND), `|` (OR), and `!` (NOT), as well as the phrase search operator `<->` (FOLLOWED BY). There is also a variant `<N>` of the FOLLOWED BY operator, where *N* is an integer constant that specifies the distance between the two lexemes being searched for. `<->` is equivalent to `<1>`.

Parentheses can be used to enforce grouping of these operators. In the absence of parentheses, `!` (NOT) binds most tightly, `<->` (FOLLOWED BY) next most tightly, then `&` (AND), with `|` (OR) binding the least tightly.

Here are some examples:

```
SELECT 'fat & rat'::tsquery;
    tsquery
---------------
 'fat' & 'rat'

SELECT 'fat & (rat | cat)'::tsquery;
          tsquery
---------------------------
 'fat' & ( 'rat' | 'cat' )

SELECT 'fat & rat & ! cat'::tsquery;
        tsquery
------------------------
 'fat' & 'rat' & !'cat'
```

Optionally, lexemes in a `tsquery` can be labeled with one or more weight letters, which restricts them to match only `tsvector` lexemes with one of those weights:

```
SELECT 'fat:ab & cat'::tsquery;
    tsquery
------------------
 'fat':AB & 'cat'
```

Also, lexemes in a `tsquery` can be labeled with `*` to specify prefix matching:

```
SELECT 'super:*'::tsquery;
  tsquery
-----------
 'super':*
```

This query will match any word in a `tsvector` that begins with “super”.

Quoting rules for lexemes are the same as described previously for lexemes in `tsvector`; and, as with `tsvector`, any required normalization of words must be done before converting to the `tsquery` type. The `to_tsquery` function is convenient for performing such normalization:

```
SELECT to_tsquery('Fat:ab & Cats');
    to_tsquery
------------------
 'fat':AB & 'cat'
```

Note that `to_tsquery` will process prefixes in the same way as other words, which means this comparison returns true:

```
SELECT to_tsvector( 'postgraduate' ) @@ to_tsquery( 'postgres:*' );
 ?column?
----------
 t
```

because `postgres` gets stemmed to `postgr`:

```
SELECT to_tsvector( 'postgraduate' ), to_tsquery( 'postgres:*' );
  to_tsvector  | to_tsquery
---------------+------------
 'postgradu':1 | 'postgr':*
```

which will match the stemmed form of `postgraduate`.

8.12. UUID Type

The data type `uuid` stores Universally Unique Identifiers (UUID) as defined by *RFC 4122*, ISO/IEC 9834-8:2005, and related standards. (Some systems refer to this data type as a globally unique identifier, or GUID, instead.) This identifier is a 128-bit quantity that is generated by an algorithm chosen to make it very unlikely that the same identifier will be generated by anyone else in the known universe using the same algorithm. Therefore, for distributed systems, these identifiers provide a better uniqueness guarantee than sequence generators, which are only unique within a single database.

A UUID is written as a sequence of lower-case hexadecimal digits, in several groups separated by hyphens, specifically a group of 8 digits followed by three groups of 4 digits followed by a group of 12 digits, for a total of 32 digits representing the 128 bits. An example of a UUID in this standard form is:

```
a0eebc99-9c0b-4ef8-bb6d-6bb9bd380a11
```

Postgres Pro also accepts the following alternative forms for input: use of upper-case digits, the standard format surrounded by braces, omitting some or all hyphens, adding a hyphen after any group of four digits. Examples are:

```
A0EEBC99-9C0B-4EF8-BB6D-6BB9BD380A11
{a0eebc99-9c0b-4ef8-bb6d-6bb9bd380a11}
a0eebc999c0b4ef8bb6d6bb9bd380a11
a0ee-bc99-9c0b-4ef8-bb6d-6bb9-bd38-0a11
{a0eebc99-9c0b4ef8-bb6d6bb9-bd380a11}
```

Output is always in the standard form.

See Section 9.14 for how to generate a UUID in PostgreSQL.

8.13. XML Type

The xml data type can be used to store XML data. Its advantage over storing XML data in a text field is that it checks the input values for well-formedness, and there are support functions to perform type-safe operations on it; see Section 9.15. Use of this data type requires the installation to have been built with configure --with-libxml.

The xml type can store well-formed "documents", as defined by the XML standard, as well as "content" fragments, which are defined by reference to the more permissive *"document node"* of the XQuery and XPath data model. Roughly, this means that content fragments can have more than one top-level element or character node. The expression *xmlvalue* IS DOCUMENT can be used to evaluate whether a particular xml value is a full document or only a content fragment.

Limits and compatibility notes for the xml data type can be found in Section D.3.

8.13.1. Creating XML Values

To produce a value of type xml from character data, use the function xmlparse:

```
XMLPARSE ( { DOCUMENT | CONTENT } value)
```

Examples:

```
XMLPARSE (DOCUMENT '<?xml version="1.0"?><book><title>Manual</title><chapter>...</
chapter></book>')
XMLPARSE (CONTENT 'abc<foo>bar</foo><bar>foo</bar>')
```

While this is the only way to convert character strings into XML values according to the SQL standard, the Postgres Pro-specific syntaxes:

```
xml '<foo>bar</foo>'
'<foo>bar</foo>'::xml
```

can also be used.

The xml type does not validate input values against a document type declaration (DTD), even when the input value specifies a DTD. There is also currently no built-in support for validating against other XML schema languages such as XML Schema.

The inverse operation, producing a character string value from xml, uses the function xmlserialize:

```
XMLSERIALIZE ( { DOCUMENT | CONTENT } value AS type )
```

type can be character, character varying, or text (or an alias for one of those). Again, according to the SQL standard, this is the only way to convert between type xml and character types, but Postgres Pro also allows you to simply cast the value.

When a character string value is cast to or from type xml without going through XMLPARSE or XMLSERIALIZE, respectively, the choice of DOCUMENT versus CONTENT is determined by the "XML option" session configuration parameter, which can be set using the standard command:

```
SET XML OPTION { DOCUMENT | CONTENT };
```

or the more Postgres Pro-like syntax

```
SET xmloption TO { DOCUMENT | CONTENT };
```

The default is CONTENT, so all forms of XML data are allowed.

8.13.2. Encoding Handling

Care must be taken when dealing with multiple character encodings on the client, server, and in the XML data passed through them. When using the text mode to pass queries to the server and query results to the client (which is the normal mode), Postgres Pro converts all character data passed between the client and the server and vice versa to the character encoding of the respective end; see Section 23.3. This includes string representations of XML values, such as in the above examples. This would ordinarily

mean that encoding declarations contained in XML data can become invalid as the character data is converted to other encodings while traveling between client and server, because the embedded encoding declaration is not changed. To cope with this behavior, encoding declarations contained in character strings presented for input to the `xml` type are *ignored*, and content is assumed to be in the current server encoding. Consequently, for correct processing, character strings of XML data must be sent from the client in the current client encoding. It is the responsibility of the client to either convert documents to the current client encoding before sending them to the server, or to adjust the client encoding appropriately. On output, values of type `xml` will not have an encoding declaration, and clients should assume all data is in the current client encoding.

When using binary mode to pass query parameters to the server and query results back to the client, no encoding conversion is performed, so the situation is different. In this case, an encoding declaration in the XML data will be observed, and if it is absent, the data will be assumed to be in UTF-8 (as required by the XML standard; note that Postgres Pro does not support UTF-16). On output, data will have an encoding declaration specifying the client encoding, unless the client encoding is UTF-8, in which case it will be omitted.

Needless to say, processing XML data with Postgres Pro will be less error-prone and more efficient if the XML data encoding, client encoding, and server encoding are the same. Since XML data is internally processed in UTF-8, computations will be most efficient if the server encoding is also UTF-8.

> **Caution**
>
> Some XML-related functions may not work at all on non-ASCII data when the server encoding is not UTF-8. This is known to be an issue for `xmltable()` and `xpath()` in particular.

8.13.3. Accessing XML Values

The `xml` data type is unusual in that it does not provide any comparison operators. This is because there is no well-defined and universally useful comparison algorithm for XML data. One consequence of this is that you cannot retrieve rows by comparing an `xml` column against a search value. XML values should therefore typically be accompanied by a separate key field such as an ID. An alternative solution for comparing XML values is to convert them to character strings first, but note that character string comparison has little to do with a useful XML comparison method.

Since there are no comparison operators for the `xml` data type, it is not possible to create an index directly on a column of this type. If speedy searches in XML data are desired, possible workarounds include casting the expression to a character string type and indexing that, or indexing an XPath expression. Of course, the actual query would have to be adjusted to search by the indexed expression.

The text-search functionality in Postgres Pro can also be used to speed up full-document searches of XML data. The necessary preprocessing support is, however, not yet available in the Postgres Pro distribution.

8.14. JSON Types

JSON data types are for storing JSON (JavaScript Object Notation) data, as specified in *RFC 7159*. Such data can also be stored as `text`, but the JSON data types have the advantage of enforcing that each stored value is valid according to the JSON rules. There are also assorted JSON-specific functions and operators available for data stored in these data types; see Section 9.16.

Postgres Pro offers two types for storing JSON data: `json` and `jsonb`. To implement efficient query mechanisms for these data types, Postgres Pro also provides the `jsonpath` data type described in Section 8.14.7.

The `json` and `jsonb` data types accept *almost* identical sets of values as input. The major practical difference is one of efficiency. The `json` data type stores an exact copy of the input text, which processing functions must reparse on each execution; while `jsonb` data is stored in a decomposed binary format that

makes it slightly slower to input due to added conversion overhead, but significantly faster to process, since no reparsing is needed. `jsonb` also supports indexing, which can be a significant advantage.

Because the `json` type stores an exact copy of the input text, it will preserve semantically-insignificant white space between tokens, as well as the order of keys within JSON objects. Also, if a JSON object within the value contains the same key more than once, all the key/value pairs are kept. (The processing functions consider the last value as the operative one.) By contrast, `jsonb` does not preserve white space, does not preserve the order of object keys, and does not keep duplicate object keys. If duplicate keys are specified in the input, only the last value is kept.

In general, most applications should prefer to store JSON data as `jsonb`, unless there are quite specialized needs, such as legacy assumptions about ordering of object keys.

RFC 7159 specifies that JSON strings should be encoded in UTF8. It is therefore not possible for the JSON types to conform rigidly to the JSON specification unless the database encoding is UTF8. Attempts to directly include characters that cannot be represented in the database encoding will fail; conversely, characters that can be represented in the database encoding but not in UTF8 will be allowed.

RFC 7159 permits JSON strings to contain Unicode escape sequences denoted by `\u`*XXXX*. In the input function for the `json` type, Unicode escapes are allowed regardless of the database encoding, and are checked only for syntactic correctness (that is, that four hex digits follow `\u`). However, the input function for `jsonb` is stricter: it disallows Unicode escapes for characters that cannot be represented in the database encoding. The `jsonb` type also rejects `\u0000` (because that cannot be represented in Postgres Pro's `text` type), and it insists that any use of Unicode surrogate pairs to designate characters outside the Unicode Basic Multilingual Plane be correct. Valid Unicode escapes are converted to the equivalent single character for storage; this includes folding surrogate pairs into a single character.

> **Note**
>
> Many of the JSON processing functions described in Section 9.16 will convert Unicode escapes to regular characters, and will therefore throw the same types of errors just described even if their input is of type `json` not `jsonb`. The fact that the `json` input function does not make these checks may be considered a historical artifact, although it does allow for simple storage (without processing) of JSON Unicode escapes in a database encoding that does not support the represented characters.

When converting textual JSON input into `jsonb`, the primitive types described by RFC 7159 are effectively mapped onto native Postgres Pro types, as shown in Table 8.23. Therefore, there are some minor additional constraints on what constitutes valid `jsonb` data that do not apply to the `json` type, nor to JSON in the abstract, corresponding to limits on what can be represented by the underlying data type. Notably, `jsonb` will reject numbers that are outside the range of the Postgres Pro `numeric` data type, while `json` will not. Such implementation-defined restrictions are permitted by RFC 7159. However, in practice such problems are far more likely to occur in other implementations, as it is common to represent JSON's `number` primitive type as IEEE 754 double precision floating point (which RFC 7159 explicitly anticipates and allows for). When using JSON as an interchange format with such systems, the danger of losing numeric precision compared to data originally stored by Postgres Pro should be considered.

Conversely, as noted in the table there are some minor restrictions on the input format of JSON primitive types that do not apply to the corresponding Postgres Pro types.

Table 8.23. JSON Primitive Types and Corresponding Postgres Pro Types

JSON primitive type	Postgres Pro type	Notes
`string`	`text`	`\u0000` is disallowed, as are Unicode escapes representing characters not available in the database encoding
`number`	`numeric`	`NaN` and `infinity` values are disallowed

JSON primitive type	Postgres Pro type	Notes
boolean	boolean	Only lowercase true and false spellings are accepted
null	(none)	SQL NULL is a different concept

8.14.1. JSON Input and Output Syntax

The input/output syntax for the JSON data types is as specified in RFC 7159.

The following are all valid json (or jsonb) expressions:

```
-- Simple scalar/primitive value
-- Primitive values can be numbers, quoted strings, true, false, or null
SELECT '5'::json;

-- Array of zero or more elements (elements need not be of same type)
SELECT '[1, 2, "foo", null]'::json;

-- Object containing pairs of keys and values
-- Note that object keys must always be quoted strings
SELECT '{"bar": "baz", "balance": 7.77, "active": false}'::json;

-- Arrays and objects can be nested arbitrarily
SELECT '{"foo": [true, "bar"], "tags": {"a": 1, "b": null}}'::json;
```

As previously stated, when a JSON value is input and then printed without any additional processing, json outputs the same text that was input, while jsonb does not preserve semantically-insignificant details such as whitespace. For example, note the differences here:

```
SELECT '{"bar": "baz", "balance": 7.77, "active":false}'::json;
                      json
-------------------------------------------------
 {"bar": "baz", "balance": 7.77, "active":false}
(1 row)

SELECT '{"bar": "baz", "balance": 7.77, "active":false}'::jsonb;
                      jsonb
-------------------------------------------------
 {"bar": "baz", "active": false, "balance": 7.77}
(1 row)
```

One semantically-insignificant detail worth noting is that in jsonb, numbers will be printed according to the behavior of the underlying numeric type. In practice this means that numbers entered with E notation will be printed without it, for example:

```
SELECT '{"reading": 1.230e-5}'::json, '{"reading": 1.230e-5}'::jsonb;
         json          |          jsonb
-----------------------+-------------------------
 {"reading": 1.230e-5} | {"reading": 0.00001230}
(1 row)
```

However, jsonb will preserve trailing fractional zeroes, as seen in this example, even though those are semantically insignificant for purposes such as equality checks.

For the list of built-in functions and operators available for constructing and processing JSON values, see Section 9.16.

8.14.2. Designing JSON Documents

Representing data as JSON can be considerably more flexible than the traditional relational data model, which is compelling in environments where requirements are fluid. It is quite possible for both approach-

es to co-exist and complement each other within the same application. However, even for applications where maximal flexibility is desired, it is still recommended that JSON documents have a somewhat fixed structure. The structure is typically unenforced (though enforcing some business rules declaratively is possible), but having a predictable structure makes it easier to write queries that usefully summarize a set of “documents” (datums) in a table.

JSON data is subject to the same concurrency-control considerations as any other data type when stored in a table. Although storing large documents is practicable, keep in mind that any update acquires a row-level lock on the whole row. Consider limiting JSON documents to a manageable size in order to decrease lock contention among updating transactions. Ideally, JSON documents should each represent an atomic datum that business rules dictate cannot reasonably be further subdivided into smaller datums that could be modified independently.

8.14.3. `jsonb` Containment and Existence

Testing *containment* is an important capability of `jsonb`. There is no parallel set of facilities for the `json` type. Containment tests whether one `jsonb` document has contained within it another one. These examples return true except as noted:

```
-- Simple scalar/primitive values contain only the identical value:
SELECT '"foo"'::jsonb @> '"foo"'::jsonb;

-- The array on the right side is contained within the one on the left:
SELECT '[1, 2, 3]'::jsonb @> '[1, 3]'::jsonb;

-- Order of array elements is not significant, so this is also true:
SELECT '[1, 2, 3]'::jsonb @> '[3, 1]'::jsonb;

-- Duplicate array elements don't matter either:
SELECT '[1, 2, 3]'::jsonb @> '[1, 2, 2]'::jsonb;

-- The object with a single pair on the right side is contained
-- within the object on the left side:
SELECT '{"product": "PostgreSQL", "version": 9.4, "jsonb": true}'::jsonb @>
 '{"version": 9.4}'::jsonb;

-- The array on the right side is not considered contained within the
-- array on the left, even though a similar array is nested within it:
SELECT '[1, 2, [1, 3]]'::jsonb @> '[1, 3]'::jsonb;  -- yields false

-- But with a layer of nesting, it is contained:
SELECT '[1, 2, [1, 3]]'::jsonb @> '[[1, 3]]'::jsonb;

-- Similarly, containment is not reported here:
SELECT '{"foo": {"bar": "baz"}}'::jsonb @> '{"bar": "baz"}'::jsonb;  -- yields false

-- A top-level key and an empty object is contained:
SELECT '{"foo": {"bar": "baz"}}'::jsonb @> '{"foo": {}}'::jsonb;
```

The general principle is that the contained object must match the containing object as to structure and data contents, possibly after discarding some non-matching array elements or object key/value pairs from the containing object. But remember that the order of array elements is not significant when doing a containment match, and duplicate array elements are effectively considered only once.

As a special exception to the general principle that the structures must match, an array may contain a primitive value:

```
-- This array contains the primitive string value:
SELECT '["foo", "bar"]'::jsonb @> '"bar"'::jsonb;
```

```
-- This exception is not reciprocal -- non-containment is reported here:
SELECT '"bar"'::jsonb @> '["bar"]'::jsonb;  -- yields false
```

`jsonb` also has an *existence* operator, which is a variation on the theme of containment: it tests whether a string (given as a `text` value) appears as an object key or array element at the top level of the `jsonb` value. These examples return true except as noted:

```
-- String exists as array element:
SELECT '["foo", "bar", "baz"]'::jsonb ? 'bar';

-- String exists as object key:
SELECT '{"foo": "bar"}'::jsonb ? 'foo';

-- Object values are not considered:
SELECT '{"foo": "bar"}'::jsonb ? 'bar';  -- yields false

-- As with containment, existence must match at the top level:
SELECT '{"foo": {"bar": "baz"}}'::jsonb ? 'bar'; -- yields false

-- A string is considered to exist if it matches a primitive JSON string:
SELECT '"foo"'::jsonb ? 'foo';
```

JSON objects are better suited than arrays for testing containment or existence when there are many keys or elements involved, because unlike arrays they are internally optimized for searching, and do not need to be searched linearly.

> **Tip**
>
> Because JSON containment is nested, an appropriate query can skip explicit selection of sub-objects. As an example, suppose that we have a `doc` column containing objects at the top level, with most objects containing `tags` fields that contain arrays of sub-objects. This query finds entries in which sub-objects containing both `"term":"paris"` and `"term":"food"` appear, while ignoring any such keys outside the `tags` array:
>
> ```
> SELECT doc->'site_name' FROM websites
>   WHERE doc @> '{"tags":[{"term":"paris"}, {"term":"food"}]}';
> ```
>
> One could accomplish the same thing with, say,
>
> ```
> SELECT doc->'site_name' FROM websites
>   WHERE doc->'tags' @> '[{"term":"paris"}, {"term":"food"}]';
> ```
>
> but that approach is less flexible, and often less efficient as well.
>
> On the other hand, the JSON existence operator is not nested: it will only look for the specified key or array element at top level of the JSON value.

The various containment and existence operators, along with all other JSON operators and functions are documented in Section 9.16.

8.14.4. `jsonb` Indexing

GIN indexes can be used to efficiently search for keys or key/value pairs occurring within a large number of `jsonb` documents (datums). Two GIN “operator classes” are provided, offering different performance and flexibility trade-offs.

The default GIN operator class for `jsonb` supports queries with the key-exists operators `?`, `?|` and `?&`, the containment operator `@>`, and the `jsonpath` match operators `@?` and `@@`. (For details of the semantics that these operators implement, see Table 9.45.) An example of creating an index with this operator class is:

```
CREATE INDEX idxgin ON api USING GIN (jdoc);
```

The non-default GIN operator class `jsonb_path_ops` does not support the key-exists operators, but it does support `@>`, `@?` and `@@`. An example of creating an index with this operator class is:

```
CREATE INDEX idxginp ON api USING GIN (jdoc jsonb_path_ops);
```

Consider the example of a table that stores JSON documents retrieved from a third-party web service, with a documented schema definition. A typical document is:

```
{
    "guid": "9c36adc1-7fb5-4d5b-83b4-90356a46061a",
    "name": "Angela Barton",
    "is_active": true,
    "company": "Magnafone",
    "address": "178 Howard Place, Gulf, Washington, 702",
    "registered": "2009-11-07T08:53:22 +08:00",
    "latitude": 19.793713,
    "longitude": 86.513373,
    "tags": [
        "enim",
        "aliquip",
        "qui"
    ]
}
```

We store these documents in a table named `api`, in a `jsonb` column named `jdoc`. If a GIN index is created on this column, queries like the following can make use of the index:

```
-- Find documents in which the key "company" has value "Magnafone"
SELECT jdoc->'guid', jdoc->'name' FROM api WHERE jdoc @> '{"company": "Magnafone"}';
```

However, the index could not be used for queries like the following, because though the operator `?` is indexable, it is not applied directly to the indexed column `jdoc`:

```
-- Find documents in which the key "tags" contains key or array element "qui"
SELECT jdoc->'guid', jdoc->'name' FROM api WHERE jdoc -> 'tags' ? 'qui';
```

Still, with appropriate use of expression indexes, the above query can use an index. If querying for particular items within the `"tags"` key is common, defining an index like this may be worthwhile:

```
CREATE INDEX idxgintags ON api USING GIN ((jdoc -> 'tags'));
```

Now, the `WHERE` clause `jdoc -> 'tags' ? 'qui'` will be recognized as an application of the indexable operator `?` to the indexed expression `jdoc -> 'tags'`. (More information on expression indexes can be found in Section 11.7.)

Another approach to querying is to exploit containment, for example:

```
-- Find documents in which the key "tags" contains array element "qui"
SELECT jdoc->'guid', jdoc->'name' FROM api WHERE jdoc @> '{"tags": ["qui"]}';
```

A simple GIN index on the `jdoc` column can support this query. But note that such an index will store copies of every key and value in the `jdoc` column, whereas the expression index of the previous example stores only data found under the `tags` key. While the simple-index approach is far more flexible (since it supports queries about any key), targeted expression indexes are likely to be smaller and faster to search than a simple index.

GIN indexes also support the `@?` and `@@` operators, which perform `jsonpath` matching. Examples are

```
SELECT jdoc->'guid', jdoc->'name' FROM api WHERE jdoc @? '$.tags[*] ? (@ == "qui")';
```

```
SELECT jdoc->'guid', jdoc->'name' FROM api WHERE jdoc @@ '$.tags[*] == "qui"';
```

For these operators, a GIN index extracts clauses of the form *`accessors_chain = constant`* out of the `jsonpath` pattern, and does the index search based on the keys and values mentioned in these clauses.

The accessors chain may include `.key`, `[*]`, and `[index]` accessors. The `jsonb_ops` operator class also supports `.*` and `.**` accessors, but the `jsonb_path_ops` operator class does not.

Although the `jsonb_path_ops` operator class supports only queries with the `@>`, `@?` and `@@` operators, it has notable performance advantages over the default operator class `jsonb_ops`. A `jsonb_path_ops` index is usually much smaller than a `jsonb_ops` index over the same data, and the specificity of searches is better, particularly when queries contain keys that appear frequently in the data. Therefore search operations typically perform better than with the default operator class.

The technical difference between a `jsonb_ops` and a `jsonb_path_ops` GIN index is that the former creates independent index items for each key and value in the data, while the latter creates index items only for each value in the data. [1] Basically, each `jsonb_path_ops` index item is a hash of the value and the key(s) leading to it; for example to index `{"foo": {"bar": "baz"}}`, a single index item would be created incorporating all three of `foo`, `bar`, and `baz` into the hash value. Thus a containment query looking for this structure would result in an extremely specific index search; but there is no way at all to find out whether `foo` appears as a key. On the other hand, a `jsonb_ops` index would create three index items representing `foo`, `bar`, and `baz` separately; then to do the containment query, it would look for rows containing all three of these items. While GIN indexes can perform such an AND search fairly efficiently, it will still be less specific and slower than the equivalent `jsonb_path_ops` search, especially if there are a very large number of rows containing any single one of the three index items.

A disadvantage of the `jsonb_path_ops` approach is that it produces no index entries for JSON structures not containing any values, such as `{"a": {}}`. If a search for documents containing such a structure is requested, it will require a full-index scan, which is quite slow. `jsonb_path_ops` is therefore ill-suited for applications that often perform such searches.

`jsonb` also supports `btree` and `hash` indexes. These are usually useful only if it's important to check equality of complete JSON documents. The `btree` ordering for `jsonb` datums is seldom of great interest, but for completeness it is:

Object > Array > Boolean > Number > String > null

Object with n pairs > object with n - 1 pairs

Array with n elements > array with n - 1 elements

with the exception that (for historical reasons) an empty top level array sorts less than *null*. Objects with equal numbers of pairs are compared in the order:

key-1, *value-1*, *key-2* ...

Note that object keys are compared in their storage order; in particular, since shorter keys are stored before longer keys, this can lead to results that might be unintuitive, such as:

```
{ "aa": 1, "c": 1} > {"b": 1, "d": 1}
```

Similarly, arrays with equal numbers of elements are compared in the order:

element-1, *element-2* ...

Primitive JSON values are compared using the same comparison rules as for the underlying Postgres Pro data type. Strings are compared using the default database collation.

8.14.5. `jsonb` Subscripting

The `jsonb` data type supports array-style subscripting expressions to extract and modify elements. Nested values can be indicated by chaining subscripting expressions, following the same rules as the `path` argument in the `jsonb_set` function. If a `jsonb` value is an array, numeric subscripts start at zero, and negative integers count backwards from the last element of the array. Slice expressions are not supported. The result of a subscripting expression is always of the jsonb data type.

[1] For this purpose, the term “value” includes array elements, though JSON terminology sometimes considers array elements distinct from values within objects.

`UPDATE` statements may use subscripting in the `SET` clause to modify `jsonb` values. Subscript paths must be traversable for all affected values insofar as they exist. For instance, the path `val['a']['b']['c']` can be traversed all the way to `c` if every `val`, `val['a']`, and `val['a']['b']` is an object. If any `val['a']` or `val['a']['b']` is not defined, it will be created as an empty object and filled as necessary. However, if any `val` itself or one of the intermediary values is defined as a non-object such as a string, number, or `jsonb` `null`, traversal cannot proceed so an error is raised and the transaction aborted.

An example of subscripting syntax:

```
-- Extract object value by key
SELECT ('{"a": 1}'::jsonb)['a'];

-- Extract nested object value by key path
SELECT ('{"a": {"b": {"c": 1}}}'::jsonb)['a']['b']['c'];

-- Extract array element by index
SELECT ('[1, "2", null]'::jsonb)[1];

-- Update object value by key. Note the quotes around '1': the assigned
-- value must be of the jsonb type as well
UPDATE table_name SET jsonb_field['key'] = '1';

-- This will raise an error if any record's jsonb_field['a']['b'] is something
-- other than an object. For example, the value {"a": 1} has a numeric value
-- of the key 'a'.
UPDATE table_name SET jsonb_field['a']['b']['c'] = '1';

-- Filter records using a WHERE clause with subscripting. Since the result of
-- subscripting is jsonb, the value we compare it against must also be jsonb.
-- The double quotes make "value" also a valid jsonb string.
SELECT * FROM table_name WHERE jsonb_field['key'] = '"value"';
```

`jsonb` assignment via subscripting handles a few edge cases differently from `jsonb_set`. When a source `jsonb` value is `NULL`, assignment via subscripting will proceed as if it was an empty JSON value of the type (object or array) implied by the subscript key:

```
-- Where jsonb_field was NULL, it is now {"a": 1}
UPDATE table_name SET jsonb_field['a'] = '1';

-- Where jsonb_field was NULL, it is now [1]
UPDATE table_name SET jsonb_field[0] = '1';
```

If an index is specified for an array containing too few elements, `NULL` elements will be appended until the index is reachable and the value can be set.

```
-- Where jsonb_field was [], it is now [null, null, 2];
-- where jsonb_field was [0], it is now [0, null, 2]
UPDATE table_name SET jsonb_field[2] = '2';
```

A `jsonb` value will accept assignments to nonexistent subscript paths as long as the last existing element to be traversed is an object or array, as implied by the corresponding subscript (the element indicated by the last subscript in the path is not traversed and may be anything). Nested array and object structures will be created, and in the former case `null`-padded, as specified by the subscript path until the assigned value can be placed.

```
-- Where jsonb_field was {}, it is now {"a": [{"b": 1}]}
UPDATE table_name SET jsonb_field['a'][0]['b'] = '1';

-- Where jsonb_field was [], it is now [null, {"a": 1}]
UPDATE table_name SET jsonb_field[1]['a'] = '1';
```

8.14.6. Transforms

Additional extensions are available that implement transforms for the `jsonb` type for different procedural languages.

The extensions for PL/Perl are called `jsonb_plperl` and `jsonb_plperlu`. If you use them, `jsonb` values are mapped to Perl arrays, hashes, and scalars, as appropriate.

The extensions for PL/Python are called `jsonb_plpythonu`, `jsonb_plpython2u`, and `jsonb_plpython3u` (see Section 48.1 for the PL/Python naming convention). If you use them, `jsonb` values are mapped to Python dictionaries, lists, and scalars, as appropriate.

Of these extensions, `jsonb_plperl` is considered "trusted", that is, it can be installed by non-superusers who have `CREATE` privilege on the current database. The rest require superuser privilege to install.

8.14.7. jsonpath Type

The `jsonpath` type implements support for the SQL/JSON path language in Postgres Pro to efficiently query JSON data. It provides a binary representation of the parsed SQL/JSON path expression that specifies the items to be retrieved by the path engine from the JSON data for further processing with the SQL/JSON query functions.

The semantics of SQL/JSON path predicates and operators generally follow SQL. At the same time, to provide a natural way of working with JSON data, SQL/JSON path syntax uses some JavaScript conventions:

- Dot (`.`) is used for member access.
- Square brackets (`[]`) are used for array access.
- SQL/JSON arrays are 0-relative, unlike regular SQL arrays that start from 1.

An SQL/JSON path expression is typically written in an SQL query as an SQL character string literal, so it must be enclosed in single quotes, and any single quotes desired within the value must be doubled (see Section 4.1.2.1). Some forms of path expressions require string literals within them. These embedded string literals follow JavaScript/ECMAScript conventions: they must be surrounded by double quotes, and backslash escapes may be used within them to represent otherwise-hard-to-type characters. In particular, the way to write a double quote within an embedded string literal is `\"`, and to write a backslash itself, you must write `\\`. Other special backslash sequences include those recognized in JavaScript strings: `\b`, `\f`, `\n`, `\r`, `\t`, `\v` for various ASCII control characters, `\x`*`NN`* for a character code written with only two hex digits, `\u`*`NNNN`* for a Unicode character identified by its 4-hex-digit code point, and `\u{`*`N...`*`}` for a Unicode character code point written with 1 to 6 hex digits.

A path expression consists of a sequence of path elements, which can be any of the following:

- Path literals of JSON primitive types: Unicode text, numeric, true, false, or null.
- Path variables listed in Table 8.24.
- Accessor operators listed in Table 8.25.
- `jsonpath` operators and methods listed in Section 9.16.2.2.
- Parentheses, which can be used to provide filter expressions or define the order of path evaluation.

For details on using `jsonpath` expressions with SQL/JSON query functions, see Section 9.16.2.

Table 8.24. `jsonpath` Variables

Variable	Description
`$`	A variable representing the JSON value being queried (the *context item*).
`$varname`	A named variable. Its value can be set by the parameter *`vars`* of several JSON processing functions; see Table 9.47 for details.

Variable	Description
`@`	A variable representing the result of path evaluation in filter expressions.

Table 8.25. `jsonpath` Accessors

Accessor Operator	Description
`.`*`key`* `."$`*`varname`*`"`	Member accessor that returns an object member with the specified key. If the key name matches some named variable starting with `$` or does not meet the JavaScript rules for an identifier, it must be enclosed in double quotes to make it a string literal.
`.*`	Wildcard member accessor that returns the values of all members located at the top level of the current object.
`.**`	Recursive wildcard member accessor that processes all levels of the JSON hierarchy of the current object and returns all the member values, regardless of their nesting level. This is a Postgres Pro extension of the SQL/JSON standard.

`.**{`*`level`*`}`
 	
`.**{`*`start_level`* `to` *`end_level`*`}`
	Like `.**`, but selects only the specified levels of the JSON hierarchy. Nesting levels are specified as integers. Level zero corresponds to the current object. To access the lowest nesting level, you can use the `last` keyword. This is a Postgres Pro extension of the SQL/JSON standard.

`[`*`subscript`*`, ...]`	Array element accessor. *`subscript`* can be given in two forms: *`index`* or *`start_index`* `to` *`end_index`* . The first form returns a single array element by its index. The second form returns an array slice by the range of indexes, including the elements that correspond to the provided *`start_index`* and *`end_index`* . The specified *`index`* can be an integer, as well as an expression returning a single numeric value, which is automatically cast to integer. Index zero corresponds to the first array element. You can also use the `last` keyword to denote the last array element, which is useful for handling arrays of unknown length.
`[*]`	Wildcard array element accessor that returns all array elements.

8.15. Arrays

Postgres Pro allows columns of a table to be defined as variable-length multidimensional arrays. Arrays of any built-in or user-defined base type, enum type, composite type, range type, or domain can be created.

8.15.1. Declaration of Array Types

To illustrate the use of array types, we create this table:

```
CREATE TABLE sal_emp (
    name            text,
    pay_by_quarter  integer[],
    schedule        text[][]
);
```

As shown, an array data type is named by appending square brackets (`[]`) to the data type name of the array elements. The above command will create a table named `sal_emp` with a column of type `text` (`name`), a one-dimensional array of type `integer` (`pay_by_quarter`), which represents the employee's salary by quarter, and a two-dimensional array of `text` (`schedule`), which represents the employee's weekly schedule.

The syntax for `CREATE TABLE` allows the exact size of arrays to be specified, for example:

```
CREATE TABLE tictactoe (
    squares   integer[3][3]
);
```

However, the current implementation ignores any supplied array size limits, i.e., the behavior is the same as for arrays of unspecified length.

The current implementation does not enforce the declared number of dimensions either. Arrays of a particular element type are all considered to be of the same type, regardless of size or number of dimensions. So, declaring the array size or number of dimensions in `CREATE TABLE` is simply documentation; it does not affect run-time behavior.

An alternative syntax, which conforms to the SQL standard by using the keyword `ARRAY`, can be used for one-dimensional arrays. `pay_by_quarter` could have been defined as:

```
    pay_by_quarter  integer ARRAY[4],
```

Or, if no array size is to be specified:

```
    pay_by_quarter  integer ARRAY,
```

As before, however, Postgres Pro does not enforce the size restriction in any case.

8.15.2. Array Value Input

To write an array value as a literal constant, enclose the element values within curly braces and separate them by commas. (If you know C, this is not unlike the C syntax for initializing structures.) You can put double quotes around any element value, and must do so if it contains commas or curly braces. (More details appear below.) Thus, the general format of an array constant is the following:

```
'{ val1 delim val2 delim ... }'
```

where *delim* is the delimiter character for the type, as recorded in its `pg_type` entry. Among the standard data types provided in the Postgres Pro distribution, all use a comma (`,`), except for type `box` which uses a semicolon (`;`). Each *val* is either a constant of the array element type, or a subarray. An example of an array constant is:

```
'{{1,2,3},{4,5,6},{7,8,9}}'
```

This constant is a two-dimensional, 3-by-3 array consisting of three subarrays of integers.

To set an element of an array constant to NULL, write `NULL` for the element value. (Any upper- or lower-case variant of `NULL` will do.) If you want an actual string value “NULL”, you must put double quotes around it.

(These kinds of array constants are actually only a special case of the generic type constants discussed in Section 4.1.2.7. The constant is initially treated as a string and passed to the array input conversion routine. An explicit type specification might be necessary.)

Now we can show some `INSERT` statements:

```
INSERT INTO sal_emp
    VALUES ('Bill',
    '{10000, 10000, 10000, 10000}',
    '{{"meeting", "lunch"}, {"training", "presentation"}}');

INSERT INTO sal_emp
    VALUES ('Carol',
    '{20000, 25000, 25000, 25000}',
    '{{"breakfast", "consulting"}, {"meeting", "lunch"}}');
```

The result of the previous two inserts looks like this:

```
SELECT * FROM sal_emp;
```

```
 name  |      pay_by_quarter       |                  schedule
-------+---------------------------+-------------------------------------------
 Bill  | {10000,10000,10000,10000} | {{meeting,lunch},{training,presentation}}
 Carol | {20000,25000,25000,25000} | {{breakfast,consulting},{meeting,lunch}}
(2 rows)
```

Multidimensional arrays must have matching extents for each dimension. A mismatch causes an error, for example:

```
INSERT INTO sal_emp
    VALUES ('Bill',
    '{10000, 10000, 10000, 10000}',
    '{{"meeting", "lunch"}, {"meeting"}}');
ERROR:  multidimensional arrays must have array expressions with matching dimensions
```

The `ARRAY` constructor syntax can also be used:

```
INSERT INTO sal_emp
    VALUES ('Bill',
    ARRAY[10000, 10000, 10000, 10000],
    ARRAY[['meeting', 'lunch'], ['training', 'presentation']]);

INSERT INTO sal_emp
    VALUES ('Carol',
    ARRAY[20000, 25000, 25000, 25000],
    ARRAY[['breakfast', 'consulting'], ['meeting', 'lunch']]);
```

Notice that the array elements are ordinary SQL constants or expressions; for instance, string literals are single quoted, instead of double quoted as they would be in an array literal. The `ARRAY` constructor syntax is discussed in more detail in Section 4.2.12.

8.15.3. Accessing Arrays

Now, we can run some queries on the table. First, we show how to access a single element of an array. This query retrieves the names of the employees whose pay changed in the second quarter:

```
SELECT name FROM sal_emp WHERE pay_by_quarter[1] <> pay_by_quarter[2];

 name
-------
 Carol
(1 row)
```

The array subscript numbers are written within square brackets. By default Postgres Pro uses a one-based numbering convention for arrays, that is, an array of *n* elements starts with `array[1]` and ends with `array[`*n*`]`.

This query retrieves the third quarter pay of all employees:

```
SELECT pay_by_quarter[3] FROM sal_emp;

 pay_by_quarter
----------------
          10000
          25000
(2 rows)
```

We can also access arbitrary rectangular slices of an array, or subarrays. An array slice is denoted by writing *lower-bound*`:`*upper-bound* for one or more array dimensions. For example, this query retrieves the first item on Bill's schedule for the first two days of the week:

```
SELECT schedule[1:2][1:1] FROM sal_emp WHERE name = 'Bill';
```

```
        schedule
------------------------
 {{meeting},{training}}
(1 row)
```

If any dimension is written as a slice, i.e., contains a colon, then all dimensions are treated as slices. Any dimension that has only a single number (no colon) is treated as being from 1 to the number specified. For example, `[2]` is treated as `[1:2]`, as in this example:

```
SELECT schedule[1:2][2] FROM sal_emp WHERE name = 'Bill';

                 schedule
-----------------------------------------
 {{meeting,lunch},{training,presentation}}
(1 row)
```

To avoid confusion with the non-slice case, it's best to use slice syntax for all dimensions, e.g., `[1:2][1:1]`, not `[2][1:1]`.

It is possible to omit the *`lower-bound`* and/or *`upper-bound`* of a slice specifier; the missing bound is replaced by the lower or upper limit of the array's subscripts. For example:

```
SELECT schedule[:2][2:] FROM sal_emp WHERE name = 'Bill';

        schedule
------------------------
 {{lunch},{presentation}}
(1 row)

SELECT schedule[:][1:1] FROM sal_emp WHERE name = 'Bill';

        schedule
------------------------
 {{meeting},{training}}
(1 row)
```

An array subscript expression will return null if either the array itself or any of the subscript expressions are null. Also, null is returned if a subscript is outside the array bounds (this case does not raise an error). For example, if `schedule` currently has the dimensions `[1:3][1:2]` then referencing `schedule[3][3]` yields NULL. Similarly, an array reference with the wrong number of subscripts yields a null rather than an error.

An array slice expression likewise yields null if the array itself or any of the subscript expressions are null. However, in other cases such as selecting an array slice that is completely outside the current array bounds, a slice expression yields an empty (zero-dimensional) array instead of null. (This does not match non-slice behavior and is done for historical reasons.) If the requested slice partially overlaps the array bounds, then it is silently reduced to just the overlapping region instead of returning null.

The current dimensions of any array value can be retrieved with the `array_dims` function:

```
SELECT array_dims(schedule) FROM sal_emp WHERE name = 'Carol';

 array_dims
------------
 [1:2][1:2]
(1 row)
```

`array_dims` produces a `text` result, which is convenient for people to read but perhaps inconvenient for programs. Dimensions can also be retrieved with `array_upper` and `array_lower`, which return the upper and lower bound of a specified array dimension, respectively:

```
SELECT array_upper(schedule, 1) FROM sal_emp WHERE name = 'Carol';

 array_upper
-------------
           2
(1 row)
```

`array_length` will return the length of a specified array dimension:

```
SELECT array_length(schedule, 1) FROM sal_emp WHERE name = 'Carol';

 array_length
--------------
            2
(1 row)
```

`cardinality` returns the total number of elements in an array across all dimensions. It is effectively the number of rows a call to `unnest` would yield:

```
SELECT cardinality(schedule) FROM sal_emp WHERE name = 'Carol';

 cardinality
-------------
           4
(1 row)
```

8.15.4. Modifying Arrays

An array value can be replaced completely:

```
UPDATE sal_emp SET pay_by_quarter = '{25000,25000,27000,27000}'
    WHERE name = 'Carol';
```

or using the `ARRAY` expression syntax:

```
UPDATE sal_emp SET pay_by_quarter = ARRAY[25000,25000,27000,27000]
    WHERE name = 'Carol';
```

An array can also be updated at a single element:

```
UPDATE sal_emp SET pay_by_quarter[4] = 15000
    WHERE name = 'Bill';
```

or updated in a slice:

```
UPDATE sal_emp SET pay_by_quarter[1:2] = '{27000,27000}'
    WHERE name = 'Carol';
```

The slice syntaxes with omitted *`lower-bound`* and/or *`upper-bound`* can be used too, but only when updating an array value that is not NULL or zero-dimensional (otherwise, there is no existing subscript limit to substitute).

A stored array value can be enlarged by assigning to elements not already present. Any positions between those previously present and the newly assigned elements will be filled with nulls. For example, if array `myarray` currently has 4 elements, it will have six elements after an update that assigns to `myarray[6]`; `myarray[5]` will contain null. Currently, enlargement in this fashion is only allowed for one-dimensional arrays, not multidimensional arrays.

Subscripted assignment allows creation of arrays that do not use one-based subscripts. For example one might assign to `myarray[-2:7]` to create an array with subscript values from -2 to 7.

New array values can also be constructed using the concatenation operator, `||`:

```
SELECT ARRAY[1,2] || ARRAY[3,4];
```

```
 ?column?
-----------
 {1,2,3,4}
(1 row)

SELECT ARRAY[5,6] || ARRAY[[1,2],[3,4]];
      ?column?
---------------------
 {{5,6},{1,2},{3,4}}
(1 row)
```

The concatenation operator allows a single element to be pushed onto the beginning or end of a one-dimensional array. It also accepts two *N*-dimensional arrays, or an *N*-dimensional and an *N+1*-dimensional array.

When a single element is pushed onto either the beginning or end of a one-dimensional array, the result is an array with the same lower bound subscript as the array operand. For example:

```
SELECT array_dims(1 || '[0:1]={2,3}'::int[]);
 array_dims
------------
 [0:2]
(1 row)

SELECT array_dims(ARRAY[1,2] || 3);
 array_dims
------------
 [1:3]
(1 row)
```

When two arrays with an equal number of dimensions are concatenated, the result retains the lower bound subscript of the left-hand operand's outer dimension. The result is an array comprising every element of the left-hand operand followed by every element of the right-hand operand. For example:

```
SELECT array_dims(ARRAY[1,2] || ARRAY[3,4,5]);
 array_dims
------------
 [1:5]
(1 row)

SELECT array_dims(ARRAY[[1,2],[3,4]] || ARRAY[[5,6],[7,8],[9,0]]);
 array_dims
------------
 [1:5][1:2]
(1 row)
```

When an *N*-dimensional array is pushed onto the beginning or end of an *N+1*-dimensional array, the result is analogous to the element-array case above. Each *N*-dimensional sub-array is essentially an element of the *N+1*-dimensional array's outer dimension. For example:

```
SELECT array_dims(ARRAY[1,2] || ARRAY[[3,4],[5,6]]);
 array_dims
------------
 [1:3][1:2]
(1 row)
```

An array can also be constructed by using the functions `array_prepend`, `array_append`, or `array_cat`. The first two only support one-dimensional arrays, but `array_cat` supports multidimensional arrays. Some examples:

```
SELECT array_prepend(1, ARRAY[2,3]);
```

```
 array_prepend
---------------
 {1,2,3}
(1 row)

SELECT array_append(ARRAY[1,2], 3);
 array_append
--------------
 {1,2,3}
(1 row)

SELECT array_cat(ARRAY[1,2], ARRAY[3,4]);
 array_cat
-----------
 {1,2,3,4}
(1 row)

SELECT array_cat(ARRAY[[1,2],[3,4]], ARRAY[5,6]);
      array_cat
---------------------
 {{1,2},{3,4},{5,6}}
(1 row)

SELECT array_cat(ARRAY[5,6], ARRAY[[1,2],[3,4]]);
      array_cat
---------------------
 {{5,6},{1,2},{3,4}}
```

In simple cases, the concatenation operator discussed above is preferred over direct use of these functions. However, because the concatenation operator is overloaded to serve all three cases, there are situations where use of one of the functions is helpful to avoid ambiguity. For example consider:

```
SELECT ARRAY[1, 2] || '{3, 4}';  -- the untyped literal is taken as an array
 ?column?
-----------
 {1,2,3,4}

SELECT ARRAY[1, 2] || '7';                -- so is this one
ERROR:  malformed array literal: "7"

SELECT ARRAY[1, 2] || NULL;               -- so is an undecorated NULL
 ?column?
----------
 {1,2}
(1 row)

SELECT array_append(ARRAY[1, 2], NULL);    -- this might have been meant
 array_append
--------------
 {1,2,NULL}
```

In the examples above, the parser sees an integer array on one side of the concatenation operator, and a constant of undetermined type on the other. The heuristic it uses to resolve the constant's type is to assume it's of the same type as the operator's other input — in this case, integer array. So the concatenation operator is presumed to represent `array_cat`, not `array_append`. When that's the wrong choice, it could be fixed by casting the constant to the array's element type; but explicit use of `array_append` might be a preferable solution.

8.15.5. Searching in Arrays

To search for a value in an array, each value must be checked. This can be done manually, if you know the size of the array. For example:

```
SELECT * FROM sal_emp WHERE pay_by_quarter[1] = 10000 OR
                            pay_by_quarter[2] = 10000 OR
                            pay_by_quarter[3] = 10000 OR
                            pay_by_quarter[4] = 10000;
```

However, this quickly becomes tedious for large arrays, and is not helpful if the size of the array is unknown. An alternative method is described in Section 9.24. The above query could be replaced by:

```
SELECT * FROM sal_emp WHERE 10000 = ANY (pay_by_quarter);
```

In addition, you can find rows where the array has all values equal to 10000 with:

```
SELECT * FROM sal_emp WHERE 10000 = ALL (pay_by_quarter);
```

Alternatively, the `generate_subscripts` function can be used. For example:

```
SELECT * FROM
   (SELECT pay_by_quarter,
           generate_subscripts(pay_by_quarter, 1) AS s
      FROM sal_emp) AS foo
 WHERE pay_by_quarter[s] = 10000;
```

This function is described in Table 9.64.

You can also search an array using the `&&` operator, which checks whether the left operand overlaps with the right operand. For instance:

```
SELECT * FROM sal_emp WHERE pay_by_quarter && ARRAY[10000];
```

This and other array operators are further described in Section 9.19. It can be accelerated by an appropriate index, as described in Section 11.2.

You can also search for specific values in an array using the `array_position` and `array_positions` functions. The former returns the subscript of the first occurrence of a value in an array; the latter returns an array with the subscripts of all occurrences of the value in the array. For example:

```
SELECT array_position(ARRAY['sun','mon','tue','wed','thu','fri','sat'], 'mon');
 array_position
----------------
              2
(1 row)

SELECT array_positions(ARRAY[1, 4, 3, 1, 3, 4, 2, 1], 1);
 array_positions
-----------------
 {1,4,8}
(1 row)
```

> **Tip**
>
> Arrays are not sets; searching for specific array elements can be a sign of database misdesign. Consider using a separate table with a row for each item that would be an array element. This will be easier to search, and is likely to scale better for a large number of elements.

8.15.6. Array Input and Output Syntax

The external text representation of an array value consists of items that are interpreted according to the I/O conversion rules for the array's element type, plus decoration that indicates the array structure. The decoration consists of curly braces (`{` and `}`) around the array value plus delimiter characters between

adjacent items. The delimiter character is usually a comma (,) but can be something else: it is determined by the `typdelim` setting for the array's element type. Among the standard data types provided in the Postgres Pro distribution, all use a comma, except for type `box`, which uses a semicolon (;). In a multidimensional array, each dimension (row, plane, cube, etc.) gets its own level of curly braces, and delimiters must be written between adjacent curly-braced entities of the same level.

The array output routine will put double quotes around element values if they are empty strings, contain curly braces, delimiter characters, double quotes, backslashes, or white space, or match the word `NULL`. Double quotes and backslashes embedded in element values will be backslash-escaped. For numeric data types it is safe to assume that double quotes will never appear, but for textual data types one should be prepared to cope with either the presence or absence of quotes.

By default, the lower bound index value of an array's dimensions is set to one. To represent arrays with other lower bounds, the array subscript ranges can be specified explicitly before writing the array contents. This decoration consists of square brackets ([]) around each array dimension's lower and upper bounds, with a colon (:) delimiter character in between. The array dimension decoration is followed by an equal sign (=). For example:

```
SELECT f1[1][-2][3] AS e1, f1[1][-1][5] AS e2
 FROM (SELECT '[1:1][-2:-1][3:5]={{{1,2,3},{4,5,6}}}'::int[] AS f1) AS ss;

 e1 | e2
----+----
  1 |  6
(1 row)
```

The array output routine will include explicit dimensions in its result only when there are one or more lower bounds different from one.

If the value written for an element is `NULL` (in any case variant), the element is taken to be NULL. The presence of any quotes or backslashes disables this and allows the literal string value “NULL” to be entered. Also, for backward compatibility with pre-8.2 versions of PostgreSQL, the array_nulls configuration parameter can be turned `off` to suppress recognition of `NULL` as a NULL.

As shown previously, when writing an array value you can use double quotes around any individual array element. You *must* do so if the element value would otherwise confuse the array-value parser. For example, elements containing curly braces, commas (or the data type's delimiter character), double quotes, backslashes, or leading or trailing whitespace must be double-quoted. Empty strings and strings matching the word `NULL` must be quoted, too. To put a double quote or backslash in a quoted array element value, precede it with a backslash. Alternatively, you can avoid quotes and use backslash-escaping to protect all data characters that would otherwise be taken as array syntax.

You can add whitespace before a left brace or after a right brace. You can also add whitespace before or after any individual item string. In all of these cases the whitespace will be ignored. However, whitespace within double-quoted elements, or surrounded on both sides by non-whitespace characters of an element, is not ignored.

> **Tip**
>
> The `ARRAY` constructor syntax (see Section 4.2.12) is often easier to work with than the array-literal syntax when writing array values in SQL commands. In `ARRAY`, individual element values are written the same way they would be written when not members of an array.

8.16. Composite Types

A *composite type* represents the structure of a row or record; it is essentially just a list of field names and their data types. Postgres Pro allows composite types to be used in many of the same ways that simple types can be used. For example, a column of a table can be declared to be of a composite type.

8.16.1. Declaration of Composite Types

Here are two simple examples of defining composite types:

```
CREATE TYPE complex AS (
    r       double precision,
    i       double precision
);

CREATE TYPE inventory_item AS (
    name            text,
    supplier_id     integer,
    price           numeric
);
```

The syntax is comparable to `CREATE TABLE`, except that only field names and types can be specified; no constraints (such as `NOT NULL`) can presently be included. Note that the `AS` keyword is essential; without it, the system will think a different kind of `CREATE TYPE` command is meant, and you will get odd syntax errors.

Having defined the types, we can use them to create tables:

```
CREATE TABLE on_hand (
    item      inventory_item,
    count     integer
);

INSERT INTO on_hand VALUES (ROW('fuzzy dice', 42, 1.99), 1000);
```

or functions:

```
CREATE FUNCTION price_extension(inventory_item, integer) RETURNS numeric
AS 'SELECT $1.price * $2' LANGUAGE SQL;

SELECT price_extension(item, 10) FROM on_hand;
```

Whenever you create a table, a composite type is also automatically created, with the same name as the table, to represent the table's row type. For example, had we said:

```
CREATE TABLE inventory_item (
    name            text,
    supplier_id     integer REFERENCES suppliers,
    price           numeric CHECK (price > 0)
);
```

then the same `inventory_item` composite type shown above would come into being as a byproduct, and could be used just as above. Note however an important restriction of the current implementation: since no constraints are associated with a composite type, the constraints shown in the table definition *do not apply* to values of the composite type outside the table. (To work around this, create a domain over the composite type, and apply the desired constraints as `CHECK` constraints of the domain.)

8.16.2. Constructing Composite Values

To write a composite value as a literal constant, enclose the field values within parentheses and separate them by commas. You can put double quotes around any field value, and must do so if it contains commas or parentheses. (More details appear below.) Thus, the general format of a composite constant is the following:

```
'( val1 , val2 , ... )'
```

An example is:

```
'("fuzzy dice",42,1.99)'
```

which would be a valid value of the `inventory_item` type defined above. To make a field be NULL, write no characters at all in its position in the list. For example, this constant specifies a NULL third field:

```
'("fuzzy dice",42,)'
```

If you want an empty string rather than NULL, write double quotes:

```
'("",42,)'
```

Here the first field is a non-NULL empty string, the third is NULL.

(These constants are actually only a special case of the generic type constants discussed in Section 4.1.2.7. The constant is initially treated as a string and passed to the composite-type input conversion routine. An explicit type specification might be necessary to tell which type to convert the constant to.)

The `ROW` expression syntax can also be used to construct composite values. In most cases this is considerably simpler to use than the string-literal syntax since you don't have to worry about multiple layers of quoting. We already used this method above:

```
ROW('fuzzy dice', 42, 1.99)
ROW('', 42, NULL)
```

The ROW keyword is actually optional as long as you have more than one field in the expression, so these can be simplified to:

```
('fuzzy dice', 42, 1.99)
('', 42, NULL)
```

The `ROW` expression syntax is discussed in more detail in Section 4.2.13.

8.16.3. Accessing Composite Types

To access a field of a composite column, one writes a dot and the field name, much like selecting a field from a table name. In fact, it's so much like selecting from a table name that you often have to use parentheses to keep from confusing the parser. For example, you might try to select some subfields from our `on_hand` example table with something like:

```
SELECT item.name FROM on_hand WHERE item.price > 9.99;
```

This will not work since the name `item` is taken to be a table name, not a column name of `on_hand`, per SQL syntax rules. You must write it like this:

```
SELECT (item).name FROM on_hand WHERE (item).price > 9.99;
```

or if you need to use the table name as well (for instance in a multitable query), like this:

```
SELECT (on_hand.item).name FROM on_hand WHERE (on_hand.item).price > 9.99;
```

Now the parenthesized object is correctly interpreted as a reference to the `item` column, and then the subfield can be selected from it.

Similar syntactic issues apply whenever you select a field from a composite value. For instance, to select just one field from the result of a function that returns a composite value, you'd need to write something like:

```
SELECT (my_func(...)).field FROM ...
```

Without the extra parentheses, this will generate a syntax error.

The special field name `*` means “all fields”, as further explained in Section 8.16.5.

8.16.4. Modifying Composite Types

Here are some examples of the proper syntax for inserting and updating composite columns. First, inserting or updating a whole column:

```
INSERT INTO mytab (complex_col) VALUES((1.1,2.2));
```

```
UPDATE mytab SET complex_col = ROW(1.1,2.2) WHERE ...;
```

The first example omits `ROW`, the second uses it; we could have done it either way.

We can update an individual subfield of a composite column:

```
UPDATE mytab SET complex_col.r = (complex_col).r + 1 WHERE ...;
```

Notice here that we don't need to (and indeed cannot) put parentheses around the column name appearing just after `SET`, but we do need parentheses when referencing the same column in the expression to the right of the equal sign.

And we can specify subfields as targets for `INSERT`, too:

```
INSERT INTO mytab (complex_col.r, complex_col.i) VALUES(1.1, 2.2);
```

Had we not supplied values for all the subfields of the column, the remaining subfields would have been filled with null values.

8.16.5. Using Composite Types in Queries

There are various special syntax rules and behaviors associated with composite types in queries. These rules provide useful shortcuts, but can be confusing if you don't know the logic behind them.

In Postgres Pro, a reference to a table name (or alias) in a query is effectively a reference to the composite value of the table's current row. For example, if we had a table `inventory_item` as shown above, we could write:

```
SELECT c FROM inventory_item c;
```

This query produces a single composite-valued column, so we might get output like:

```
           c
------------------------
 ("fuzzy dice",42,1.99)
(1 row)
```

Note however that simple names are matched to column names before table names, so this example works only because there is no column named `c` in the query's tables.

The ordinary qualified-column-name syntax *`table_name.column_name`* can be understood as applying field selection to the composite value of the table's current row. (For efficiency reasons, it's not actually implemented that way.)

When we write

```
SELECT c.* FROM inventory_item c;
```

then, according to the SQL standard, we should get the contents of the table expanded into separate columns:

```
    name     | supplier_id | price
-------------+-------------+-------
 fuzzy dice |          42 |  1.99
(1 row)
```

as if the query were

```
SELECT c.name, c.supplier_id, c.price FROM inventory_item c;
```

Postgres Pro will apply this expansion behavior to any composite-valued expression, although as shown above, you need to write parentheses around the value that `.*` is applied to whenever it's not a simple table name. For example, if `myfunc()` is a function returning a composite type with columns `a`, `b`, and `c`, then these two queries have the same result:

```
SELECT (myfunc(x)).* FROM some_table;
SELECT (myfunc(x)).a, (myfunc(x)).b, (myfunc(x)).c FROM some_table;
```

Tip

Postgres Pro handles column expansion by actually transforming the first form into the second. So, in this example, `myfunc()` would get invoked three times per row with either syntax. If it's an expensive function you may wish to avoid that, which you can do with a query like:

```
SELECT m.* FROM some_table, LATERAL myfunc(x) AS m;
```

Placing the function in a `LATERAL FROM` item keeps it from being invoked more than once per row. `m.*` is still expanded into `m.a, m.b, m.c`, but now those variables are just references to the output of the `FROM` item. (The `LATERAL` keyword is optional here, but we show it to clarify that the function is getting `x` from `some_table`.)

The *composite_value*`.*` syntax results in column expansion of this kind when it appears at the top level of a `SELECT` output list, a `RETURNING` list in `INSERT`/`UPDATE`/`DELETE`, a `VALUES` clause, or a row constructor. In all other contexts (including when nested inside one of those constructs), attaching `.*` to a composite value does not change the value, since it means “all columns” and so the same composite value is produced again. For example, if `somefunc()` accepts a composite-valued argument, these queries are the same:

```
SELECT somefunc(c.*) FROM inventory_item c;
SELECT somefunc(c) FROM inventory_item c;
```

In both cases, the current row of `inventory_item` is passed to the function as a single composite-valued argument. Even though `.*` does nothing in such cases, using it is good style, since it makes clear that a composite value is intended. In particular, the parser will consider `c` in `c.*` to refer to a table name or alias, not to a column name, so that there is no ambiguity; whereas without `.*`, it is not clear whether `c` means a table name or a column name, and in fact the column-name interpretation will be preferred if there is a column named `c`.

Another example demonstrating these concepts is that all these queries mean the same thing:

```
SELECT * FROM inventory_item c ORDER BY c;
SELECT * FROM inventory_item c ORDER BY c.*;
SELECT * FROM inventory_item c ORDER BY ROW(c.*);
```

All of these `ORDER BY` clauses specify the row's composite value, resulting in sorting the rows according to the rules described in Section 9.24.6. However, if `inventory_item` contained a column named `c`, the first case would be different from the others, as it would mean to sort by that column only. Given the column names previously shown, these queries are also equivalent to those above:

```
SELECT * FROM inventory_item c ORDER BY ROW(c.name, c.supplier_id, c.price);
SELECT * FROM inventory_item c ORDER BY (c.name, c.supplier_id, c.price);
```

(The last case uses a row constructor with the key word `ROW` omitted.)

Another special syntactical behavior associated with composite values is that we can use *functional notation* for extracting a field of a composite value. The simple way to explain this is that the notations *field*`(`*table*`)` and *table*`.`*field* are interchangeable. For example, these queries are equivalent:

```
SELECT c.name FROM inventory_item c WHERE c.price > 1000;
SELECT name(c) FROM inventory_item c WHERE price(c) > 1000;
```

Moreover, if we have a function that accepts a single argument of a composite type, we can call it with either notation. These queries are all equivalent:

```
SELECT somefunc(c) FROM inventory_item c;
SELECT somefunc(c.*) FROM inventory_item c;
```

```
SELECT c.somefunc FROM inventory_item c;
```

This equivalence between functional notation and field notation makes it possible to use functions on composite types to implement “computed fields”. An application using the last query above wouldn't need to be directly aware that `somefunc` isn't a real column of the table.

> **Tip**
>
> Because of this behavior, it's unwise to give a function that takes a single composite-type argument the same name as any of the fields of that composite type. If there is ambiguity, the field-name interpretation will be chosen if field-name syntax is used, while the function will be chosen if function-call syntax is used. However, PostgreSQL versions before 11 always chose the field-name interpretation, unless the syntax of the call required it to be a function call. One way to force the function interpretation in older versions is to schema-qualify the function name, that is, write *schema*`.`*func*`(`*compositevalue*`)`.

8.16.6. Composite Type Input and Output Syntax

The external text representation of a composite value consists of items that are interpreted according to the I/O conversion rules for the individual field types, plus decoration that indicates the composite structure. The decoration consists of parentheses (`(` and `)`) around the whole value, plus commas (`,`) between adjacent items. Whitespace outside the parentheses is ignored, but within the parentheses it is considered part of the field value, and might or might not be significant depending on the input conversion rules for the field data type. For example, in:

```
'(  42)'
```

the whitespace will be ignored if the field type is integer, but not if it is text.

As shown previously, when writing a composite value you can write double quotes around any individual field value. You *must* do so if the field value would otherwise confuse the composite-value parser. In particular, fields containing parentheses, commas, double quotes, or backslashes must be double-quoted. To put a double quote or backslash in a quoted composite field value, precede it with a backslash. (Also, a pair of double quotes within a double-quoted field value is taken to represent a double quote character, analogously to the rules for single quotes in SQL literal strings.) Alternatively, you can avoid quoting and use backslash-escaping to protect all data characters that would otherwise be taken as composite syntax.

A completely empty field value (no characters at all between the commas or parentheses) represents a NULL. To write a value that is an empty string rather than NULL, write `""`.

The composite output routine will put double quotes around field values if they are empty strings or contain parentheses, commas, double quotes, backslashes, or white space. (Doing so for white space is not essential, but aids legibility.) Double quotes and backslashes embedded in field values will be doubled.

> **Note**
>
> Remember that what you write in an SQL command will first be interpreted as a string literal, and then as a composite. This doubles the number of backslashes you need (assuming escape string syntax is used). For example, to insert a `text` field containing a double quote and a backslash in a composite value, you'd need to write:
>
> ```
> INSERT ... VALUES ('("\"\\")');
> ```
>
> The string-literal processor removes one level of backslashes, so that what arrives at the composite-value parser looks like `("\"\\")`. In turn, the string fed to the `text` data type's input routine becomes `"\`. (If we were working with a data type whose input routine also treated backslashes specially, `bytea` for example, we might need as many as eight backslashes in the command to get

one backslash into the stored composite field.) Dollar quoting (see Section 4.1.2.4) can be used to avoid the need to double backslashes.

Tip

The `ROW` constructor syntax is usually easier to work with than the composite-literal syntax when writing composite values in SQL commands. In `ROW`, individual field values are written the same way they would be written when not members of a composite.

8.17. Range Types

Range types are data types representing a range of values of some element type (called the range's *subtype*). For instance, ranges of `timestamp` might be used to represent the ranges of time that a meeting room is reserved. In this case the data type is `tsrange` (short for "timestamp range"), and `timestamp` is the subtype. The subtype must have a total order so that it is well-defined whether element values are within, before, or after a range of values.

Range types are useful because they represent many element values in a single range value, and because concepts such as overlapping ranges can be expressed clearly. The use of time and date ranges for scheduling purposes is the clearest example; but price ranges, measurement ranges from an instrument, and so forth can also be useful.

Every range type has a corresponding multirange type. A multirange is an ordered list of non-contiguous, non-empty, non-null ranges. Most range operators also work on multiranges, and they have a few functions of their own.

8.17.1. Built-in Range and Multirange Types

Postgres Pro comes with the following built-in range types:

- `int4range` — Range of `integer`, `int4multirange` — corresponding Multirange
- `int8range` — Range of `bigint`, `int8multirange` — corresponding Multirange
- `numrange` — Range of `numeric`, `nummultirange` — corresponding Multirange
- `tsrange` — Range of `timestamp without time zone`, `tsmultirange` — corresponding Multirange
- `tstzrange` — Range of `timestamp with time zone`, `tstzmultirange` — corresponding Multirange
- `daterange` — Range of `date`, `datemultirange` — corresponding Multirange

In addition, you can define your own range types; see CREATE TYPE for more information.

8.17.2. Examples

```
CREATE TABLE reservation (room int, during tsrange);
INSERT INTO reservation VALUES
    (1108, '[2010-01-01 14:30, 2010-01-01 15:30)');

-- Containment
SELECT int4range(10, 20) @> 3;

-- Overlaps
SELECT numrange(11.1, 22.2) && numrange(20.0, 30.0);

-- Extract the upper bound
SELECT upper(int8range(15, 25));
```

```
-- Compute the intersection
SELECT int4range(10, 20) * int4range(15, 25);

-- Is the range empty?
SELECT isempty(numrange(1, 5));
```

See Table 9.53 and Table 9.55 for complete lists of operators and functions on range types.

8.17.3. Inclusive and Exclusive Bounds

Every non-empty range has two bounds, the lower bound and the upper bound. All points between these values are included in the range. An inclusive bound means that the boundary point itself is included in the range as well, while an exclusive bound means that the boundary point is not included in the range.

In the text form of a range, an inclusive lower bound is represented by "`[`" while an exclusive lower bound is represented by "`(`". Likewise, an inclusive upper bound is represented by "`]`", while an exclusive upper bound is represented by "`)`". (See Section 8.17.5 for more details.)

The functions `lower_inc` and `upper_inc` test the inclusivity of the lower and upper bounds of a range value, respectively.

8.17.4. Infinite (Unbounded) Ranges

The lower bound of a range can be omitted, meaning that all values less than the upper bound are included in the range, e.g., `(,3]`. Likewise, if the upper bound of the range is omitted, then all values greater than the lower bound are included in the range. If both lower and upper bounds are omitted, all values of the element type are considered to be in the range. Specifying a missing bound as inclusive is automatically converted to exclusive, e.g., `[,]` is converted to `(,)`. You can think of these missing values as +/-infinity, but they are special range type values and are considered to be beyond any range element type's +/-infinity values.

Element types that have the notion of "infinity" can use them as explicit bound values. For example, with timestamp ranges, `[today,infinity)` excludes the special `timestamp` value `infinity`, while `[today,infinity]` include it, as does `[today,)` and `[today,]`.

The functions `lower_inf` and `upper_inf` test for infinite lower and upper bounds of a range, respectively.

8.17.5. Range Input/Output

The input for a range value must follow one of the following patterns:

```
(lower-bound,upper-bound)
(lower-bound,upper-bound]
[lower-bound,upper-bound)
[lower-bound,upper-bound]
empty
```

The parentheses or brackets indicate whether the lower and upper bounds are exclusive or inclusive, as described previously. Notice that the final pattern is `empty`, which represents an empty range (a range that contains no points).

The *`lower-bound`* may be either a string that is valid input for the subtype, or empty to indicate no lower bound. Likewise, *`upper-bound`* may be either a string that is valid input for the subtype, or empty to indicate no upper bound.

Each bound value can be quoted using `"` (double quote) characters. This is necessary if the bound value contains parentheses, brackets, commas, double quotes, or backslashes, since these characters would otherwise be taken as part of the range syntax. To put a double quote or backslash in a quoted bound value, precede it with a backslash. (Also, a pair of double quotes within a double-quoted bound value is taken to represent a double quote character, analogously to the rules for single quotes in SQL literal strings.) Alternatively, you can avoid quoting and use backslash-escaping to protect all data characters

that would otherwise be taken as range syntax. Also, to write a bound value that is an empty string, write `""`, since writing nothing means an infinite bound.

Whitespace is allowed before and after the range value, but any whitespace between the parentheses or brackets is taken as part of the lower or upper bound value. (Depending on the element type, it might or might not be significant.)

> **Note**
>
> These rules are very similar to those for writing field values in composite-type literals. See Section 8.16.6 for additional commentary.

Examples:

```
-- includes 3, does not include 7, and does include all points in between
SELECT '[3,7)'::int4range;

-- does not include either 3 or 7, but includes all points in between
SELECT '(3,7)'::int4range;

-- includes only the single point 4
SELECT '[4,4]'::int4range;

-- includes no points (and will be normalized to 'empty')
SELECT '[4,4)'::int4range;
```

The input for a multirange is curly brackets (`{` and `}`) containing zero or more valid ranges, separated by commas. Whitespace is permitted around the brackets and commas. This is intended to be reminiscent of array syntax, although multiranges are much simpler: they have just one dimension and there is no need to quote their contents. (The bounds of their ranges may be quoted as above however.)

Examples:

```
SELECT '{}'::int4multirange;
SELECT '{[3,7)}'::int4multirange;
SELECT '{[3,7), [8,9)}'::int4multirange;
```

8.17.6. Constructing Ranges and Multiranges

Each range type has a constructor function with the same name as the range type. Using the constructor function is frequently more convenient than writing a range literal constant, since it avoids the need for extra quoting of the bound values. The constructor function accepts two or three arguments. The two-argument form constructs a range in standard form (lower bound inclusive, upper bound exclusive), while the three-argument form constructs a range with bounds of the form specified by the third argument. The third argument must be one of the strings “`()`”, “`(]`”, “`[)`”, or “`[]`”. For example:

```
-- The full form is: lower bound, upper bound, and text argument indicating
-- inclusivity/exclusivity of bounds.
SELECT numrange(1.0, 14.0, '(]');

-- If the third argument is omitted, '[)' is assumed.
SELECT numrange(1.0, 14.0);

-- Although '(]' is specified here, on display the value will be converted to
-- canonical form, since int8range is a discrete range type (see below).
SELECT int8range(1, 14, '(]');

-- Using NULL for either bound causes the range to be unbounded on that side.
SELECT numrange(NULL, 2.2);
```

Each range type also has a multirange constructor with the same name as the multirange type. The constructor function takes zero or more arguments which are all ranges of the appropriate type. For example:

```
SELECT nummultirange();
SELECT nummultirange(numrange(1.0, 14.0));
SELECT nummultirange(numrange(1.0, 14.0), numrange(20.0, 25.0));
```

8.17.7. Discrete Range Types

A discrete range is one whose element type has a well-defined “step”, such as `integer` or `date`. In these types two elements can be said to be adjacent, when there are no valid values between them. This contrasts with continuous ranges, where it's always (or almost always) possible to identify other element values between two given values. For example, a range over the `numeric` type is continuous, as is a range over `timestamp`. (Even though `timestamp` has limited precision, and so could theoretically be treated as discrete, it's better to consider it continuous since the step size is normally not of interest.)

Another way to think about a discrete range type is that there is a clear idea of a “next” or “previous” value for each element value. Knowing that, it is possible to convert between inclusive and exclusive representations of a range's bounds, by choosing the next or previous element value instead of the one originally given. For example, in an integer range type `[4,8]` and `(3,9)` denote the same set of values; but this would not be so for a range over numeric.

A discrete range type should have a *canonicalization* function that is aware of the desired step size for the element type. The canonicalization function is charged with converting equivalent values of the range type to have identical representations, in particular consistently inclusive or exclusive bounds. If a canonicalization function is not specified, then ranges with different formatting will always be treated as unequal, even though they might represent the same set of values in reality.

The built-in range types `int4range`, `int8range`, and `daterange` all use a canonical form that includes the lower bound and excludes the upper bound; that is, `[)`. User-defined range types can use other conventions, however.

8.17.8. Defining New Range Types

Users can define their own range types. The most common reason to do this is to use ranges over subtypes not provided among the built-in range types. For example, to define a new range type of subtype `float8`:

```
CREATE TYPE floatrange AS RANGE (
    subtype = float8,
    subtype_diff = float8mi
);

SELECT '[1.234, 5.678]'::floatrange;
```

Because `float8` has no meaningful “step”, we do not define a canonicalization function in this example.

When you define your own range you automatically get a corresponding multirange type.

Defining your own range type also allows you to specify a different subtype B-tree operator class or collation to use, so as to change the sort ordering that determines which values fall into a given range.

If the subtype is considered to have discrete rather than continuous values, the `CREATE TYPE` command should specify a `canonical` function. The canonicalization function takes an input range value, and must return an equivalent range value that may have different bounds and formatting. The canonical output for two ranges that represent the same set of values, for example the integer ranges `[1, 7]` and `[1, 8)`, must be identical. It doesn't matter which representation you choose to be the canonical one, so long as two equivalent values with different formattings are always mapped to the same value with the same formatting. In addition to adjusting the inclusive/exclusive bounds format, a canonicalization function might round off boundary values, in case the desired step size is larger than what the subtype is capable

of storing. For instance, a range type over `timestamp` could be defined to have a step size of an hour, in which case the canonicalization function would need to round off bounds that weren't a multiple of an hour, or perhaps throw an error instead.

In addition, any range type that is meant to be used with GiST or SP-GiST indexes should define a subtype difference, or `subtype_diff`, function. (The index will still work without `subtype_diff`, but it is likely to be considerably less efficient than if a difference function is provided.) The subtype difference function takes two input values of the subtype, and returns their difference (i.e., *X* minus *Y*) represented as a `float8` value. In our example above, the function `float8mi` that underlies the regular `float8` minus operator can be used; but for any other subtype, some type conversion would be necessary. Some creative thought about how to represent differences as numbers might be needed, too. To the greatest extent possible, the `subtype_diff` function should agree with the sort ordering implied by the selected operator class and collation; that is, its result should be positive whenever its first argument is greater than its second according to the sort ordering.

A less-oversimplified example of a `subtype_diff` function is:

```
CREATE FUNCTION time_subtype_diff(x time, y time) RETURNS float8 AS
'SELECT EXTRACT(EPOCH FROM (x - y))' LANGUAGE sql STRICT IMMUTABLE;

CREATE TYPE timerange AS RANGE (
    subtype = time,
    subtype_diff = time_subtype_diff
);

SELECT '[11:10, 23:00]'::timerange;
```

See CREATE TYPE for more information about creating range types.

8.17.9. Indexing

GiST and SP-GiST indexes can be created for table columns of range types. GiST indexes can be also created for table columns of multirange types. For instance, to create a GiST index:

```
CREATE INDEX reservation_idx ON reservation USING GIST (during);
```

A GiST or SP-GiST index on ranges can accelerate queries involving these range operators: `=`, `&&`, `<@`, `@>`, `<<`, `>>`, `-|-`, `&<`, and `&>`. A GiST index on multiranges can accelerate queries involving the same set of multirange operators. A GiST index on ranges and GiST index on multiranges can also accelerate queries involving these cross-type range to multirange and multirange to range operators correspondingly: `&&`, `<@`, `@>`, `<<`, `>>`, `-|-`, `&<`, and `&>`. See Table 9.53 for more information.

In addition, B-tree and hash indexes can be created for table columns of range types. For these index types, basically the only useful range operation is equality. There is a B-tree sort ordering defined for range values, with corresponding `<` and `>` operators, but the ordering is rather arbitrary and not usually useful in the real world. Range types' B-tree and hash support is primarily meant to allow sorting and hashing internally in queries, rather than creation of actual indexes.

8.17.10. Constraints on Ranges

While `UNIQUE` is a natural constraint for scalar values, it is usually unsuitable for range types. Instead, an exclusion constraint is often more appropriate (see CREATE TABLE ... CONSTRAINT ... EXCLUDE). Exclusion constraints allow the specification of constraints such as “non-overlapping” on a range type. For example:

```
CREATE TABLE reservation (
    during tsrange,
    EXCLUDE USING GIST (during WITH &&)
);
```

That constraint will prevent any overlapping values from existing in the table at the same time:

```
INSERT INTO reservation VALUES
    ('[2010-01-01 11:30, 2010-01-01 15:00)');
INSERT 0 1

INSERT INTO reservation VALUES
    ('[2010-01-01 14:45, 2010-01-01 15:45)');
ERROR:  conflicting key value violates exclusion constraint "reservation_during_excl"
DETAIL:  Key (during)=(["2010-01-01 14:45:00","2010-01-01 15:45:00")) conflicts
with existing key (during)=(["2010-01-01 11:30:00","2010-01-01 15:00:00")).
```

You can use the `btree_gist` extension to define exclusion constraints on plain scalar data types, which can then be combined with range exclusions for maximum flexibility. For example, after `btree_gist` is installed, the following constraint will reject overlapping ranges only if the meeting room numbers are equal:

```
CREATE EXTENSION btree_gist;
CREATE TABLE room_reservation (
    room text,
    during tsrange,
    EXCLUDE USING GIST (room WITH =, during WITH &&)
);

INSERT INTO room_reservation VALUES
    ('123A', '[2010-01-01 14:00, 2010-01-01 15:00)');
INSERT 0 1

INSERT INTO room_reservation VALUES
    ('123A', '[2010-01-01 14:30, 2010-01-01 15:30)');
ERROR:  conflicting key value violates exclusion constraint
 "room_reservation_room_during_excl"
DETAIL:  Key (room, during)=(123A, ["2010-01-01 14:30:00","2010-01-01 15:30:00"))
 conflicts
with existing key (room, during)=(123A, ["2010-01-01 14:00:00","2010-01-01 15:00:00")).

INSERT INTO room_reservation VALUES
    ('123B', '[2010-01-01 14:30, 2010-01-01 15:30)');
INSERT 0 1
```

8.18. Domain Types

A *domain* is a user-defined data type that is based on another *underlying type*. Optionally, it can have constraints that restrict its valid values to a subset of what the underlying type would allow. Otherwise it behaves like the underlying type — for example, any operator or function that can be applied to the underlying type will work on the domain type. The underlying type can be any built-in or user-defined base type, enum type, array type, composite type, range type, or another domain.

For example, we could create a domain over integers that accepts only positive integers:

```
CREATE DOMAIN posint AS integer CHECK (VALUE > 0);
CREATE TABLE mytable (id posint);
INSERT INTO mytable VALUES(1);   -- works
INSERT INTO mytable VALUES(-1);  -- fails
```

When an operator or function of the underlying type is applied to a domain value, the domain is automatically down-cast to the underlying type. Thus, for example, the result of `mytable.id - 1` is considered to be of type `integer` not `posint`. We could write `(mytable.id - 1)::posint` to cast the result back to `posint`, causing the domain's constraints to be rechecked. In this case, that would result in an error if the expression had been applied to an `id` value of 1. Assigning a value of the underlying type to a field or variable of the domain type is allowed without writing an explicit cast, but the domain's constraints will be checked.

For additional information see CREATE DOMAIN.

8.19. Object Identifier Types

Object identifiers (OIDs) are used internally by Postgres Pro as primary keys for various system tables. Type `oid` represents an object identifier. There are also several alias types for `oid`, each named `reg-something`. Table 8.26 shows an overview.

The `oid` type is currently implemented as an unsigned four-byte integer. Therefore, it is not large enough to provide database-wide uniqueness in large databases, or even in large individual tables.

The `oid` type itself has few operations beyond comparison. It can be cast to integer, however, and then manipulated using the standard integer operators. (Beware of possible signed-versus-unsigned confusion if you do this.)

The OID alias types have no operations of their own except for specialized input and output routines. These routines are able to accept and display symbolic names for system objects, rather than the raw numeric value that type `oid` would use. The alias types allow simplified lookup of OID values for objects. For example, to examine the `pg_attribute` rows related to a table `mytable`, one could write:

```
SELECT * FROM pg_attribute WHERE attrelid = 'mytable'::regclass;
```

rather than:

```
SELECT * FROM pg_attribute
  WHERE attrelid = (SELECT oid FROM pg_class WHERE relname = 'mytable');
```

While that doesn't look all that bad by itself, it's still oversimplified. A far more complicated sub-select would be needed to select the right OID if there are multiple tables named `mytable` in different schemas. The `regclass` input converter handles the table lookup according to the schema path setting, and so it does the “right thing” automatically. Similarly, casting a table's OID to `regclass` is handy for symbolic display of a numeric OID.

Table 8.26. Object Identifier Types

Name	References	Description	Value Example
`oid`	any	numeric object identifier	`564182`
`regclass`	`pg_class`	relation name	`pg_type`
`regcollation`	`pg_collation`	collation name	`"POSIX"`
`regconfig`	`pg_ts_config`	text search configuration	`english`
`regdictionary`	`pg_ts_dict`	text search dictionary	`simple`
`regnamespace`	`pg_namespace`	namespace name	`pg_catalog`
`regoper`	`pg_operator`	operator name	`+`
`regoperator`	`pg_operator`	operator with argument types	`*(integer,integer)` or `-(NONE,integer)`
`regproc`	`pg_proc`	function name	`sum`
`regprocedure`	`pg_proc`	function with argument types	`sum(int4)`
`regrole`	`pg_authid`	role name	`smithee`
`regtype`	`pg_type`	data type name	`integer`

All of the OID alias types for objects that are grouped by namespace accept schema-qualified names, and will display schema-qualified names on output if the object would not be found in the current search path without being qualified. For example, `myschema.mytable` is acceptable input for `regclass` (if there is such a table). That value might be output as `myschema.mytable`, or just `mytable`, depending on the

current search path. The `regproc` and `regoper` alias types will only accept input names that are unique (not overloaded), so they are of limited use; for most uses `regprocedure` or `regoperator` are more appropriate. For `regoperator`, unary operators are identified by writing `NONE` for the unused operand.

The input functions for these types allow whitespace between tokens, and will fold upper-case letters to lower case, except within double quotes; this is done to make the syntax rules similar to the way object names are written in SQL. Conversely, the output functions will use double quotes if needed to make the output be a valid SQL identifier. For example, the OID of a function named `Foo` (with upper case `F`) taking two integer arguments could be entered as `' "Foo" ( int, integer ) '::regprocedure`. The output would look like `"Foo"(integer,integer)`. Both the function name and the argument type names could be schema-qualified, too.

Many built-in PostgreSQL functions accept the OID of a table, or another kind of database object, and for convenience are declared as taking `regclass` (or the appropriate OID alias type). This means you do not have to look up the object's OID by hand, but can just enter its name as a string literal. For example, the `nextval(regclass)` function takes a sequence relation's OID, so you could call it like this:

```
nextval('foo')              operates on sequence foo
nextval('FOO')              same as above
nextval('"Foo"')            operates on sequence Foo
nextval('myschema.foo')     operates on myschema.foo
nextval('"myschema".foo')   same as above
nextval('foo')              searches search path for foo
```

> **Note**
>
> When you write the argument of such a function as an unadorned literal string, it becomes a constant of type `regclass` (or the appropriate type). Since this is really just an OID, it will track the originally identified object despite later renaming, schema reassignment, etc. This “early binding” behavior is usually desirable for object references in column defaults and views. But sometimes you might want “late binding” where the object reference is resolved at run time. To get late-binding behavior, force the constant to be stored as a `text` constant instead of `regclass`:
>
> ```
> nextval('foo'::text)      foo is looked up at runtime
> ```
>
> The `to_regclass()` function and its siblings can also be used to perform run-time lookups. See Table 9.70.

Another practical example of use of `regclass` is to look up the OID of a table listed in the `information_schema` views, which don't supply such OIDs directly. One might for example wish to call the `pg_relation_size()` function, which requires the table OID. Taking the above rules into account, the correct way to do that is

```
SELECT table_schema, table_name,
       pg_relation_size((quote_ident(table_schema) || '.' ||
                         quote_ident(table_name))::regclass)
FROM information_schema.tables
WHERE ...
```

The `quote_ident()` function will take care of double-quoting the identifiers where needed. The seemingly easier

```
SELECT pg_relation_size(table_name)
FROM information_schema.tables
WHERE ...
```

is *not recommended*, because it will fail for tables that are outside your search path or have names that require quoting.

An additional property of most of the OID alias types is the creation of dependencies. If a constant of one of these types appears in a stored expression (such as a column default expression or view),

it creates a dependency on the referenced object. For example, if a column has a default expression `nextval('my_seq'::regclass)`, Postgres Pro understands that the default expression depends on the sequence `my_seq`, so the system will not let the sequence be dropped without first removing the default expression. The alternative of `nextval('my_seq'::text)` does not create a dependency. (`regrole` is an exception to this property. Constants of this type are not allowed in stored expressions.)

Another identifier type used by the system is `xid`, or transaction (abbreviated xact) identifier. This is the data type of the system columns `xmin` and `xmax`. In Postgres Pro Enterprise, transaction IDs are implemented as 64-bit counters to prevent transaction ID wraparound. For details, see Section 24.1.5. In some contexts, `xid8` is also used. The `xid` and `xid8` values increase strictly monotonically and cannot be reused in the lifetime of a database cluster.

A third identifier type used by the system is `cid`, or command identifier. This is the data type of the system columns `cmin` and `cmax`. Command identifiers are 32-bit quantities.

A final identifier type used by the system is `tid`, or tuple identifier (row identifier). This is the data type of the system column `ctid`. A tuple ID is a pair (block number, tuple index within block) that identifies the physical location of the row within its table.

(The system columns are further explained in Section 5.5.)

8.20. `pg_lsn` Type

The `pg_lsn` data type can be used to store LSN (Log Sequence Number) data which is a pointer to a location in the WAL. This type is a representation of `XLogRecPtr` and an internal system type of Postgres Pro.

Internally, an LSN is a 64-bit integer, representing a byte position in the write-ahead log stream. It is printed as two hexadecimal numbers of up to 8 digits each, separated by a slash; for example, `16/B374D848`. The `pg_lsn` type supports the standard comparison operators, like `=` and `>`. Two LSNs can be subtracted using the `-` operator; the result is the number of bytes separating those write-ahead log locations. Also the number of bytes can be added into and subtracted from LSN using the `+(pg_lsn,numeric)` and `-(pg_lsn,numeric)` operators, respectively. Note that the calculated LSN should be in the range of `pg_lsn` type, i.e., between `0/0` and `FFFFFFFF/FFFFFFFF`.

8.21. Pseudo-Types

The Postgres Pro type system contains a number of special-purpose entries that are collectively called *pseudo-types*. A pseudo-type cannot be used as a column data type, but it can be used to declare a function's argument or result type. Each of the available pseudo-types is useful in situations where a function's behavior does not correspond to simply taking or returning a value of a specific SQL data type. Table 8.27 lists the existing pseudo-types.

Table 8.27. Pseudo-Types

Name	Description
`any`	Indicates that a function accepts any input data type.
`anyelement`	Indicates that a function accepts any data type (see Section 40.2.5).
`anyarray`	Indicates that a function accepts any array data type (see Section 40.2.5).
`anynonarray`	Indicates that a function accepts any non-array data type (see Section 40.2.5).
`anyenum`	Indicates that a function accepts any enum data type (see Section 40.2.5 and Section 8.7).
`anyrange`	Indicates that a function accepts any range data type (see Section 40.2.5 and Section 8.17).

Name	Description
anymultirange	Indicates that a function accepts any multirange data type (see Section 40.2.5 and Section 8.17).
anycompatible	Indicates that a function accepts any data type, with automatic promotion of multiple arguments to a common data type (see Section 40.2.5).
anycompatiblearray	Indicates that a function accepts any array data type, with automatic promotion of multiple arguments to a common data type (see Section 40.2.5).
anycompatiblenonarray	Indicates that a function accepts any non-array data type, with automatic promotion of multiple arguments to a common data type (see Section 40.2.5).
anycompatiblerange	Indicates that a function accepts any range data type, with automatic promotion of multiple arguments to a common data type (see Section 40.2.5 and Section 8.17).
anycompatiblemultirange	Indicates that a function accepts any multirange data type, with automatic promotion of multiple arguments to a common data type (see Section 40.2.5 and Section 8.17).
cstring	Indicates that a function accepts or returns a null-terminated C string.
internal	Indicates that a function accepts or returns a server-internal data type.
language_handler	A procedural language call handler is declared to return language_handler .
fdw_handler	A foreign-data wrapper handler is declared to return fdw_handler.
table_am_handler	A table access method handler is declared to return table_am_handler .
index_am_handler	An index access method handler is declared to return index_am_handler .
tsm_handler	A tablesample method handler is declared to return tsm_handler.
record	Identifies a function taking or returning an unspecified row type.
trigger	A trigger function is declared to return trigger.
event_trigger	An event trigger function is declared to return event_trigger.
pg_ddl_command	Identifies a representation of DDL commands that is available to event triggers.
void	Indicates that a function returns no value.
unknown	Identifies a not-yet-resolved type, e.g., of an undecorated string literal.

Functions coded in C (whether built-in or dynamically loaded) can be declared to accept or return any of these pseudo-types. It is up to the function author to ensure that the function will behave safely when a pseudo-type is used as an argument type.

Functions coded in procedural languages can use pseudo-types only as allowed by their implementation languages. At present most procedural languages forbid use of a pseudo-type as an argument type, and allow only void and record as a result type (plus trigger or event_trigger when the function

is used as a trigger or event trigger). Some also support polymorphic functions using the polymorphic pseudo-types, which are shown above and discussed in detail in Section 40.2.5.

The `internal` pseudo-type is used to declare functions that are meant only to be called internally by the database system, and not by direct invocation in an SQL query. If a function has at least one `internal`-type argument then it cannot be called from SQL. To preserve the type safety of this restriction it is important to follow this coding rule: do not create any function that is declared to return `internal` unless it has at least one `internal` argument.

Chapter 9. Functions and Operators

Postgres Pro provides a large number of functions and operators for the built-in data types. This chapter describes most of them, although additional special-purpose functions appear in relevant sections of the manual. Users can also define their own functions and operators, as described in Part V. The psql commands `\df` and `\do` can be used to list all available functions and operators, respectively.

The notation used throughout this chapter to describe the argument and result data types of a function or operator is like this:

```
repeat ( text, integer ) → text
```

which says that the function `repeat` takes one text and one integer argument and returns a result of type text. The right arrow is also used to indicate the result of an example, thus:

```
repeat('Pg', 4) → PgPgPgPg
```

If you are concerned about portability then note that most of the functions and operators described in this chapter, with the exception of the most trivial arithmetic and comparison operators and some explicitly marked functions, are not specified by the SQL standard. Some of this extended functionality is present in other SQL database management systems, and in many cases this functionality is compatible and consistent between the various implementations.

9.1. Logical Operators

The usual logical operators are available:

```
boolean AND boolean → boolean
boolean OR boolean → boolean
NOT boolean → boolean
```

SQL uses a three-valued logic system with true, false, and `null`, which represents “unknown”. Observe the following truth tables:

a	*b*	*a* AND *b*	*a* OR *b*
TRUE	TRUE	TRUE	TRUE
TRUE	FALSE	FALSE	TRUE
TRUE	NULL	NULL	TRUE
FALSE	FALSE	FALSE	FALSE
FALSE	NULL	FALSE	NULL
NULL	NULL	NULL	NULL

a	NOT *a*
TRUE	FALSE
FALSE	TRUE
NULL	NULL

The operators `AND` and `OR` are commutative, that is, you can switch the left and right operands without affecting the result. (However, it is not guaranteed that the left operand is evaluated before the right operand. See Section 4.2.14 for more information about the order of evaluation of subexpressions.)

9.2. Comparison Functions and Operators

The usual comparison operators are available, as shown in Table 9.1.

Table 9.1. Comparison Operators

Operator	Description
datatype < *datatype* → boolean	Less than
datatype > *datatype* → boolean	Greater than
datatype <= *datatype* → boolean	Less than or equal to
datatype >= *datatype* → boolean	Greater than or equal to
datatype = *datatype* → boolean	Equal
datatype <> *datatype* → boolean	Not equal
datatype != *datatype* → boolean	Not equal

> **Note**
>
> <> is the standard SQL notation for "not equal". != is an alias, which is converted to <> at a very early stage of parsing. Hence, it is not possible to implement != and <> operators that do different things.

These comparison operators are available for all built-in data types that have a natural ordering, including numeric, string, and date/time types. In addition, arrays, composite types, and ranges can be compared if their component data types are comparable.

It is usually possible to compare values of related data types as well; for example integer > bigint will work. Some cases of this sort are implemented directly by "cross-type" comparison operators, but if no such operator is available, the parser will coerce the less-general type to the more-general type and apply the latter's comparison operator.

As shown above, all comparison operators are binary operators that return values of type boolean. Thus, expressions like 1 < 2 < 3 are not valid (because there is no < operator to compare a Boolean value with 3). Use the BETWEEN predicates shown below to perform range tests.

There are also some comparison predicates, as shown in Table 9.2. These behave much like operators, but have special syntax mandated by the SQL standard.

Table 9.2. Comparison Predicates

Predicate Description Example(s)
datatype BETWEEN *datatype* AND *datatype* → boolean Between (inclusive of the range endpoints). 2 BETWEEN 1 AND 3 → t 2 BETWEEN 3 AND 1 → f
datatype NOT BETWEEN *datatype* AND *datatype* → boolean Not between (the negation of BETWEEN). 2 NOT BETWEEN 1 AND 3 → f
datatype BETWEEN SYMMETRIC *datatype* AND *datatype* → boolean Between, after sorting the two endpoint values. 2 BETWEEN SYMMETRIC 3 AND 1 → t
datatype NOT BETWEEN SYMMETRIC *datatype* AND *datatype* → boolean Not between, after sorting the two endpoint values. 2 NOT BETWEEN SYMMETRIC 3 AND 1 → f

Predicate **Description** **Example(s)**
datatype `IS DISTINCT FROM` *datatype* → `boolean` Not equal, treating null as a comparable value. `1 IS DISTINCT FROM NULL` → `t` (rather than `NULL`) `NULL IS DISTINCT FROM NULL` → `f` (rather than `NULL`)
datatype `IS NOT DISTINCT FROM` *datatype* → `boolean` Equal, treating null as a comparable value. `1 IS NOT DISTINCT FROM NULL` → `f` (rather than `NULL`) `NULL IS NOT DISTINCT FROM NULL` → `t` (rather than `NULL`)
datatype `IS NULL` → `boolean` Test whether value is null. `1.5 IS NULL` → `f`
datatype `IS NOT NULL` → `boolean` Test whether value is not null. `'null' IS NOT NULL` → `t`
datatype `ISNULL` → `boolean` Test whether value is null (nonstandard syntax).
datatype `NOTNULL` → `boolean` Test whether value is not null (nonstandard syntax).

`boolean IS TRUE` → `boolean`
Test whether boolean expression yields true.
`true IS TRUE` → `t`
`NULL::boolean IS TRUE` → `f` (rather than `NULL`)

`boolean IS NOT TRUE` → `boolean`
Test whether boolean expression yields false or unknown.
`true IS NOT TRUE` → `f`
`NULL::boolean IS NOT TRUE` → `t` (rather than `NULL`)

`boolean IS FALSE` → `boolean`
Test whether boolean expression yields false.
`true IS FALSE` → `f`
`NULL::boolean IS FALSE` → `f` (rather than `NULL`)

`boolean IS NOT FALSE` → `boolean`
Test whether boolean expression yields true or unknown.
`true IS NOT FALSE` → `t`
`NULL::boolean IS NOT FALSE` → `t` (rather than `NULL`)

`boolean IS UNKNOWN` → `boolean`
Test whether boolean expression yields unknown.
`true IS UNKNOWN` → `f`
`NULL::boolean IS UNKNOWN` → `t` (rather than `NULL`)

`boolean IS NOT UNKNOWN` → `boolean`
Test whether boolean expression yields true or false.
`true IS NOT UNKNOWN` → `t`
`NULL::boolean IS NOT UNKNOWN` → `f` (rather than `NULL`)

The BETWEEN predicate simplifies range tests:

a BETWEEN *x* AND *y*

is equivalent to

a >= *x* AND *a* <= *y*

Notice that BETWEEN treats the endpoint values as included in the range. BETWEEN SYMMETRIC is like BETWEEN except there is no requirement that the argument to the left of AND be less than or equal to the argument on the right. If it is not, those two arguments are automatically swapped, so that a nonempty range is always implied.

The various variants of BETWEEN are implemented in terms of the ordinary comparison operators, and therefore will work for any data type(s) that can be compared.

> **Note**
>
> The use of AND in the BETWEEN syntax creates an ambiguity with the use of AND as a logical operator. To resolve this, only a limited set of expression types are allowed as the second argument of a BETWEEN clause. If you need to write a more complex sub-expression in BETWEEN, write parentheses around the sub-expression.

Ordinary comparison operators yield null (signifying "unknown"), not true or false, when either input is null. For example, 7 = NULL yields null, as does 7 <> NULL. When this behavior is not suitable, use the IS [NOT] DISTINCT FROM predicates:

a IS DISTINCT FROM *b*
a IS NOT DISTINCT FROM *b*

For non-null inputs, IS DISTINCT FROM is the same as the <> operator. However, if both inputs are null it returns false, and if only one input is null it returns true. Similarly, IS NOT DISTINCT FROM is identical to = for non-null inputs, but it returns true when both inputs are null, and false when only one input is null. Thus, these predicates effectively act as though null were a normal data value, rather than "unknown".

To check whether a value is or is not null, use the predicates:

expression IS NULL
expression IS NOT NULL

or the equivalent, but nonstandard, predicates:

expression ISNULL
expression NOTNULL

Do *not* write *expression* = NULL because NULL is not "equal to" NULL. (The null value represents an unknown value, and it is not known whether two unknown values are equal.)

> **Tip**
>
> Some applications might expect that *expression* = NULL returns true if *expression* evaluates to the null value. It is highly recommended that these applications be modified to comply with the SQL standard. However, if that cannot be done the transform_null_equals configuration variable is available. If it is enabled, Postgres Pro will convert x = NULL clauses to x IS NULL.

If the *expression* is row-valued, then IS NULL is true when the row expression itself is null or when all the row's fields are null, while IS NOT NULL is true when the row expression itself is non-null and all the row's fields are non-null. Because of this behavior, IS NULL and IS NOT NULL do not always return inverse results for row-valued expressions; in particular, a row-valued expression that contains both null and non-null fields will return false for both tests. In some cases, it may be preferable to write *row* IS DISTINCT FROM NULL or *row* IS NOT DISTINCT FROM NULL, which will simply check whether the overall row value is null without any additional tests on the row fields.

Boolean values can also be tested using the predicates

```
boolean_expression IS TRUE
boolean_expression IS NOT TRUE
boolean_expression IS FALSE
boolean_expression IS NOT FALSE
boolean_expression IS UNKNOWN
boolean_expression IS NOT UNKNOWN
```

These will always return true or false, never a null value, even when the operand is null. A null input is treated as the logical value "unknown". Notice that `IS UNKNOWN` and `IS NOT UNKNOWN` are effectively the same as `IS NULL` and `IS NOT NULL`, respectively, except that the input expression must be of Boolean type.

Some comparison-related functions are also available, as shown in Table 9.3.

Table 9.3. Comparison Functions

Function **Description** **Example(s)**

`num_nonnulls ( VARIADIC "any" ) → integer`
Returns the number of non-null arguments.
`num_nonnulls(1, NULL, 2) → 2`

`num_nulls ( VARIADIC "any" ) → integer`
Returns the number of null arguments.
`num_nulls(1, NULL, 2) → 1`

9.3. Mathematical Functions and Operators

Mathematical operators are provided for many Postgres Pro types. For types without standard mathematical conventions (e.g., date/time types) we describe the actual behavior in subsequent sections.

Table 9.4 shows the mathematical operators that are available for the standard numeric types. Unless otherwise noted, operators shown as accepting *numeric_type* are available for all the types `smallint`, `integer`, `bigint`, `numeric`, `real`, and `double precision`. Operators shown as accepting *integral_type* are available for the types `smallint`, `integer`, and `bigint`. Except where noted, each form of an operator returns the same data type as its argument(s). Calls involving multiple argument data types, such as `integer + numeric`, are resolved by using the type appearing later in these lists.

Table 9.4. Mathematical Operators

Operator **Description** **Example(s)**
numeric_type `+` *numeric_type* `→` *numeric_type* Addition `2 + 3 → 5`
`+` *numeric_type* `→` *numeric_type* Unary plus (no operation) `+ 3.5 → 3.5`
numeric_type `-` *numeric_type* `→` *numeric_type* Subtraction `2 - 3 → -1`
`-` *numeric_type* `→` *numeric_type* Negation `- (-4) → 4`

Operator **Description** **Example(s)**
numeric_type * *numeric_type* → *numeric_type* Multiplication `2 * 3 → 6`

numeric_type / *numeric_type* → *numeric_type*
Division (for integral types, division truncates the result towards zero)
`5.0 / 2 → 2.5000000000000000`
`5 / 2 → 2`
`(-5) / 2 → -2`

numeric_type % *numeric_type* → *numeric_type* Modulo (remainder); available for `smallint`, `integer`, `bigint`, and `numeric` `5 % 4 → 1`

`numeric ^ numeric → numeric`
`double precision ^ double precision → double precision`
Exponentiation
`2 ^ 3 → 8`
Unlike typical mathematical practice, multiple uses of `^` will associate left to right by default:
`2 ^ 3 ^ 3 → 512`
`2 ^ (3 ^ 3) → 134217728`

`|/ double precision → double precision`
Square root
`|/ 25.0 → 5`

`||/ double precision → double precision`
Cube root
`||/ 64.0 → 4`

`@` *numeric_type* → *numeric_type* Absolute value `@ -5.0 → 5.0`
integral_type & *integral_type* → *integral_type* Bitwise AND `91 & 15 → 11`
integral_type | *integral_type* → *integral_type* Bitwise OR `32 | 3 → 35`
integral_type # *integral_type* → *integral_type* Bitwise exclusive OR `17 # 5 → 20`
`~` *integral_type* → *integral_type* Bitwise NOT `~1 → -2`
integral_type << `integer` → *integral_type* Bitwise shift left `1 << 4 → 16`

Operator Description Example(s)
integral_type >> integer → *integral_type* Bitwise shift right `8 >> 2` → `2`

Table 9.5 shows the available mathematical functions. Many of these functions are provided in multiple forms with different argument types. Except where noted, any given form of a function returns the same data type as its argument(s); cross-type cases are resolved in the same way as explained above for operators. The functions working with `double precision` data are mostly implemented on top of the host system's C library; accuracy and behavior in boundary cases can therefore vary depending on the host system.

Table 9.5. Mathematical Functions

Function Description Example(s)
`abs` (*numeric_type*) → *numeric_type* Absolute value `abs(-17.4)` → `17.4`

`cbrt` (`double precision`) → `double precision`
Cube root
`cbrt(64.0)` → `4`

`ceil` (`numeric`) → `numeric`
`ceil` (`double precision`) → `double precision`
Nearest integer greater than or equal to argument
`ceil(42.2)` → `43`
`ceil(-42.8)` → `-42`

`ceiling` (`numeric`) → `numeric`
`ceiling` (`double precision`) → `double precision`
Nearest integer greater than or equal to argument (same as `ceil`)
`ceiling(95.3)` → `96`

`degrees` (`double precision`) → `double precision`
Converts radians to degrees
`degrees(0.5)` → `28.64788975654116`

`div` (*y* `numeric`, *x* `numeric`) → `numeric`
Integer quotient of *y*/*x* (truncates towards zero)
`div(9, 4)` → `2`

`exp` (`numeric`) → `numeric`
`exp` (`double precision`) → `double precision`
Exponential (`e` raised to the given power)
`exp(1.0)` → `2.7182818284590452`

`factorial` (`bigint`) → `numeric`
Factorial
`factorial(5)` → `120`

`floor` (`numeric`) → `numeric` `floor` (`double precision`) → `double precision`

Function
Description
Example(s)

Nearest integer less than or equal to argument

```
floor(42.8)  → 42
floor(-42.8)  → -43
```

`gcd ( numeric_type , numeric_type ) → numeric_type`

Greatest common divisor (the largest positive number that divides both inputs with no remainder); returns `0` if both inputs are zero; available for `integer`, `bigint`, and `numeric`

```
gcd(1071, 462)   → 21
```

`lcm ( numeric_type , numeric_type ) → numeric_type`

Least common multiple (the smallest strictly positive number that is an integral multiple of both inputs); returns `0` if either input is zero; available for `integer`, `bigint`, and `numeric`

```
lcm(1071, 462)   → 23562
```

`ln ( numeric ) → numeric`
`ln ( double precision ) → double precision`

Natural logarithm

```
ln(2.0)  → 0.6931471805599453
```

`log ( numeric ) → numeric`
`log ( double precision ) → double precision`

Base 10 logarithm

```
log(100)  → 2
```

`log10 ( numeric ) → numeric`
`log10 ( double precision ) → double precision`

Base 10 logarithm (same as `log`)

```
log10(1000)  → 3
```

`log ( b numeric, x numeric ) → numeric`

Logarithm of *x* to base *b*

```
log(2.0, 64.0)   → 6.0000000000000000
```

`min_scale ( numeric ) → integer`

Minimum scale (number of fractional decimal digits) needed to represent the supplied value precisely

```
min_scale(8.4100)   → 2
```

`mod ( y numeric_type , x numeric_type ) → numeric_type`

Remainder of *y*/*x*; available for `smallint`, `integer`, `bigint`, and `numeric`

```
mod(9, 4)   → 1
```

`pi ( ) → double precision`

Approximate value of π

```
pi()  → 3.141592653589793
```

`power ( a numeric, b numeric ) → numeric`
`power ( a double precision, b double precision ) → double precision`

a raised to the power of *b*

```
power(9, 3)   → 729
```

`radians ( double precision ) → double precision`

Converts degrees to radians

Function **Description** **Example(s)**
`radians(45.0)` → `0.7853981633974483`

`round ( numeric ) → numeric`
`round ( double precision ) → double precision`
Rounds to nearest integer. For `numeric`, ties are broken by rounding away from zero. For `double precision`, the tie-breaking behavior is platform dependent, but "round to nearest even" is the most common rule.
`round(42.4)` → `42`

`round ( v numeric, s integer ) → numeric`
Rounds *v* to *s* decimal places. Ties are broken by rounding away from zero.
`round(42.4382, 2)` → `42.44`
`round(1234.56, -1)` → `1230`

`scale ( numeric ) → integer`
Scale of the argument (the number of decimal digits in the fractional part)
`scale(8.4100)` → `4`

`sign ( numeric ) → numeric`
`sign ( double precision ) → double precision`
Sign of the argument (-1, 0, or +1)
`sign(-8.4)` → `-1`

`sqrt ( numeric ) → numeric`
`sqrt ( double precision ) → double precision`
Square root
`sqrt(2)` → `1.4142135623730951`

`trim_scale ( numeric ) → numeric`
Reduces the value's scale (number of fractional decimal digits) by removing trailing zeroes
`trim_scale(8.4100)` → `8.41`

`trunc ( numeric ) → numeric`
`trunc ( double precision ) → double precision`
Truncates to integer (towards zero)
`trunc(42.8)` → `42`
`trunc(-42.8)` → `-42`

`trunc ( v numeric, s integer ) → numeric`
Truncates *v* to *s* decimal places
`trunc(42.4382, 2)` → `42.43`

`width_bucket ( operand numeric, low numeric, high numeric, count integer ) → integer`
`width_bucket ( operand double precision, low double precision, high double precision, count integer ) → integer`
Returns the number of the bucket in which *operand* falls in a histogram having *count* equal-width buckets spanning the range *low* to *high*. Returns `0` or *count*`+1` for an input outside that range.
`width_bucket(5.35, 0.024, 10.06, 5)` → `3`

`width_bucket ( operand anycompatible, thresholds anycompatiblearray ) → integer` Returns the number of the bucket in which *operand* falls given an array listing the lower bounds of the buckets. Returns `0` for an input less than the first lower bound. *operand* and the

Function Description Example(s)
array elements can be of any type having standard comparison operators. The *thresholds* array *must be sorted*, smallest first, or unexpected results will be obtained. `width_bucket(now(), array['yesterday', 'today', 'tomorrow']::timestamptz[])` → `2`

Table 9.6 shows functions for generating random numbers.

Table 9.6. Random Functions

Function Description Example(s)

`random ( )` → `double precision`
Returns a random value in the range 0.0 <= x < 1.0
`random()` → `0.897124072839091`

`setseed ( double precision )` → `void`
Sets the seed for subsequent `random()` calls; argument must be between -1.0 and 1.0, inclusive
`setseed(0.12345)`

The `random()` function uses a simple linear congruential algorithm. It is fast but not suitable for cryptographic applications; see the pgcrypto module for a more secure alternative. If `setseed()` is called, the series of results of subsequent `random()` calls in the current session can be repeated by re-issuing `setseed()` with the same argument. Without any prior `setseed()` call in the same session, the first `random()` call obtains a seed from a platform-dependent source of random bits.

Table 9.7 shows the available trigonometric functions. Each of these functions comes in two variants, one that measures angles in radians and one that measures angles in degrees.

Table 9.7. Trigonometric Functions

Function Description Example(s)

`acos ( double precision )` → `double precision`
Inverse cosine, result in radians
`acos(1)` → `0`

`acosd ( double precision )` → `double precision`
Inverse cosine, result in degrees
`acosd(0.5)` → `60`

`asin ( double precision )` → `double precision`
Inverse sine, result in radians
`asin(1)` → `1.5707963267948966`

`asind ( double precision )` → `double precision`
Inverse sine, result in degrees
`asind(0.5)` → `30`

`atan ( double precision )` → `double precision` Inverse tangent, result in radians

Function **Description** **Example(s)**
`atan(1)` → `0.7853981633974483`

`atand ( double precision )` → `double precision`
Inverse tangent, result in degrees
`atand(1)` → `45`

`atan2 ( y double precision, x double precision )` → `double precision`
Inverse tangent of *y*/*x*, result in radians
`atan2(1, 0)` → `1.5707963267948966`

`atan2d ( y double precision, x double precision )` → `double precision`
Inverse tangent of *y*/*x*, result in degrees
`atan2d(1, 0)` → `90`

`cos ( double precision )` → `double precision`
Cosine, argument in radians
`cos(0)` → `1`

`cosd ( double precision )` → `double precision`
Cosine, argument in degrees
`cosd(60)` → `0.5`

`cot ( double precision )` → `double precision`
Cotangent, argument in radians
`cot(0.5)` → `1.830487721712452`

`cotd ( double precision )` → `double precision`
Cotangent, argument in degrees
`cotd(45)` → `1`

`sin ( double precision )` → `double precision`
Sine, argument in radians
`sin(1)` → `0.8414709848078965`

`sind ( double precision )` → `double precision`
Sine, argument in degrees
`sind(30)` → `0.5`

`tan ( double precision )` → `double precision`
Tangent, argument in radians
`tan(1)` → `1.5574077246549023`

`tand ( double precision )` → `double precision`
Tangent, argument in degrees
`tand(45)` → `1`

Note

Another way to work with angles measured in degrees is to use the unit transformation functions `radians()` and `degrees()` shown earlier. However, using the degree-based trigonometric functions is preferred, as that way avoids round-off error for special cases such as `sind(30)`.

Table 9.8 shows the available hyperbolic functions.

Table 9.8. Hyperbolic Functions

Function Description Example(s)

`sinh ( double precision ) → double precision`
Hyperbolic sine
`sinh(1) → 1.1752011936438014`

`cosh ( double precision ) → double precision`
Hyperbolic cosine
`cosh(0) → 1`

`tanh ( double precision ) → double precision`
Hyperbolic tangent
`tanh(1) → 0.7615941559557649`

`asinh ( double precision ) → double precision`
Inverse hyperbolic sine
`asinh(1) → 0.881373587019543`

`acosh ( double precision ) → double precision`
Inverse hyperbolic cosine
`acosh(1) → 0`

`atanh ( double precision ) → double precision`
Inverse hyperbolic tangent
`atanh(0.5) → 0.5493061443340548`

9.4. String Functions and Operators

This section describes functions and operators for examining and manipulating string values. Strings in this context include values of the types `character`, `character varying`, and `text`. Except where noted, these functions and operators are declared to accept and return type `text`. They will interchangeably accept `character varying` arguments. Values of type `character` will be converted to `text` before the function or operator is applied, resulting in stripping any trailing spaces in the `character` value.

SQL defines some string functions that use key words, rather than commas, to separate arguments. Details are in Table 9.9. Postgres Pro also provides versions of these functions that use the regular function invocation syntax (see Table 9.10).

> **Note**
>
> The string concatenation operator (`||`) will accept non-string input, so long as at least one input is of string type, as shown in Table 9.9. For other cases, inserting an explicit coercion to `text` can be used to have non-string input accepted.

Table 9.9. SQL String Functions and Operators

Function/Operator Description Example(s)

`text || text → text`
Concatenates the two strings.
`'Post' || 'greSQL' → PostgreSQL`

`text || anynonarray → text`

Function/Operator
Description
Example(s)

`anynonarray || text → text`
Converts the non-string input to text, then concatenates the two strings. (The non-string input cannot be of an array type, because that would create ambiguity with the array `||` operators. If you want to concatenate an array's text equivalent, cast it to `text` explicitly.)
`'Value: ' || 42 → Value: 42`

`text IS [NOT] [form] NORMALIZED → boolean`
Checks whether the string is in the specified Unicode normalization form. The optional *form* key word specifies the form: `NFC` (the default), `NFD`, `NFKC`, or `NFKD`. This expression can only be used when the server encoding is `UTF8`. Note that checking for normalization using this expression is often faster than normalizing possibly already normalized strings.
`U&'\0061\0308bc' IS NFD NORMALIZED → t`

`bit_length ( text ) → integer`
Returns number of bits in the string (8 times the `octet_length`).
`bit_length('jose') → 32`

`char_length ( text ) → integer`
`character_length ( text ) → integer`
Returns number of characters in the string.
`char_length('josé') → 4`

`lower ( text ) → text`
Converts the string to all lower case, according to the rules of the database's locale.
`lower('TOM') → tom`

`normalize ( text [, form ] ) → text`
Converts the string to the specified Unicode normalization form. The optional *form* key word specifies the form: `NFC` (the default), `NFD`, `NFKC`, or `NFKD`. This function can only be used when the server encoding is `UTF8`.
`normalize(U&'\0061\0308bc', NFC) → U&'\00E4bc'`

`octet_length ( text ) → integer`
Returns number of bytes in the string.
`octet_length('josé') → 5` (if server encoding is UTF8)

`octet_length ( character ) → integer`
Returns number of bytes in the string. Since this version of the function accepts type `character` directly, it will not strip trailing spaces.
`octet_length('abc '::character(4)) → 4`

`overlay ( string text PLACING newsubstring text FROM start integer [ FOR count integer ] ) → text`
Replaces the substring of *string* that starts at the *start*'th character and extends for *count* characters with *newsubstring*. If *count* is omitted, it defaults to the length of *newsubstring*.
`overlay('Txxxxas' placing 'hom' from 2 for 4) → Thomas`

`position ( substring text IN string text ) → integer`
Returns first starting index of the specified *substring* within *string*, or zero if it's not present.
`position('om' in 'Thomas') → 3`

`substring ( string text [ FROM start integer ] [ FOR count integer ] ) → text`

Function/Operator **Description** **Example(s)**

Extracts the substring of *string* starting at the *start*'th character if that is specified, and stopping after *count* characters if that is specified. Provide at least one of *start* and *count*.
`substring('Thomas' from 2 for 3)` → `hom`
`substring('Thomas' from 3)` → `omas`
`substring('Thomas' for 2)` → `Th`

`substring ( string text FROM pattern text ) → text`
Extracts the first substring matching POSIX regular expression; see Section 9.7.3.
`substring('Thomas' from '...$')` → `mas`

`substring ( string text SIMILAR pattern text ESCAPE escape text ) → text`
`substring ( string text FROM pattern text FOR escape text ) → text`
Extracts the first substring matching SQL regular expression; see Section 9.7.2. The first form has been specified since SQL:2003; the second form was only in SQL:1999 and should be considered obsolete.
`substring('Thomas' similar '%#"o_a#"_' escape '#')` → `oma`

`trim ( [ LEADING | TRAILING | BOTH ] [ characters text ] FROM string text ) → text`
Removes the longest string containing only characters in *characters* (a space by default) from the start, end, or both ends (`BOTH` is the default) of *string*.
`trim(both 'xyz' from 'yxTomxx')` → `Tom`

`trim ( [ LEADING | TRAILING | BOTH ] [ FROM ] string text [, characters text ] ) → text`
This is a non-standard syntax for `trim()` .
`trim(both from 'yxTomxx', 'xyz')` → `Tom`

`upper ( text ) → text`
Converts the string to all upper case, according to the rules of the database's locale.
`upper('tom')` → `TOM`

Additional string manipulation functions are available and are listed in Table 9.10. Some of them are used internally to implement the SQL-standard string functions listed in Table 9.9.

Table 9.10. Other String Functions

Function **Description** **Example(s)**

`ascii ( text ) → integer`
Returns the numeric code of the first character of the argument. In UTF8 encoding, returns the Unicode code point of the character. In other multibyte encodings, the argument must be an ASCII character.
`ascii('x')` → `120`

`btrim ( string text [, characters text ] ) → text`
Removes the longest string containing only characters in *characters* (a space by default) from the start and end of *string*.
`btrim('xyxtrimyyx', 'xyz')` → `trim`

`chr ( integer ) → text`
Returns the character with the given code. In UTF8 encoding the argument is treated as a Unicode code point. In other multibyte encodings the argument must designate an ASCII character. `chr(0)` is disallowed because text data types cannot store that character.
`chr(65)` → `A`

Function
Description
Example(s)

`concat` (*val1* "any" [, *val2* "any" [, ...]]) → `text`
Concatenates the text representations of all the arguments. NULL arguments are ignored.
`concat('abcde', 2, NULL, 22)` → `abcde222`

`concat_ws` (*sep* `text`, *val1* "any" [, *val2* "any" [, ...]]) → `text`
Concatenates all but the first argument, with separators. The first argument is used as the separator string, and should not be NULL. Other NULL arguments are ignored.
`concat_ws(',', 'abcde', 2, NULL, 22)` → `abcde,2,22`

`format` (*formatstr* `text` [, *formatarg* "any" [, ...]]) → `text`
Formats arguments according to a format string; see Section 9.4.1. This function is similar to the C function `sprintf`.
`format('Hello %s, %1$s', 'World')` → `Hello World, World`

`initcap` (`text`) → `text`
Converts the first letter of each word to upper case and the rest to lower case. Words are sequences of alphanumeric characters separated by non-alphanumeric characters.
`initcap('hi THOMAS')` → `Hi Thomas`

`left` (*string* `text`, *n* `integer`) → `text`
Returns first *n* characters in the string, or when *n* is negative, returns all but last |*n*| characters.
`left('abcde', 2)` → `ab`

`length` (`text`) → `integer`
Returns the number of characters in the string.
`length('jose')` → `4`

`lpad` (*string* `text`, *length* `integer` [, *fill* `text`]) → `text`
Extends the *string* to length *length* by prepending the characters *fill* (a space by default). If the *string* is already longer than *length* then it is truncated (on the right).
`lpad('hi', 5, 'xy')` → `xyxhi`

`ltrim` (*string* `text` [, *characters* `text`]) → `text`
Removes the longest string containing only characters in *characters* (a space by default) from the start of *string*.
`ltrim('zzzytest', 'xyz')` → `test`

`md5` (`text`) → `text`
Computes the MD5 hash of the argument, with the result written in hexadecimal.
`md5('abc')` → `900150983cd24fb0d6963f7d28e17f72`

`parse_ident` (*qualified_identifier* `text` [, *strict_mode* `boolean DEFAULT true`]) → `text[]`
Splits *qualified_identifier* into an array of identifiers, removing any quoting of individual identifiers. By default, extra characters after the last identifier are considered an error; but if the second parameter is `false`, then such extra characters are ignored. (This behavior is useful for parsing names for objects like functions.) Note that this function does not truncate over-length identifiers. If you want truncation you can cast the result to `name[]`.
`parse_ident('"SomeSchema".someTable')` → `{SomeSchema,sometable}`

`pg_client_encoding` ( ) → `name`
Returns current client encoding name.
`pg_client_encoding()` → `UTF8`

`quote_ident` (`text`) → `text`

Function **Description** **Example(s)**
Returns the given string suitably quoted to be used as an identifier in an SQL statement string. Quotes are added only if necessary (i.e., if the string contains non-identifier characters or would be case-folded). Embedded quotes are properly doubled. See also Example 45.1. `quote_ident('Foo bar')` → `"Foo bar"`

`quote_literal ( text ) → text`
Returns the given string suitably quoted to be used as a string literal in an SQL statement string. Embedded single-quotes and backslashes are properly doubled. Note that `quote_literal` returns null on null input; if the argument might be null, `quote_nullable` is often more suitable. See also Example 45.1.
`quote_literal(E'O\'Reilly')` → `'O''Reilly'`

`quote_literal ( anyelement ) → text`
Converts the given value to text and then quotes it as a literal. Embedded single-quotes and backslashes are properly doubled.
`quote_literal(42.5)` → `'42.5'`

`quote_nullable ( text ) → text`
Returns the given string suitably quoted to be used as a string literal in an SQL statement string; or, if the argument is null, returns `NULL`. Embedded single-quotes and backslashes are properly doubled. See also Example 45.1.
`quote_nullable(NULL)` → `NULL`

`quote_nullable ( anyelement ) → text`
Converts the given value to text and then quotes it as a literal; or, if the argument is null, returns `NULL`. Embedded single-quotes and backslashes are properly doubled.
`quote_nullable(42.5)` → `'42.5'`

`regexp_match ( string text, pattern text [, flags text ] ) → text[]`
Returns captured substrings resulting from the first match of a POSIX regular expression to the *string*; see Section 9.7.3.
`regexp_match('foobarbequebaz', '(bar)(beque)')` → `{bar,beque}`

`regexp_matches ( string text, pattern text [, flags text ] ) → setof text[]`
Returns captured substrings resulting from the first match of a POSIX regular expression to the *string*, or multiple matches if the `g` flag is used; see Section 9.7.3.
`regexp_matches('foobarbequebaz', 'ba.', 'g')` →
`{bar}`
`{baz}`

`regexp_replace ( string text, pattern text, replacement text [, flags text ] ) → text`
Replaces substrings resulting from the first match of a POSIX regular expression, or multiple substring matches if the `g` flag is used; see Section 9.7.3.
`regexp_replace('Thomas', '.[mN]a.', 'M')` → `ThM`

`regexp_split_to_array ( string text, pattern text [, flags text ] ) → text[]`
Splits *string* using a POSIX regular expression as the delimiter, producing an array of results; see Section 9.7.3.
`regexp_split_to_array('hello world', '\s+')` → `{hello,world}`

`regexp_split_to_table ( string text, pattern text [, flags text ] ) → setof text` Splits *string* using a POSIX regular expression as the delimiter, producing a set of results; see Section 9.7.3. `regexp_split_to_table('hello world', '\s+')` →

Function **Description** **Example(s)**
hello world
repeat (*string* text, *number* integer) → text Repeats *string* the specified *number* of times. repeat('Pg', 4) → PgPgPgPg
replace (*string* text, *from* text, *to* text) → text Replaces all occurrences in *string* of substring *from* with substring *to*. replace('abcdefabcdef', 'cd', 'XX') → abXXefabXXef
reverse (text) → text Reverses the order of the characters in the string. reverse('abcde') → edcba
right (*string* text, *n* integer) → text Returns last *n* characters in the string, or when *n* is negative, returns all but first |*n*| characters. right('abcde', 2) → de
rpad (*string* text, *length* integer [, *fill* text]) → text Extends the *string* to length *length* by appending the characters *fill* (a space by default). If the *string* is already longer than *length* then it is truncated. rpad('hi', 5, 'xy') → hixyx
rtrim (*string* text [, *characters* text]) → text Removes the longest string containing only characters in *characters* (a space by default) from the end of *string*. rtrim('testxxzx', 'xyz') → test
split_part (*string* text, *delimiter* text, *n* integer) → text Splits *string* at occurrences of *delimiter* and returns the *n*'th field (counting from one), or when *n* is negative, returns the |*n*|'th-from-last field. split_part('abc~@~def~@~ghi', '~@~', 2) → def split_part('abc,def,ghi,jkl', ',', -2) → ghi
strpos (*string* text, *substring* text) → integer Returns first starting index of the specified *substring* within *string*, or zero if it's not present. (Same as position(*substring* in *string*), but note the reversed argument order.) strpos('high', 'ig') → 2
substr (*string* text, *start* integer [, *count* integer]) → text Extracts the substring of *string* starting at the *start*'th character, and extending for *count* characters if that is specified. (Same as substring(*string* from *start* for *count*).) substr('alphabet', 3) → phabet substr('alphabet', 3, 2) → ph
starts_with (*string* text, *prefix* text) → boolean Returns true if *string* starts with *prefix*. starts_with('alphabet', 'alph') → t
string_to_array (*string* text, *delimiter* text [, *null_string* text]) → text[] Splits the *string* at occurrences of *delimiter* and forms the resulting fields into a text array. If *delimiter* is NULL, each character in the *string* will become a separate element in the

Function **Description** **Example(s)**
array. If *delimiter* is an empty string, then the *string* is treated as a single field. If *null_string* is supplied and is not NULL, fields matching that string are replaced by NULL. `string_to_array('xx~~yy~~zz', '~~', 'yy')` → {xx,NULL,zz}

`string_to_table ( string text, delimiter text [, null_string text ] )` → `setof text`
Splits the *string* at occurrences of *delimiter* and returns the resulting fields as a set of text rows. If *delimiter* is NULL, each character in the *string* will become a separate row of the result. If *delimiter* is an empty string, then the *string* is treated as a single field. If *null_string* is supplied and is not NULL, fields matching that string are replaced by NULL.
`string_to_table('xx~^~yy~^~zz', '~^~', 'yy')` →
`xx`
`NULL`
`zz`

`to_ascii ( string text )` → `text`
`to_ascii ( string text, encoding name )` → `text`
`to_ascii ( string text, encoding integer )` → `text`
Converts *string* to ASCII from another encoding, which may be identified by name or number. If *encoding* is omitted the database encoding is assumed (which in practice is the only useful case). The conversion consists primarily of dropping accents. Conversion is only supported from LATIN1, LATIN2, LATIN9, and WIN1250 encodings. (See the unaccent module for another, more flexible solution.)
`to_ascii('Karél')` → Karel

`to_hex ( integer )` → `text`
`to_hex ( bigint )` → `text`
Converts the number to its equivalent hexadecimal representation.
`to_hex(2147483647)` → 7fffffff

`translate ( string text, from text, to text )` → `text` Replaces each character in *string* that matches a character in the *from* set with the corresponding character in the *to* set. If *from* is longer than *to*, occurrences of the extra characters in *from* are deleted. `translate('12345', '143', 'ax')` → a2x5
`unistr ( text )` → `text` Evaluate escaped Unicode characters in the argument. Unicode characters can be specified as *XXXX* (4 hexadecimal digits), \+*XXXXXX* (6 hexadecimal digits), \u*XXXX* (4 hexadecimal digits), or \U*XXXXXXXX* (8 hexadecimal digits). To specify a backslash, write two backslashes. All other characters are taken literally. If the server encoding is not UTF-8, the Unicode code point identified by one of these escape sequences is converted to the actual server encoding; an error is reported if that's not possible. This function provides a (non-standard) alternative to string constants with Unicode escapes (see Section 4.1.2.3). `unistr('d\0061t\+000061')` → data `unistr('d\u0061t\U00000061')` → data

The concat, concat_ws and format functions are variadic, so it is possible to pass the values to be concatenated or formatted as an array marked with the VARIADIC keyword (see Section 40.5.6). The array's elements are treated as if they were separate ordinary arguments to the function. If the variadic array argument is NULL, concat and concat_ws return NULL, but format treats a NULL as a zero-element array.

See also the aggregate function `string_agg` in Section 9.21, and the functions for converting between strings and the `bytea` type in Table 9.13.

9.4.1. `format`

The function `format` produces output formatted according to a format string, in a style similar to the C function `sprintf`.

`format(`*`formatstr`* `text [,` *`formatarg`* `"any" [, ...] ])`

`formatstr` is a format string that specifies how the result should be formatted. Text in the format string is copied directly to the result, except where *format specifiers* are used. Format specifiers act as placeholders in the string, defining how subsequent function arguments should be formatted and inserted into the result. Each *`formatarg`* argument is converted to text according to the usual output rules for its data type, and then formatted and inserted into the result string according to the format specifier(s).

Format specifiers are introduced by a `%` character and have the form

`%[`*`position`*`][`*`flags`*`][`*`width`*`]`*`type`*

where the component fields are:

`position` (optional)

A string of the form *`n`*`$` where *`n`* is the index of the argument to print. Index 1 means the first argument after *`formatstr`*. If the *`position`* is omitted, the default is to use the next argument in sequence.

`flags` (optional)

Additional options controlling how the format specifier's output is formatted. Currently the only supported flag is a minus sign (`-`) which will cause the format specifier's output to be left-justified. This has no effect unless the *`width`* field is also specified.

`width` (optional)

Specifies the *minimum* number of characters to use to display the format specifier's output. The output is padded on the left or right (depending on the `-` flag) with spaces as needed to fill the width. A too-small width does not cause truncation of the output, but is simply ignored. The width may be specified using any of the following: a positive integer; an asterisk (`*`) to use the next function argument as the width; or a string of the form `*`*`n`*`$` to use the *`n`*th function argument as the width.

If the width comes from a function argument, that argument is consumed before the argument that is used for the format specifier's value. If the width argument is negative, the result is left aligned (as if the `-` flag had been specified) within a field of length `abs(`*`width`*`)`.

`type` (required)

The type of format conversion to use to produce the format specifier's output. The following types are supported:

- `s` formats the argument value as a simple string. A null value is treated as an empty string.
- `I` treats the argument value as an SQL identifier, double-quoting it if necessary. It is an error for the value to be null (equivalent to `quote_ident`).
- `L` quotes the argument value as an SQL literal. A null value is displayed as the string `NULL`, without quotes (equivalent to `quote_nullable`).

In addition to the format specifiers described above, the special sequence `%%` may be used to output a literal `%` character.

Here are some examples of the basic format conversions:

```
SELECT format('Hello %s', 'World');
Result: Hello World
```

```
SELECT format('Testing %s, %s, %s, %%', 'one', 'two', 'three');
Result: Testing one, two, three, %

SELECT format('INSERT INTO %I VALUES(%L)', 'Foo bar', E'O\'Reilly');
Result: INSERT INTO "Foo bar" VALUES('O''Reilly')

SELECT format('INSERT INTO %I VALUES(%L)', 'locations', 'C:\Program Files');
Result: INSERT INTO locations VALUES('C:\Program Files')
```

Here are examples using *width* fields and the - flag:

```
SELECT format('|%10s|', 'foo');
Result: |       foo|

SELECT format('|%-10s|', 'foo');
Result: |foo       |

SELECT format('|%*s|', 10, 'foo');
Result: |       foo|

SELECT format('|%*s|', -10, 'foo');
Result: |foo       |

SELECT format('|%-*s|', 10, 'foo');
Result: |foo       |

SELECT format('|%-*s|', -10, 'foo');
Result: |foo       |
```

These examples show use of *position* fields:

```
SELECT format('Testing %3$s, %2$s, %1$s', 'one', 'two', 'three');
Result: Testing three, two, one

SELECT format('|%*2$s|', 'foo', 10, 'bar');
Result: |       bar|

SELECT format('|%1$*2$s|', 'foo', 10, 'bar');
Result: |       foo|
```

Unlike the standard C function `sprintf`, Postgres Pro's `format` function allows format specifiers with and without *position* fields to be mixed in the same format string. A format specifier without a *position* field always uses the next argument after the last argument consumed. In addition, the `format` function does not require all function arguments to be used in the format string. For example:

```
SELECT format('Testing %3$s, %2$s, %s', 'one', 'two', 'three');
Result: Testing three, two, three
```

The `%I` and `%L` format specifiers are particularly useful for safely constructing dynamic SQL statements. See Example 45.1.

9.5. Binary String Functions and Operators

This section describes functions and operators for examining and manipulating binary strings, that is values of type `bytea`. Many of these are equivalent, in purpose and syntax, to the text-string functions described in the previous section.

SQL defines some string functions that use key words, rather than commas, to separate arguments. Details are in Table 9.11. Postgres Pro also provides versions of these functions that use the regular function invocation syntax (see Table 9.12).

Table 9.11. SQL Binary String Functions and Operators

Function/Operator Description Example(s)

`bytea || bytea → bytea`
Concatenates the two binary strings.
`'\x123456'::bytea || '\x789a00bcde'::bytea → \x123456789a00bcde`

`bit_length ( bytea ) → integer`
Returns number of bits in the binary string (8 times the `octet_length`).
`bit_length('\x123456'::bytea) → 24`

`octet_length ( bytea ) → integer`
Returns number of bytes in the binary string.
`octet_length('\x123456'::bytea) → 3`

`overlay ( bytes bytea PLACING newsubstring bytea FROM start integer [ FOR count integer ] ) → bytea`
Replaces the substring of *bytes* that starts at the *start*'th byte and extends for *count* bytes with *newsubstring*. If *count* is omitted, it defaults to the length of *newsubstring*.
`overlay('\x1234567890'::bytea placing '\002\003'::bytea from 2 for 3) → \x12020390`

`position ( substring bytea IN bytes bytea ) → integer`
Returns first starting index of the specified *substring* within *bytes*, or zero if it's not present.
`position('\x5678'::bytea in '\x1234567890'::bytea) → 3`

`substring ( bytes bytea [ FROM start integer ] [ FOR count integer ] ) → bytea`
Extracts the substring of *bytes* starting at the *start*'th byte if that is specified, and stopping after *count* bytes if that is specified. Provide at least one of *start* and *count*.
`substring('\x1234567890'::bytea from 3 for 2) → \x5678`

`trim ( [ LEADING | TRAILING | BOTH ] bytesremoved bytea FROM bytes bytea ) → bytea`
Removes the longest string containing only bytes appearing in *bytesremoved* from the start, end, or both ends (`BOTH` is the default) of *bytes*.
`trim('\x9012'::bytea from '\x1234567890'::bytea) → \x345678`

`trim ( [ LEADING | TRAILING | BOTH ] [ FROM ] bytes bytea, bytesremoved bytea ) → bytea`
This is a non-standard syntax for `trim()` .
`trim(both from '\x1234567890'::bytea, '\x9012'::bytea) → \x345678`

Additional binary string manipulation functions are available and are listed in Table 9.12. Some of them are used internally to implement the SQL-standard string functions listed in Table 9.11.

Table 9.12. Other Binary String Functions

Function Description Example(s)

`bit_count ( bytes bytea ) → bigint`
Returns the number of bits set in the binary string (also known as “popcount”).
`bit_count('\x1234567890'::bytea) → 15`

`btrim ( bytes bytea, bytesremoved bytea ) → bytea`
Removes the longest string containing only bytes appearing in *bytesremoved* from the start and end of *bytes*.
`btrim('\x1234567890'::bytea, '\x9012'::bytea) → \x345678`

Function **Description** **Example(s)**

`get_bit ( bytes bytea, n bigint ) → integer`
Extracts n'th bit from binary string.
`get_bit('\x1234567890'::bytea, 30)  → 1`

`get_byte ( bytes bytea, n integer ) → integer`
Extracts n'th byte from binary string.
`get_byte('\x1234567890'::bytea, 4)  → 144`

`length ( bytea ) → integer`
Returns the number of bytes in the binary string.
`length('\x1234567890'::bytea)  → 5`

`length ( bytes bytea, encoding name ) → integer`
Returns the number of characters in the binary string, assuming that it is text in the given *encoding*.
`length('jose'::bytea, 'UTF8')  → 4`

`ltrim ( bytes bytea, bytesremoved bytea ) → bytea`
Removes the longest string containing only bytes appearing in *bytesremoved* from the start of *bytes*.
`ltrim('\x1234567890'::bytea, '\x9012'::bytea)  → \x34567890`

`md5 ( bytea ) → text`
Computes the MD5 hash of the binary string, with the result written in hexadecimal.
`md5('Th\000omas'::bytea)  → 8ab2d3c9689aaf18b4958c334c82d8b1`

`rtrim ( bytes bytea, bytesremoved bytea ) → bytea`
Removes the longest string containing only bytes appearing in *bytesremoved* from the end of *bytes*.
`rtrim('\x1234567890'::bytea, '\x9012'::bytea)  → \x12345678`

`set_bit ( bytes bytea, n bigint, newvalue integer ) → bytea`
Sets n'th bit in binary string to *newvalue*.
`set_bit('\x1234567890'::bytea, 30, 0)  → \x1234563890`

`set_byte ( bytes bytea, n integer, newvalue integer ) → bytea`
Sets n'th byte in binary string to *newvalue*.
`set_byte('\x1234567890'::bytea, 4, 64)  → \x1234567840`

`sha224 ( bytea ) → bytea`
Computes the SHA-224 hash of the binary string.
`sha224('abc'::bytea)  → \x23097d223405d8228642a477bda255b32aadbce4b-da0b3f7e36c9da7`

`sha256 ( bytea ) → bytea`
Computes the SHA-256 hash of the binary string.
`sha256('abc'::bytea)  → \xba7816bf8f01cfea414140de5dae2223b00361a396177a9cb410ff61f20015ad`

`sha384 ( bytea ) → bytea`
Computes the SHA-384 hash of the binary string.
`sha384('abc'::bytea)  → \xcb00753f45a35e8bb5a03d699ac65007272c32ab0ed-ed1631a8b605a43ff5bed8086072ba1e7cc2358baeca134c825a7`

`sha512 ( bytea ) → bytea`

Function Description Example(s)
Computes the SHA-512 hash of the binary string. `sha512('abc'::bytea)` → `\xddaf35a193617abacc417349ae204131 12e6fa4e89a97ea20a9eeee64b55d39a2192992a274fc1a836ba3c23a3feebbd 454d4423643ce80e2a9ac94fa54ca49f`

`substr ( bytes bytea, start integer [, count integer ] ) → bytea`
Extracts the substring of *bytes* starting at the *start*'th byte, and extending for *count* bytes if that is specified. (Same as `substring( bytes from start for count)`.)
`substr('\x1234567890'::bytea, 3, 2)` → `\x5678`

Functions `get_byte` and `set_byte` number the first byte of a binary string as byte 0. Functions `get_bit` and `set_bit` number bits from the right within each byte; for example bit 0 is the least significant bit of the first byte, and bit 15 is the most significant bit of the second byte.

For historical reasons, the function `md5` returns a hex-encoded value of type `text` whereas the SHA-2 functions return type `bytea`. Use the functions `encode` and `decode` to convert between the two. For example write `encode(sha256('abc'), 'hex')` to get a hex-encoded text representation, or `decode(md5('abc'), 'hex')` to get a `bytea` value.

Functions for converting strings between different character sets (encodings), and for representing arbitrary binary data in textual form, are shown in Table 9.13. For these functions, an argument or result of type `text` is expressed in the database's default encoding, while arguments or results of type `bytea` are in an encoding named by another argument.

Table 9.13. Text/Binary String Conversion Functions

Function Description Example(s)

`convert ( bytes bytea, src_encoding name, dest_encoding name ) → bytea`
Converts a binary string representing text in encoding *src_encoding* to a binary string in encoding *dest_encoding* (see Section 23.3.4 for available conversions).
`convert('text_in_utf8', 'UTF8', 'LATIN1')` → `\x746578745f696e5f75746638`

`convert_from ( bytes bytea, src_encoding name ) → text`
Converts a binary string representing text in encoding *src_encoding* to `text` in the database encoding (see Section 23.3.4 for available conversions).
`convert_from('text_in_utf8', 'UTF8')` → `text_in_utf8`

`convert_to ( string text, dest_encoding name ) → bytea`
Converts a `text` string (in the database encoding) to a binary string encoded in encoding *dest_encoding* (see Section 23.3.4 for available conversions).
`convert_to('some_text', 'UTF8')` → `\x736f6d655f74657874`

`encode ( bytes bytea, format text ) → text`
Encodes binary data into a textual representation; supported *format* values are: `base64`, `escape`, `hex`.
`encode('123\000\001', 'base64')` → `MTIzAAE=`

`decode ( string text, format text ) → bytea`
Decodes binary data from a textual representation; supported *format* values are the same as for `encode`.
`decode('MTIzAAE=', 'base64')` → `\x3132330001`

The `encode` and `decode` functions support the following textual formats:

base64

The `base64` format is that of *RFC 2045 Section 6.8*. As per the RFC, encoded lines are broken at 76 characters. However instead of the MIME CRLF end-of-line marker, only a newline is used for end-of-line. The `decode` function ignores carriage-return, newline, space, and tab characters. Otherwise, an error is raised when `decode` is supplied invalid base64 data — including when trailing padding is incorrect.

escape

The `escape` format converts zero bytes and bytes with the high bit set into octal escape sequences (`\nnn`), and it doubles backslashes. Other byte values are represented literally. The `decode` function will raise an error if a backslash is not followed by either a second backslash or three octal digits; it accepts other byte values unchanged.

hex

The `hex` format represents each 4 bits of data as one hexadecimal digit, `0` through `f`, writing the higher-order digit of each byte first. The `encode` function outputs the `a-f` hex digits in lower case. Because the smallest unit of data is 8 bits, there are always an even number of characters returned by `encode`. The `decode` function accepts the `a-f` characters in either upper or lower case. An error is raised when `decode` is given invalid hex data — including when given an odd number of characters.

See also the aggregate function `string_agg` in Section 9.21 and the large object functions in Section 37.4.

9.6. Bit String Functions and Operators

This section describes functions and operators for examining and manipulating bit strings, that is values of the types `bit` and `bit varying`. (While only type `bit` is mentioned in these tables, values of type `bit varying` can be used interchangeably.) Bit strings support the usual comparison operators shown in Table 9.1, as well as the operators shown in Table 9.14.

Table 9.14. Bit String Operators

Operator **Description** **Example(s)**

`bit || bit → bit`
Concatenation
`B'10001' || B'011' → 10001011`

`bit & bit → bit`
Bitwise AND (inputs must be of equal length)
`B'10001' & B'01101' → 00001`

`bit | bit → bit`
Bitwise OR (inputs must be of equal length)
`B'10001' | B'01101' → 11101`

`bit # bit → bit`
Bitwise exclusive OR (inputs must be of equal length)
`B'10001' # B'01101' → 11100`

`~ bit → bit`
Bitwise NOT
`~ B'10001' → 01110`

`bit << integer → bit` Bitwise shift left (string length is preserved)

Operator Description Example(s)
`B'10001' << 3` → `01000`

`bit >> integer` → `bit`
Bitwise shift right (string length is preserved)
`B'10001' >> 2` → `00100`

Some of the functions available for binary strings are also available for bit strings, as shown in Table 9.15.

Table 9.15. Bit String Functions

Function Description Example(s)

`bit_count ( bit )` → `bigint`
Returns the number of bits set in the bit string (also known as “popcount”).
`bit_count(B'10111')` → `4`

`bit_length ( bit )` → `integer`
Returns number of bits in the bit string.
`bit_length(B'10111')` → `5`

`length ( bit )` → `integer`
Returns number of bits in the bit string.
`length(B'10111')` → `5`

`octet_length ( bit )` → `integer`
Returns number of bytes in the bit string.
`octet_length(B'1011111011')` → `2`

`overlay ( bits bit PLACING newsubstring bit FROM start integer [ FOR count integer ] )` → `bit`
Replaces the substring of *bits* that starts at the *start*'th bit and extends for *count* bits with *newsubstring*. If *count* is omitted, it defaults to the length of *newsubstring*.
`overlay(B'01010101010101010' placing B'11111' from 2 for 3)` → `0111110101010101010`

`position ( substring bit IN bits bit )` → `integer`
Returns first starting index of the specified *substring* within *bits*, or zero if it's not present.
`position(B'010' in B'000001101011')` → `8`

`substring ( bits bit [ FROM start integer ] [ FOR count integer ] )` → `bit`
Extracts the substring of *bits* starting at the *start*'th bit if that is specified, and stopping after *count* bits if that is specified. Provide at least one of *start* and *count*.
`substring(B'110010111111' from 3 for 2)` → `00`

`get_bit ( bits bit, n integer )` → `integer`
Extracts *n*'th bit from bit string; the first (leftmost) bit is bit 0.
`get_bit(B'101010101010101010', 6)` → `1`

`set_bit ( bits bit, n integer, newvalue integer )` → `bit`
Sets *n*'th bit in bit string to *newvalue*; the first (leftmost) bit is bit 0.
`set_bit(B'101010101010101010', 6, 0)` → `101010001010101010`

In addition, it is possible to cast integral values to and from type `bit`. Casting an integer to `bit(n)` copies the rightmost `n` bits. Casting an integer to a bit string width wider than the integer itself will sign-extend on the left. Some examples:

```
44::bit(10)                    0000101100
44::bit(3)                     100
cast(-44 as bit(12))           111111010100
'1110'::bit(4)::integer        14
```

Note that casting to just “bit” means casting to `bit(1)`, and so will deliver only the least significant bit of the integer.

9.7. Pattern Matching

There are three separate approaches to pattern matching provided by Postgres Pro: the traditional SQL `LIKE` operator, the more recent `SIMILAR TO` operator (added in SQL:1999), and POSIX-style regular expressions. Aside from the basic “does this string match this pattern?” operators, functions are available to extract or replace matching substrings and to split a string at matching locations.

> **Tip**
>
> If you have pattern matching needs that go beyond this, consider writing a user-defined function in Perl or Tcl.

> **Caution**
>
> While most regular-expression searches can be executed very quickly, regular expressions can be contrived that take arbitrary amounts of time and memory to process. Be wary of accepting regular-expression search patterns from hostile sources. If you must do so, it is advisable to impose a statement timeout.
>
> Searches using `SIMILAR TO` patterns have the same security hazards, since `SIMILAR TO` provides many of the same capabilities as POSIX-style regular expressions.
>
> `LIKE` searches, being much simpler than the other two options, are safer to use with possibly-hostile pattern sources.

The pattern matching operators of all three kinds do not support nondeterministic collations. If required, apply a different collation to the expression to work around this limitation.

9.7.1. `LIKE`

string LIKE *pattern* [ESCAPE *escape-character*]
string NOT LIKE *pattern* [ESCAPE *escape-character*]

The `LIKE` expression returns true if the *string* matches the supplied *pattern*. (As expected, the `NOT LIKE` expression returns false if `LIKE` returns true, and vice versa. An equivalent expression is `NOT (`*string* `LIKE` *pattern*`)`.)

If *pattern* does not contain percent signs or underscores, then the pattern only represents the string itself; in that case `LIKE` acts like the equals operator. An underscore (_) in *pattern* stands for (matches) any single character; a percent sign (`%`) matches any sequence of zero or more characters.

Some examples:

```
'abc' LIKE 'abc'    true
'abc' LIKE 'a%'     true
'abc' LIKE '_b_'    true
'abc' LIKE 'c'      false
```

`LIKE` pattern matching always covers the entire string. Therefore, if it's desired to match a sequence anywhere within a string, the pattern must start and end with a percent sign.

To match a literal underscore or percent sign without matching other characters, the respective character in *pattern* must be preceded by the escape character. The default escape character is the backslash but a different one can be selected by using the ESCAPE clause. To match the escape character itself, write two escape characters.

> **Note**
>
> If you have standard_conforming_strings turned off, any backslashes you write in literal string constants will need to be doubled. See Section 4.1.2.1 for more information.

It's also possible to select no escape character by writing ESCAPE ''. This effectively disables the escape mechanism, which makes it impossible to turn off the special meaning of underscore and percent signs in the pattern.

According to the SQL standard, omitting ESCAPE means there is no escape character (rather than defaulting to a backslash), and a zero-length ESCAPE value is disallowed. Postgres Pro's behavior in this regard is therefore slightly nonstandard.

The key word ILIKE can be used instead of LIKE to make the match case-insensitive according to the active locale. This is not in the SQL standard but is a Postgres Pro extension.

The operator ~~ is equivalent to LIKE, and ~~* corresponds to ILIKE. There are also !~~ and !~~* operators that represent NOT LIKE and NOT ILIKE, respectively. All of these operators are Postgres Pro-specific. You may see these operator names in EXPLAIN output and similar places, since the parser actually translates LIKE et al. to these operators.

The phrases LIKE, ILIKE, NOT LIKE, and NOT ILIKE are generally treated as operators in Postgres Pro syntax; for example they can be used in *expression operator* ANY (*subquery*) constructs, although an ESCAPE clause cannot be included there. In some obscure cases it may be necessary to use the underlying operator names instead.

Also see the prefix operator ^@ and corresponding starts_with function, which are useful in cases where simply matching the beginning of a string is needed.

9.7.2. SIMILAR TO Regular Expressions

string SIMILAR TO *pattern* [ESCAPE *escape-character*]
string NOT SIMILAR TO *pattern* [ESCAPE *escape-character*]

The SIMILAR TO operator returns true or false depending on whether its pattern matches the given string. It is similar to LIKE, except that it interprets the pattern using the SQL standard's definition of a regular expression. SQL regular expressions are a curious cross between LIKE notation and common (POSIX) regular expression notation.

Like LIKE, the SIMILAR TO operator succeeds only if its pattern matches the entire string; this is unlike common regular expression behavior where the pattern can match any part of the string. Also like LIKE, SIMILAR TO uses _ and % as wildcard characters denoting any single character and any string, respectively (these are comparable to . and .* in POSIX regular expressions).

In addition to these facilities borrowed from LIKE, SIMILAR TO supports these pattern-matching metacharacters borrowed from POSIX regular expressions:

- | denotes alternation (either of two alternatives).
- * denotes repetition of the previous item zero or more times.
- + denotes repetition of the previous item one or more times.
- ? denotes repetition of the previous item zero or one time.
- {*m*} denotes repetition of the previous item exactly *m* times.

- `{m,}` denotes repetition of the previous item *m* or more times.
- `{m,n}` denotes repetition of the previous item at least *m* and not more than *n* times.
- Parentheses `()` can be used to group items into a single logical item.
- A bracket expression `[...]` specifies a character class, just as in POSIX regular expressions.

Notice that the period (`.`) is not a metacharacter for `SIMILAR TO`.

As with `LIKE`, a backslash disables the special meaning of any of these metacharacters. A different escape character can be specified with `ESCAPE`, or the escape capability can be disabled by writing `ESCAPE ''`.

According to the SQL standard, omitting `ESCAPE` means there is no escape character (rather than defaulting to a backslash), and a zero-length `ESCAPE` value is disallowed. Postgres Pro's behavior in this regard is therefore slightly nonstandard.

Another nonstandard extension is that following the escape character with a letter or digit provides access to the escape sequences defined for POSIX regular expressions; see Table 9.20, Table 9.21, and Table 9.22 below.

Some examples:

```
'abc' SIMILAR TO 'abc'          true
'abc' SIMILAR TO 'a'            false
'abc' SIMILAR TO '%(b|d)%'      true
'abc' SIMILAR TO '(b|c)%'       false
'-abc-' SIMILAR TO '%\mabc\M%'  true
'xabcy' SIMILAR TO '%\mabc\M%'  false
```

The `substring` function with three parameters provides extraction of a substring that matches an SQL regular expression pattern. The function can be written according to standard SQL syntax:

```
substring(string similar pattern escape escape-character)
```

or using the now obsolete SQL:1999 syntax:

```
substring(string from pattern for escape-character)
```

or as a plain three-argument function:

```
substring(string, pattern, escape-character)
```

As with `SIMILAR TO`, the specified pattern must match the entire data string, or else the function fails and returns null. To indicate the part of the pattern for which the matching data sub-string is of interest, the pattern should contain two occurrences of the escape character followed by a double quote (`"`). The text matching the portion of the pattern between these separators is returned when the match is successful.

The escape-double-quote separators actually divide `substring`'s pattern into three independent regular expressions; for example, a vertical bar (`|`) in any of the three sections affects only that section. Also, the first and third of these regular expressions are defined to match the smallest possible amount of text, not the largest, when there is any ambiguity about how much of the data string matches which pattern. (In POSIX parlance, the first and third regular expressions are forced to be non-greedy.)

As an extension to the SQL standard, Postgres Pro allows there to be just one escape-double-quote separator, in which case the third regular expression is taken as empty; or no separators, in which case the first and third regular expressions are taken as empty.

Some examples, with `#"` delimiting the return string:

```
substring('foobar' similar '%#"o_b#"%' escape '#')   oob
substring('foobar' similar '#"o_b#"%' escape '#')    NULL
```

9.7.3. POSIX Regular Expressions

Table 9.16 lists the available operators for pattern matching using POSIX regular expressions.

Table 9.16. Regular Expression Match Operators

Operator **Description** **Example(s)**

`text ~ text → boolean`
String matches regular expression, case sensitively
`'thomas' ~ 't.*ma' → t`

`text ~* text → boolean`
String matches regular expression, case insensitively
`'thomas' ~* 'T.*ma' → t`

`text !~ text → boolean`
String does not match regular expression, case sensitively
`'thomas' !~ 't.*max' → t`

`text !~* text → boolean`
String does not match regular expression, case insensitively
`'thomas' !~* 'T.*ma' → f`

POSIX regular expressions provide a more powerful means for pattern matching than the `LIKE` and `SIMILAR TO` operators. Many Unix tools such as `egrep`, `sed`, or `awk` use a pattern matching language that is similar to the one described here.

A regular expression is a character sequence that is an abbreviated definition of a set of strings (a *regular set*). A string is said to match a regular expression if it is a member of the regular set described by the regular expression. As with `LIKE`, pattern characters match string characters exactly unless they are special characters in the regular expression language — but regular expressions use different special characters than `LIKE` does. Unlike `LIKE` patterns, a regular expression is allowed to match anywhere within a string, unless the regular expression is explicitly anchored to the beginning or end of the string.

Some examples:

```
'abcd' ~ 'bc'     true
'abcd' ~ 'a.c'    true — dot matches any character
'abcd' ~ 'a.*d'   true — * repeats the preceding pattern item
'abcd' ~ '(b|x)'  true — | means OR, parentheses group
'abcd' ~ '^a'     true — ^ anchors to start of string
'abcd' ~ '^(b|c)' false — would match except for anchoring
```

The POSIX pattern language is described in much greater detail below.

The `substring` function with two parameters, `substring(`*`string`* `from` *`pattern`*`)`, provides extraction of a substring that matches a POSIX regular expression pattern. It returns null if there is no match, otherwise the first portion of the text that matched the pattern. But if the pattern contains any parentheses, the portion of the text that matched the first parenthesized subexpression (the one whose left parenthesis comes first) is returned. You can put parentheses around the whole expression if you want to use parentheses within it without triggering this exception. If you need parentheses in the pattern before the subexpression you want to extract, see the non-capturing parentheses described below.

Some examples:

```
substring('foobar' from 'o.b')     oob
substring('foobar' from 'o(.)b')   o
```

The `regexp_replace` function provides substitution of new text for substrings that match POSIX regular expression patterns. It has the syntax `regexp_replace(`*`source`*, *`pattern`*, *`replacement`* [, *`flags`*]). The *`source`* string is returned unchanged if there is no match to the *`pattern`*. If there is a match, the *`source`*

string is returned with the *replacement* string substituted for the matching substring. The *replacement* string can contain \n, where *n* is 1 through 9, to indicate that the source substring matching the *n*'th parenthesized subexpression of the pattern should be inserted, and it can contain \& to indicate that the substring matching the entire pattern should be inserted. Write \\ if you need to put a literal backslash in the replacement text. The *flags* parameter is an optional text string containing zero or more single-letter flags that change the function's behavior. Flag i specifies case-insensitive matching, while flag g specifies replacement of each matching substring rather than only the first one. Supported flags (though not g) are described in Table 9.24.

Some examples:

```
regexp_replace('foobarbaz', 'b..', 'X')
                                    fooXbaz
regexp_replace('foobarbaz', 'b..', 'X', 'g')
                                    fooXX
regexp_replace('foobarbaz', 'b(..)', 'X\1Y', 'g')
                                    fooXarYXazY
```

The regexp_match function returns a text array of captured substring(s) resulting from the first match of a POSIX regular expression pattern to a string. It has the syntax regexp_match(*string*, *pattern* [, *flags*]). If there is no match, the result is NULL. If a match is found, and the *pattern* contains no parenthesized subexpressions, then the result is a single-element text array containing the substring matching the whole pattern. If a match is found, and the *pattern* contains parenthesized subexpressions, then the result is a text array whose *n*'th element is the substring matching the *n*'th parenthesized subexpression of the *pattern* (not counting “non-capturing” parentheses; see below for details). The *flags* parameter is an optional text string containing zero or more single-letter flags that change the function's behavior. Supported flags are described in Table 9.24.

Some examples:

```
SELECT regexp_match('foobarbequebaz', 'bar.*que');
 regexp_match
--------------
 {barbeque}
(1 row)

SELECT regexp_match('foobarbequebaz', '(bar)(beque)');
 regexp_match
--------------
 {bar,beque}
(1 row)
```

In the common case where you just want the whole matching substring or NULL for no match, write something like

```
SELECT (regexp_match('foobarbequebaz', 'bar.*que'))[1];
 regexp_match
--------------
 barbeque
(1 row)
```

The regexp_matches function returns a set of text arrays of captured substring(s) resulting from matching a POSIX regular expression pattern to a string. It has the same syntax as regexp_match. This function returns no rows if there is no match, one row if there is a match and the g flag is not given, or *N* rows if there are *N* matches and the g flag is given. Each returned row is a text array containing the whole matched substring or the substrings matching parenthesized subexpressions of the *pattern*, just as described above for regexp_match. regexp_matches accepts all the flags shown in Table 9.24, plus the g flag which commands it to return all matches, not just the first one.

Some examples:

```
SELECT regexp_matches('foo', 'not there');
 regexp_matches
----------------
(0 rows)

SELECT regexp_matches('foobarbequebazilbarfbonk', '(b[^b]+)(b[^b]+)', 'g');
 regexp_matches
----------------
 {bar,beque}
 {bazil,barf}
(2 rows)
```

> **Tip**
>
> In most cases `regexp_matches()` should be used with the `g` flag, since if you only want the first match, it's easier and more efficient to use `regexp_match()`. However, `regexp_match()` only exists in Postgres Pro version 10 and up. When working in older versions, a common trick is to place a `regexp_matches()` call in a sub-select, for example:
>
> `SELECT col1, (SELECT regexp_matches(col2, '(bar)(beque)')) FROM tab;`
>
> This produces a text array if there's a match, or `NULL` if not, the same as `regexp_match()` would do. Without the sub-select, this query would produce no output at all for table rows without a match, which is typically not the desired behavior.

The `regexp_split_to_table` function splits a string using a POSIX regular expression pattern as a delimiter. It has the syntax `regexp_split_to_table(`*`string`*`, `*`pattern`*` [, `*`flags`*` ])`. If there is no match to the *`pattern`*, the function returns the *`string`*. If there is at least one match, for each match it returns the text from the end of the last match (or the beginning of the string) to the beginning of the match. When there are no more matches, it returns the text from the end of the last match to the end of the string. The *`flags`* parameter is an optional text string containing zero or more single-letter flags that change the function's behavior. `regexp_split_to_table` supports the flags described in Table 9.24.

The `regexp_split_to_array` function behaves the same as `regexp_split_to_table`, except that `regexp_split_to_array` returns its result as an array of `text`. It has the syntax `regexp_split_to_array(`*`string`*`, `*`pattern`*` [, `*`flags`*` ])`. The parameters are the same as for `regexp_split_to_table`.

Some examples:

```
SELECT foo FROM regexp_split_to_table('the quick brown fox jumps over the lazy dog',
 '\s+') AS foo;
  foo
-------
 the
 quick
 brown
 fox
 jumps
 over
 the
 lazy
 dog
(9 rows)

SELECT regexp_split_to_array('the quick brown fox jumps over the lazy dog', '\s+');
              regexp_split_to_array
-----------------------------------------------
```

```
 {the,quick,brown,fox,jumps,over,the,lazy,dog}
(1 row)

SELECT foo FROM regexp_split_to_table('the quick brown fox', '\s*') AS foo;
 foo
-----
 t
 h
 e
 q
 u
 i
 c
 k
 b
 r
 o
 w
 n
 f
 o
 x
(16 rows)
```

As the last example demonstrates, the regexp split functions ignore zero-length matches that occur at the start or end of the string or immediately after a previous match. This is contrary to the strict definition of regexp matching that is implemented by `regexp_match` and `regexp_matches`, but is usually the most convenient behavior in practice. Other software systems such as Perl use similar definitions.

9.7.3.1. Regular Expression Details

Postgres Pro's regular expressions are implemented using a software package written by Henry Spencer. Much of the description of regular expressions below is copied verbatim from his manual.

Regular expressions (REs), as defined in POSIX 1003.2, come in two forms: *extended* REs or EREs (roughly those of `egrep`), and *basic* REs or BREs (roughly those of `ed`). Postgres Pro supports both forms, and also implements some extensions that are not in the POSIX standard, but have become widely used due to their availability in programming languages such as Perl and Tcl. REs using these non-POSIX extensions are called *advanced* REs or AREs in this documentation. AREs are almost an exact superset of EREs, but BREs have several notational incompatibilities (as well as being much more limited). We first describe the ARE and ERE forms, noting features that apply only to AREs, and then describe how BREs differ.

> **Note**
>
> Postgres Pro always initially presumes that a regular expression follows the ARE rules. However, the more limited ERE or BRE rules can be chosen by prepending an *embedded option* to the RE pattern, as described in Section 9.7.3.4. This can be useful for compatibility with applications that expect exactly the POSIX 1003.2 rules.

A regular expression is defined as one or more *branches*, separated by `|`. It matches anything that matches one of the branches.

A branch is zero or more *quantified atoms* or *constraints*, concatenated. It matches a match for the first, followed by a match for the second, etc; an empty branch matches the empty string.

A quantified atom is an *atom* possibly followed by a single *quantifier*. Without a quantifier, it matches a match for the atom. With a quantifier, it can match some number of matches of the atom. An *atom* can

be any of the possibilities shown in Table 9.17. The possible quantifiers and their meanings are shown in Table 9.18.

A *constraint* matches an empty string, but matches only when specific conditions are met. A constraint can be used where an atom could be used, except it cannot be followed by a quantifier. The simple constraints are shown in Table 9.19; some more constraints are described later.

Table 9.17. Regular Expression Atoms

Atom	Description
`( re)`	(where *re* is any regular expression) matches a match for *re*, with the match noted for possible reporting
`(?: re)`	as above, but the match is not noted for reporting (a "non-capturing" set of parentheses) (AREs only)
`.`	matches any single character
`[chars]`	a *bracket expression*, matching any one of the *chars* (see Section 9.7.3.2 for more detail)
`\k`	(where *k* is a non-alphanumeric character) matches that character taken as an ordinary character, e.g., `\\` matches a backslash character
`\c`	where *c* is alphanumeric (possibly followed by other characters) is an *escape*, see Section 9.7.3.3 (AREs only; in EREs and BREs, this matches *c*)
`{`	when followed by a character other than a digit, matches the left-brace character `{`; when followed by a digit, it is the beginning of a *bound* (see below)
x	where *x* is a single character with no other significance, matches that character

An RE cannot end with a backslash (`\`).

> **Note**
>
> If you have standard_conforming_strings turned off, any backslashes you write in literal string constants will need to be doubled. See Section 4.1.2.1 for more information.

Table 9.18. Regular Expression Quantifiers

Quantifier	Matches
`*`	a sequence of 0 or more matches of the atom
`+`	a sequence of 1 or more matches of the atom
`?`	a sequence of 0 or 1 matches of the atom
`{m}`	a sequence of exactly *m* matches of the atom
`{m,}`	a sequence of *m* or more matches of the atom
`{m, n}`	a sequence of *m* through *n* (inclusive) matches of the atom; *m* cannot exceed *n*
`*?`	non-greedy version of `*`
`+?`	non-greedy version of `+`

Quantifier	Matches
??	non-greedy version of ?
{m}?	non-greedy version of {m}
{m,}?	non-greedy version of {m,}
{m, n}?	non-greedy version of {m, n}

The forms using {...} are known as *bounds*. The numbers m and n within a bound are unsigned decimal integers with permissible values from 0 to 255 inclusive.

Non-greedy quantifiers (available in AREs only) match the same possibilities as their corresponding normal (*greedy*) counterparts, but prefer the smallest number rather than the largest number of matches. See Section 9.7.3.5 for more detail.

> **Note**
>
> A quantifier cannot immediately follow another quantifier, e.g., ** is invalid. A quantifier cannot begin an expression or subexpression or follow ^ or |.

Table 9.19. Regular Expression Constraints

Constraint	Description
^	matches at the beginning of the string
$	matches at the end of the string
(?= re)	*positive lookahead* matches at any point where a substring matching re begins (AREs only)
(?! re)	*negative lookahead* matches at any point where no substring matching re begins (AREs only)
(?<= re)	*positive lookbehind* matches at any point where a substring matching re ends (AREs only)
(?<! re)	*negative lookbehind* matches at any point where no substring matching re ends (AREs only)

Lookahead and lookbehind constraints cannot contain *back references* (see Section 9.7.3.3), and all parentheses within them are considered non-capturing.

9.7.3.2. Bracket Expressions

A *bracket expression* is a list of characters enclosed in []. It normally matches any single character from the list (but see below). If the list begins with ^, it matches any single character *not* from the rest of the list. If two characters in the list are separated by -, this is shorthand for the full range of characters between those two (inclusive) in the collating sequence, e.g., [0-9] in ASCII matches any decimal digit. It is illegal for two ranges to share an endpoint, e.g., a-c-e. Ranges are very collating-sequence-dependent, so portable programs should avoid relying on them.

To include a literal] in the list, make it the first character (after ^, if that is used). To include a literal -, make it the first or last character, or the second endpoint of a range. To use a literal - as the first endpoint of a range, enclose it in [. and .] to make it a collating element (see below). With the exception of these characters, some combinations using [(see next paragraphs), and escapes (AREs only), all other special characters lose their special significance within a bracket expression. In particular, \ is not special when following ERE or BRE rules, though it is special (as introducing an escape) in AREs.

Within a bracket expression, a collating element (a character, a multiple-character sequence that collates as if it were a single character, or a collating-sequence name for either) enclosed in [. and .] stands for the sequence of characters of that collating element. The sequence is treated as a single element of

the bracket expression's list. This allows a bracket expression containing a multiple-character collating element to match more than one character, e.g., if the collating sequence includes a `ch` collating element, then the RE `[[.ch.]]*c` matches the first five characters of `chchcc`.

> **Note**
>
> Postgres Pro currently does not support multi-character collating elements. This information describes possible future behavior.

Within a bracket expression, a collating element enclosed in `[=` and `=]` is an *equivalence class*, standing for the sequences of characters of all collating elements equivalent to that one, including itself. (If there are no other equivalent collating elements, the treatment is as if the enclosing delimiters were `[.` and `.]`.) For example, if `o` and `^` are the members of an equivalence class, then `[[=o=]]`, `[[=^=]]`, and `[o^]` are all synonymous. An equivalence class cannot be an endpoint of a range.

Within a bracket expression, the name of a character class enclosed in `[:` and `:]` stands for the list of all characters belonging to that class. A character class cannot be used as an endpoint of a range. The POSIX standard defines these character class names: `alnum` (letters and numeric digits), `alpha` (letters), `blank` (space and tab), `cntrl` (control characters), `digit` (numeric digits), `graph` (printable characters except space), `lower` (lower-case letters), `print` (printable characters including space), `punct` (punctuation), `space` (any white space), `upper` (upper-case letters), and `xdigit` (hexadecimal digits). The behavior of these standard character classes is generally consistent across platforms for characters in the 7-bit ASCII set. Whether a given non-ASCII character is considered to belong to one of these classes depends on the *collation* that is used for the regular-expression function or operator (see Section 23.2), or by default on the database's `LC_CTYPE` locale setting (see Section 23.1). The classification of non-ASCII characters can vary across platforms even in similarly-named locales. (But the `C` locale never considers any non-ASCII characters to belong to any of these classes.) In addition to these standard character classes, Postgres Pro defines the `word` character class, which is the same as `alnum` plus the underscore (_) character, and the `ascii` character class, which contains exactly the 7-bit ASCII set.

There are two special cases of bracket expressions: the bracket expressions `[[:<:]]` and `[[:>:]]` are constraints, matching empty strings at the beginning and end of a word respectively. A word is defined as a sequence of word characters that is neither preceded nor followed by word characters. A word character is any character belonging to the `word` character class, that is, any letter, digit, or underscore. This is an extension, compatible with but not specified by POSIX 1003.2, and should be used with caution in software intended to be portable to other systems. The constraint escapes described below are usually preferable; they are no more standard, but are easier to type.

9.7.3.3. Regular Expression Escapes

Escapes are special sequences beginning with `\` followed by an alphanumeric character. Escapes come in several varieties: character entry, class shorthands, constraint escapes, and back references. A `\` followed by an alphanumeric character but not constituting a valid escape is illegal in AREs. In EREs, there are no escapes: outside a bracket expression, a `\` followed by an alphanumeric character merely stands for that character as an ordinary character, and inside a bracket expression, `\` is an ordinary character. (The latter is the one actual incompatibility between EREs and AREs.)

Character-entry escapes exist to make it easier to specify non-printing and other inconvenient characters in REs. They are shown in Table 9.20.

Class-shorthand escapes provide shorthands for certain commonly-used character classes. They are shown in Table 9.21.

A *constraint escape* is a constraint, matching the empty string if specific conditions are met, written as an escape. They are shown in Table 9.22.

A *back reference* (`\n`) matches the same string matched by the previous parenthesized subexpression specified by the number *n* (see Table 9.23). For example, `([bc])\1` matches `bb` or `cc` but not `bc` or `cb`.

The subexpression must entirely precede the back reference in the RE. Subexpressions are numbered in the order of their leading parentheses. Non-capturing parentheses do not define subexpressions. The back reference considers only the string characters matched by the referenced subexpression, not any constraints contained in it. For example, `(^\d)\1` will match `22`.

Table 9.20. Regular Expression Character-Entry Escapes

Escape	Description
`\a`	alert (bell) character, as in C
`\b`	backspace, as in C
`\B`	synonym for backslash (`\`) to help reduce the need for backslash doubling
`\c`*X*	(where *X* is any character) the character whose low-order 5 bits are the same as those of *X*, and whose other bits are all zero
`\e`	the character whose collating-sequence name is `ESC`, or failing that, the character with octal value `033`
`\f`	form feed, as in C
`\n`	newline, as in C
`\r`	carriage return, as in C
`\t`	horizontal tab, as in C
`\u`*wxyz*	(where *wxyz* is exactly four hexadecimal digits) the character whose hexadecimal value is `0x`*wxyz*
`\U`*stuvwxyz*	(where *stuvwxyz* is exactly eight hexadecimal digits) the character whose hexadecimal value is `0x`*stuvwxyz*
`\v`	vertical tab, as in C
`\x`*hhh*	(where *hhh* is any sequence of hexadecimal digits) the character whose hexadecimal value is `0x`*hhh* (a single character no matter how many hexadecimal digits are used)
`\0`	the character whose value is `0` (the null byte)
`\`*xy*	(where *xy* is exactly two octal digits, and is not a *back reference*) the character whose octal value is `0`*xy*
`\`*xyz*	(where *xyz* is exactly three octal digits, and is not a *back reference*) the character whose octal value is `0`*xyz*

Hexadecimal digits are `0-9`, `a-f`, and `A-F`. Octal digits are `0-7`.

Numeric character-entry escapes specifying values outside the ASCII range (0–127) have meanings dependent on the database encoding. When the encoding is UTF-8, escape values are equivalent to Unicode code points, for example `\u1234` means the character `U+1234`. For other multibyte encodings, character-entry escapes usually just specify the concatenation of the byte values for the character. If the escape value does not correspond to any legal character in the database encoding, no error will be raised, but it will never match any data.

The character-entry escapes are always taken as ordinary characters. For example, `\135` is `]` in ASCII, but `\135` does not terminate a bracket expression.

Table 9.21. Regular Expression Class-Shorthand Escapes

Escape	Description
`\d`	matches any digit, like `[[:digit:]]`
`\s`	matches any whitespace character, like `[[:space:]]`
`\w`	matches any word character, like `[[:word:]]`
`\D`	matches any non-digit, like `[^[:digit:]]`
`\S`	matches any non-whitespace character, like `[^[:space:]]`
`\W`	matches any non-word character, like `[^[:word:]]`

The class-shorthand escapes also work within bracket expressions, although the definitions shown above are not quite syntactically valid in that context. For example, `[a-c\d]` is equivalent to `[a-c[:digit:]]`.

Table 9.22. Regular Expression Constraint Escapes

Escape	Description
`\A`	matches only at the beginning of the string (see Section 9.7.3.5 for how this differs from `^`)
`\m`	matches only at the beginning of a word
`\M`	matches only at the end of a word
`\y`	matches only at the beginning or end of a word
`\Y`	matches only at a point that is not the beginning or end of a word
`\Z`	matches only at the end of the string (see Section 9.7.3.5 for how this differs from `$`)

A word is defined as in the specification of `[[:<:]]` and `[[:>:]]` above. Constraint escapes are illegal within bracket expressions.

Table 9.23. Regular Expression Back References

Escape	Description
`\`*`m`*	(where *`m`* is a nonzero digit) a back reference to the *`m`*'th subexpression
`\`*`mnn`*	(where *`m`* is a nonzero digit, and *`nn`* is some more digits, and the decimal value *`mnn`* is not greater than the number of closing capturing parentheses seen so far) a back reference to the *`mnn`*'th subexpression

> **Note**
>
> There is an inherent ambiguity between octal character-entry escapes and back references, which is resolved by the following heuristics, as hinted at above. A leading zero always indicates an octal escape. A single non-zero digit, not followed by another digit, is always taken as a back reference. A multi-digit sequence not starting with a zero is taken as a back reference if it comes after a suitable subexpression (i.e., the number is in the legal range for a back reference), and otherwise is taken as octal.

9.7.3.4. Regular Expression Metasyntax

In addition to the main syntax described above, there are some special forms and miscellaneous syntactic facilities available.

An RE can begin with one of two special *director* prefixes. If an RE begins with `***:`, the rest of the RE is taken as an ARE. (This normally has no effect in Postgres Pro, since REs are assumed to be AREs; but it does have an effect if ERE or BRE mode had been specified by the *flags* parameter to a regex function.) If an RE begins with `***=`, the rest of the RE is taken to be a literal string, with all characters considered ordinary characters.

An ARE can begin with *embedded options*: a sequence `(?xyz)` (where *xyz* is one or more alphabetic characters) specifies options affecting the rest of the RE. These options override any previously determined options — in particular, they can override the case-sensitivity behavior implied by a regex operator, or the *flags* parameter to a regex function. The available option letters are shown in Table 9.24. Note that these same option letters are used in the *flags* parameters of regex functions.

Table 9.24. ARE Embedded-Option Letters

Option	Description
`b`	rest of RE is a BRE
`c`	case-sensitive matching (overrides operator type)
`e`	rest of RE is an ERE
`i`	case-insensitive matching (see Section 9.7.3.5) (overrides operator type)
`m`	historical synonym for `n`
`n`	newline-sensitive matching (see Section 9.7.3.5)
`p`	partial newline-sensitive matching (see Section 9.7.3.5)
`q`	rest of RE is a literal (“quoted”) string, all ordinary characters
`s`	non-newline-sensitive matching (default)
`t`	tight syntax (default; see below)
`w`	inverse partial newline-sensitive (“weird”) matching (see Section 9.7.3.5)
`x`	expanded syntax (see below)

Embedded options take effect at the `)` terminating the sequence. They can appear only at the start of an ARE (after the `***:` director if any).

In addition to the usual (*tight*) RE syntax, in which all characters are significant, there is an *expanded* syntax, available by specifying the embedded `x` option. In the expanded syntax, white-space characters in the RE are ignored, as are all characters between a `#` and the following newline (or the end of the RE). This permits paragraphing and commenting a complex RE. There are three exceptions to that basic rule:

- a white-space character or `#` preceded by `\` is retained
- white space or `#` within a bracket expression is retained
- white space and comments cannot appear within multi-character symbols, such as `(?:`

For this purpose, white-space characters are blank, tab, newline, and any character that belongs to the *space* character class.

Finally, in an ARE, outside bracket expressions, the sequence `(?#ttt)` (where *ttt* is any text not containing a `)`) is a comment, completely ignored. Again, this is not allowed between the characters of mul-

ti-character symbols, like `(?:`. Such comments are more a historical artifact than a useful facility, and their use is deprecated; use the expanded syntax instead.

None of these metasyntax extensions is available if an initial `***=` director has specified that the user's input be treated as a literal string rather than as an RE.

9.7.3.5. Regular Expression Matching Rules

In the event that an RE could match more than one substring of a given string, the RE matches the one starting earliest in the string. If the RE could match more than one substring starting at that point, either the longest possible match or the shortest possible match will be taken, depending on whether the RE is *greedy* or *non-greedy*.

Whether an RE is greedy or not is determined by the following rules:

- Most atoms, and all constraints, have no greediness attribute (because they cannot match variable amounts of text anyway).
- Adding parentheses around an RE does not change its greediness.
- A quantified atom with a fixed-repetition quantifier (`{`*m*`}` or `{`*m*`}?`) has the same greediness (possibly none) as the atom itself.
- A quantified atom with other normal quantifiers (including `{`*m*`,`*n*`}` with *m* equal to *n*) is greedy (prefers longest match).
- A quantified atom with a non-greedy quantifier (including `{`*m*`,`*n*`}?` with *m* equal to *n*) is non-greedy (prefers shortest match).
- A branch — that is, an RE that has no top-level `|` operator — has the same greediness as the first quantified atom in it that has a greediness attribute.
- An RE consisting of two or more branches connected by the `|` operator is always greedy.

The above rules associate greediness attributes not only with individual quantified atoms, but with branches and entire REs that contain quantified atoms. What that means is that the matching is done in such a way that the branch, or whole RE, matches the longest or shortest possible substring *as a whole*. Once the length of the entire match is determined, the part of it that matches any particular subexpression is determined on the basis of the greediness attribute of that subexpression, with subexpressions starting earlier in the RE taking priority over ones starting later.

An example of what this means:

```
SELECT SUBSTRING('XY1234Z', 'Y*([0-9]{1,3})');
Result: 123
SELECT SUBSTRING('XY1234Z', 'Y*?([0-9]{1,3})');
Result: 1
```

In the first case, the RE as a whole is greedy because `Y*` is greedy. It can match beginning at the `Y`, and it matches the longest possible string starting there, i.e., `Y123`. The output is the parenthesized part of that, or `123`. In the second case, the RE as a whole is non-greedy because `Y*?` is non-greedy. It can match beginning at the `Y`, and it matches the shortest possible string starting there, i.e., `Y1`. The subexpression `[0-9]{1,3}` is greedy but it cannot change the decision as to the overall match length; so it is forced to match just `1`.

In short, when an RE contains both greedy and non-greedy subexpressions, the total match length is either as long as possible or as short as possible, according to the attribute assigned to the whole RE. The attributes assigned to the subexpressions only affect how much of that match they are allowed to “eat” relative to each other.

The quantifiers `{1,1}` and `{1,1}?` can be used to force greediness or non-greediness, respectively, on a subexpression or a whole RE. This is useful when you need the whole RE to have a greediness attribute different from what's deduced from its elements. As an example, suppose that we are trying to separate

a string containing some digits into the digits and the parts before and after them. We might try to do that like this:

```
SELECT regexp_match('abc01234xyz', '(.*)(\d+)(.*)');
Result: {abc0123,4,xyz}
```

That didn't work: the first `.*` is greedy so it "eats" as much as it can, leaving the `\d+` to match at the last possible place, the last digit. We might try to fix that by making it non-greedy:

```
SELECT regexp_match('abc01234xyz', '(.*?)(\d+)(.*)');
Result: {abc,0,""}
```

That didn't work either, because now the RE as a whole is non-greedy and so it ends the overall match as soon as possible. We can get what we want by forcing the RE as a whole to be greedy:

```
SELECT regexp_match('abc01234xyz', '(?:(.*?)(\d+)(.*)){1,1}');
Result: {abc,01234,xyz}
```

Controlling the RE's overall greediness separately from its components' greediness allows great flexibility in handling variable-length patterns.

When deciding what is a longer or shorter match, match lengths are measured in characters, not collating elements. An empty string is considered longer than no match at all. For example: `bb*` matches the three middle characters of `abbbc`; `(week|wee)(night|knights)` matches all ten characters of `weeknights`; when `(.*).*` is matched against `abc` the parenthesized subexpression matches all three characters; and when `(a*)*` is matched against `bc` both the whole RE and the parenthesized subexpression match an empty string.

If case-independent matching is specified, the effect is much as if all case distinctions had vanished from the alphabet. When an alphabetic that exists in multiple cases appears as an ordinary character outside a bracket expression, it is effectively transformed into a bracket expression containing both cases, e.g., `x` becomes `[xX]`. When it appears inside a bracket expression, all case counterparts of it are added to the bracket expression, e.g., `[x]` becomes `[xX]` and `[^x]` becomes `[^xX]`.

If newline-sensitive matching is specified, `.` and bracket expressions using `^` will never match the newline character (so that matches will not cross lines unless the RE explicitly includes a newline) and `^` and `$` will match the empty string after and before a newline respectively, in addition to matching at beginning and end of string respectively. But the ARE escapes `\A` and `\Z` continue to match beginning or end of string *only*. Also, the character class shorthands `\D` and `\W` will match a newline regardless of this mode. (Before Postgres Pro 14, they did not match newlines when in newline-sensitive mode. Write `[^[:digit:]]` or `[^[:word:]]` to get the old behavior.)

If partial newline-sensitive matching is specified, this affects `.` and bracket expressions as with newline-sensitive matching, but not `^` and `$`.

If inverse partial newline-sensitive matching is specified, this affects `^` and `$` as with newline-sensitive matching, but not `.` and bracket expressions. This isn't very useful but is provided for symmetry.

9.7.3.6. Limits and Compatibility

No particular limit is imposed on the length of REs in this implementation. However, programs intended to be highly portable should not employ REs longer than 256 bytes, as a POSIX-compliant implementation can refuse to accept such REs.

The only feature of AREs that is actually incompatible with POSIX EREs is that `\` does not lose its special significance inside bracket expressions. All other ARE features use syntax which is illegal or has undefined or unspecified effects in POSIX EREs; the `***` syntax of directors likewise is outside the POSIX syntax for both BREs and EREs.

Many of the ARE extensions are borrowed from Perl, but some have been changed to clean them up, and a few Perl extensions are not present. Incompatibilities of note include `\b`, `\B`, the lack of special treatment for a trailing newline, the addition of complemented bracket expressions to the things affected

by newline-sensitive matching, the restrictions on parentheses and back references in lookahead/lookbehind constraints, and the longest/shortest-match (rather than first-match) matching semantics.

9.7.3.7. Basic Regular Expressions

BREs differ from EREs in several respects. In BREs, `|`, `+`, and `?` are ordinary characters and there is no equivalent for their functionality. The delimiters for bounds are `\{` and `\}`, with `{` and `}` by themselves ordinary characters. The parentheses for nested subexpressions are `\(` and `\)`, with `(` and `)` by themselves ordinary characters. `^` is an ordinary character except at the beginning of the RE or the beginning of a parenthesized subexpression, `$` is an ordinary character except at the end of the RE or the end of a parenthesized subexpression, and `*` is an ordinary character if it appears at the beginning of the RE or the beginning of a parenthesized subexpression (after a possible leading `^`). Finally, single-digit back references are available, and `\<` and `\>` are synonyms for `[[:<:]]` and `[[:>:]]` respectively; no other escapes are available in BREs.

9.7.3.8. Differences from XQuery (`LIKE_REGEX`)

Since SQL:2008, the SQL standard includes a `LIKE_REGEX` operator that performs pattern matching according to the XQuery regular expression standard. Postgres Pro does not yet implement this operator, but you can get very similar behavior using the `regexp_match()` function, since XQuery regular expressions are quite close to the ARE syntax described above.

Notable differences between the existing POSIX-based regular-expression feature and XQuery regular expressions include:

- XQuery character class subtraction is not supported. An example of this feature is using the following to match only English consonants: `[a-z-[aeiou]]`.
- XQuery character class shorthands `\c`, `\C`, `\i`, and `\I` are not supported.
- XQuery character class elements using `\p{UnicodeProperty}` or the inverse `\P{UnicodeProperty}` are not supported.
- POSIX interprets character classes such as `\w` (see Table 9.21) according to the prevailing locale (which you can control by attaching a `COLLATE` clause to the operator or function). XQuery specifies these classes by reference to Unicode character properties, so equivalent behavior is obtained only with a locale that follows the Unicode rules.
- The SQL standard (not XQuery itself) attempts to cater for more variants of "newline" than POSIX does. The newline-sensitive matching options described above consider only ASCII NL (`\n`) to be a newline, but SQL would have us treat CR (`\r`), CRLF (`\r\n`) (a Windows-style newline), and some Unicode-only characters like LINE SEPARATOR (U+2028) as newlines as well. Notably, `.` and `\s` should count `\r\n` as one character not two according to SQL.
- Of the character-entry escapes described in Table 9.20, XQuery supports only `\n`, `\r`, and `\t`.
- XQuery does not support the `[:`*name*`:]` syntax for character classes within bracket expressions.
- XQuery does not have lookahead or lookbehind constraints, nor any of the constraint escapes described in Table 9.22.
- The metasyntax forms described in Section 9.7.3.4 do not exist in XQuery.
- The regular expression flag letters defined by XQuery are related to but not the same as the option letters for POSIX (Table 9.24). While the `i` and `q` options behave the same, others do not:
  - XQuery's `s` (allow dot to match newline) and `m` (allow `^` and `$` to match at newlines) flags provide access to the same behaviors as POSIX's `n`, `p` and `w` flags, but they do *not* match the behavior of POSIX's `s` and `m` flags. Note in particular that dot-matches-newline is the default behavior in POSIX but not XQuery.
  - XQuery's `x` (ignore whitespace in pattern) flag is noticeably different from POSIX's expanded-mode flag. POSIX's `x` flag also allows `#` to begin a comment in the pattern, and POSIX will not ignore a whitespace character after a backslash.

9.8. Data Type Formatting Functions

The Postgres Pro formatting functions provide a powerful set of tools for converting various data types (date/time, integer, floating point, numeric) to formatted strings and for converting from formatted strings to specific data types. Table 9.25 lists them. These functions all follow a common calling convention: the first argument is the value to be formatted and the second argument is a template that defines the output or input format.

Table 9.25. Formatting Functions

Function **Description** **Example(s)**

`to_char ( timestamp, text ) → text`
`to_char ( timestamp with time zone, text ) → text`
Converts time stamp to string according to the given format.
`to_char(timestamp '2002-04-20 17:31:12.66', 'HH12:MI:SS') → 05:31:12`

`to_char ( interval, text ) → text`
Converts interval to string according to the given format.
`to_char(interval '15h 2m 12s', 'HH24:MI:SS') → 15:02:12`

`to_char ( numeric_type , text ) → text`
Converts number to string according to the given format; available for `integer`, `bigint`, `numeric`, `real`, `double precision`.
`to_char(125, '999') → 125`
`to_char(125.8::real, '999D9') → 125.8`
`to_char(-125.8, '999D99S') → 125.80-`

`to_date ( text, text ) → date`
Converts string to date according to the given format.
`to_date('05 Dec 2000', 'DD Mon YYYY') → 2000-12-05`

`to_number ( text, text ) → numeric`
Converts string to numeric according to the given format.
`to_number('12,454.8-', '99G999D9S') → -12454.8`

`to_timestamp ( text, text ) → timestamp with time zone`
Converts string to time stamp according to the given format. (See also `to_timestamp(double precision)` in Table 9.32.)
`to_timestamp('05 Dec 2000', 'DD Mon YYYY') → 2000-12-05 00:00:00-05`

> **Tip**
>
> `to_timestamp` and `to_date` exist to handle input formats that cannot be converted by simple casting. For most standard date/time formats, simply casting the source string to the required data type works, and is much easier. Similarly, `to_number` is unnecessary for standard numeric representations.

In a `to_char` output template string, there are certain patterns that are recognized and replaced with appropriately-formatted data based on the given value. Any text that is not a template pattern is simply copied verbatim. Similarly, in an input template string (for the other functions), template patterns identify the values to be supplied by the input data string. If there are characters in the template string that are not template patterns, the corresponding characters in the input data string are simply skipped over (whether or not they are equal to the template string characters).

Table 9.26 shows the template patterns available for formatting date and time values.

Table 9.26. Template Patterns for Date/Time Formatting

Pattern	Description
`HH`	hour of day (01–12)
`HH12`	hour of day (01–12)
`HH24`	hour of day (00–23)
`MI`	minute (00–59)
`SS`	second (00–59)
`MS`	millisecond (000–999)
`US`	microsecond (000000–999999)
`FF1`	tenth of second (0–9)
`FF2`	hundredth of second (00–99)
`FF3`	millisecond (000–999)
`FF4`	tenth of a millisecond (0000–9999)
`FF5`	hundredth of a millisecond (00000–99999)
`FF6`	microsecond (000000–999999)
`SSSS`, `SSSSS`	seconds past midnight (0–86399)
`AM`, `am`, `PM` or `pm`	meridiem indicator (without periods)
`A.M.`, `a.m.`, `P.M.` or `p.m.`	meridiem indicator (with periods)
`Y,YYY`	year (4 or more digits) with comma
`YYYY`	year (4 or more digits)
`YYY`	last 3 digits of year
`YY`	last 2 digits of year
`Y`	last digit of year
`IYYY`	ISO 8601 week-numbering year (4 or more digits)
`IYY`	last 3 digits of ISO 8601 week-numbering year
`IY`	last 2 digits of ISO 8601 week-numbering year
`I`	last digit of ISO 8601 week-numbering year
`BC`, `bc`, `AD` or `ad`	era indicator (without periods)
`B.C.`, `b.c.`, `A.D.` or `a.d.`	era indicator (with periods)
`MONTH`	full upper case month name (blank-padded to 9 chars)
`Month`	full capitalized month name (blank-padded to 9 chars)
`month`	full lower case month name (blank-padded to 9 chars)
`MON`	abbreviated upper case month name (3 chars in English, localized lengths vary)
`Mon`	abbreviated capitalized month name (3 chars in English, localized lengths vary)
`mon`	abbreviated lower case month name (3 chars in English, localized lengths vary)
`MM`	month number (01–12)

Pattern	Description
DAY	full upper case day name (blank-padded to 9 chars)
Day	full capitalized day name (blank-padded to 9 chars)
day	full lower case day name (blank-padded to 9 chars)
DY	abbreviated upper case day name (3 chars in English, localized lengths vary)
Dy	abbreviated capitalized day name (3 chars in English, localized lengths vary)
dy	abbreviated lower case day name (3 chars in English, localized lengths vary)
DDD	day of year (001–366)
IDDD	day of ISO 8601 week-numbering year (001–371; day 1 of the year is Monday of the first ISO week)
DD	day of month (01–31)
D	day of the week, Sunday (1) to Saturday (7)
ID	ISO 8601 day of the week, Monday (1) to Sunday (7)
W	week of month (1–5) (the first week starts on the first day of the month)
WW	week number of year (1–53) (the first week starts on the first day of the year)
IW	week number of ISO 8601 week-numbering year (01–53; the first Thursday of the year is in week 1)
CC	century (2 digits) (the twenty-first century starts on 2001-01-01)
J	Julian Date (integer days since November 24, 4714 BC at local midnight; see Section B.7)
Q	quarter
RM	month in upper case Roman numerals (I–XII; I=January)
rm	month in lower case Roman numerals (i–xii; i=January)
TZ	upper case time-zone abbreviation (only supported in to_char)
tz	lower case time-zone abbreviation (only supported in to_char)
TZH	time-zone hours
TZM	time-zone minutes
OF	time-zone offset from UTC (only supported in to_char)

Modifiers can be applied to any template pattern to alter its behavior. For example, FMMonth is the Month pattern with the FM modifier. Table 9.27 shows the modifier patterns for date/time formatting.

Table 9.27. Template Pattern Modifiers for Date/Time Formatting

Modifier	Description	Example
FM prefix	fill mode (suppress leading zeroes and padding blanks)	FMMonth
TH suffix	upper case ordinal number suffix	DDTH, e.g., 12TH
th suffix	lower case ordinal number suffix	DDth, e.g., 12th
FX prefix	fixed format global option (see usage notes)	FX Month DD Day
TM prefix	translation mode (use localized day and month names based on lc_time)	TMMonth
SP suffix	spell mode (not implemented)	DDSP

Usage notes for date/time formatting:

- FM suppresses leading zeroes and trailing blanks that would otherwise be added to make the output of a pattern be fixed-width. In Postgres Pro, FM modifies only the next specification, while in Oracle FM affects all subsequent specifications, and repeated FM modifiers toggle fill mode on and off.
- TM suppresses trailing blanks whether or not FM is specified.
- to_timestamp and to_date ignore letter case in the input; so for example MON, Mon, and mon all accept the same strings. When using the TM modifier, case-folding is done according to the rules of the function's input collation (see Section 23.2).
- to_timestamp and to_date skip multiple blank spaces at the beginning of the input string and around date and time values unless the FX option is used. For example, to_timestamp(' 2000 JUN', 'YYYY MON') and to_timestamp('2000 - JUN', 'YYYY-MON') work, but to_timestamp('2000 JUN', 'FXYYYY MON') returns an error because to_timestamp expects only a single space. FX must be specified as the first item in the template.
- A separator (a space or non-letter/non-digit character) in the template string of to_timestamp and to_date matches any single separator in the input string or is skipped, unless the FX option is used. For example, to_timestamp('2000JUN', 'YYYY///MON') and to_timestamp('2000/JUN', 'YYYY MON') work, but to_timestamp('2000//JUN', 'YYYY/MON') returns an error because the number of separators in the input string exceeds the number of separators in the template.

  If FX is specified, a separator in the template string matches exactly one character in the input string. But note that the input string character is not required to be the same as the separator from the template string. For example, to_timestamp('2000/JUN', 'FXYYYY MON') works, but to_timestamp('2000/JUN', 'FXYYYY MON') returns an error because the second space in the template string consumes the letter J from the input string.
- A TZH template pattern can match a signed number. Without the FX option, minus signs may be ambiguous, and could be interpreted as a separator. This ambiguity is resolved as follows: If the number of separators before TZH in the template string is less than the number of separators before the minus sign in the input string, the minus sign is interpreted as part of TZH. Otherwise, the minus sign is considered to be a separator between values. For example, to_timestamp('2000 -10', 'YYYY TZH') matches -10 to TZH, but to_timestamp('2000 -10', 'YYYY TZH') matches 10 to TZH.
- Ordinary text is allowed in to_char templates and will be output literally. You can put a substring in double quotes to force it to be interpreted as literal text even if it contains template patterns. For example, in '"Hello Year "YYYY', the YYYY will be replaced by the year data, but the single Y in Year will not be. In to_date, to_number, and to_timestamp, literal text and double-quoted strings result in skipping the number of characters contained in the string; for example "XX" skips two input characters (whether or not they are XX).

> **Tip**
>
> Prior to Postgres Pro 12, it was possible to skip arbitrary text in the input string using non-letter or non-digit characters. For example, `to_timestamp('2000y6m1d', 'yyyy-MM-DD')` used to work. Now you can only use letter characters for this purpose. For example, `to_timestamp('2000y6m1d', 'yyyytMMtDDt')` and `to_timestamp('2000y6m1d', 'yyyy"y"MM"m"DD"d"')` skip `y`, `m`, and `d`.

- If you want to have a double quote in the output you must precede it with a backslash, for example `'\"YYYY Month\"'`. Backslashes are not otherwise special outside of double-quoted strings. Within a double-quoted string, a backslash causes the next character to be taken literally, whatever it is (but this has no special effect unless the next character is a double quote or another backslash).
- In `to_timestamp` and `to_date`, if the year format specification is less than four digits, e.g., `YYY`, and the supplied year is less than four digits, the year will be adjusted to be nearest to the year 2020, e.g., `95` becomes 1995.
- In `to_timestamp` and `to_date`, negative years are treated as signifying BC. If you write both a negative year and an explicit `BC` field, you get AD again. An input of year zero is treated as 1 BC.
- In `to_timestamp` and `to_date`, the `YYYY` conversion has a restriction when processing years with more than 4 digits. You must use some non-digit character or template after `YYYY`, otherwise the year is always interpreted as 4 digits. For example (with the year 20000): `to_date('200001130', 'YYYYMMDD')` will be interpreted as a 4-digit year; instead use a non-digit separator after the year, like `to_date('20000-1130', 'YYYY-MMDD')` or `to_date('20000Nov30', 'YYYYMonDD')`.
- In `to_timestamp` and `to_date`, the `CC` (century) field is accepted but ignored if there is a `YYY`, `YYYY` or `Y,YYY` field. If `CC` is used with `YY` or `Y` then the result is computed as that year in the specified century. If the century is specified but the year is not, the first year of the century is assumed.
- In `to_timestamp` and `to_date`, weekday names or numbers (`DAY`, `D`, and related field types) are accepted but are ignored for purposes of computing the result. The same is true for quarter (`Q`) fields.
- In `to_timestamp` and `to_date`, an ISO 8601 week-numbering date (as distinct from a Gregorian date) can be specified in one of two ways:
  - Year, week number, and weekday: for example `to_date('2006-42-4', 'IYYY-IW-ID')` returns the date `2006-10-19`. If you omit the weekday it is assumed to be 1 (Monday).
  - Year and day of year: for example `to_date('2006-291', 'IYYY-IDDD')` also returns `2006-10-19`.

  Attempting to enter a date using a mixture of ISO 8601 week-numbering fields and Gregorian date fields is nonsensical, and will cause an error. In the context of an ISO 8601 week-numbering year, the concept of a “month” or “day of month” has no meaning. In the context of a Gregorian year, the ISO week has no meaning.

  > **Caution**
  >
  > While `to_date` will reject a mixture of Gregorian and ISO week-numbering date fields, `to_char` will not, since output format specifications like `YYYY-MM-DD (IYYY-IDDD)` can be useful. But avoid writing something like `IYYY-MM-DD`; that would yield surprising results near the start of the year. (See Section 9.9.1 for more information.)

- In `to_timestamp`, millisecond (`MS`) or microsecond (`US`) fields are used as the seconds digits after the decimal point. For example `to_timestamp('12.3', 'SS.MS')` is not 3 milliseconds, but 300, because the conversion treats it as 12 + 0.3 seconds. So, for the format `SS.MS`, the input values `12.3`, `12.30`, and `12.300` specify the same number of milliseconds. To get three milliseconds, one must write `12.003`, which the conversion treats as 12 + 0.003 = 12.003 seconds.

Here is a more complex example: `to_timestamp('15:12:02.020.001230', 'HH24:MI:SS.MS.US')` is 15 hours, 12 minutes, and 2 seconds + 20 milliseconds + 1230 microseconds = 2.021230 seconds.

- `to_char(..., 'ID')`'s day of the week numbering matches the `extract(isodow from ...)` function, but `to_char(..., 'D')`'s does not match `extract(dow from ...)`'s day numbering.
- `to_char(interval)` formats `HH` and `HH12` as shown on a 12-hour clock, for example zero hours and 36 hours both output as `12`, while `HH24` outputs the full hour value, which can exceed 23 in an `interval` value.

Table 9.28 shows the template patterns available for formatting numeric values.

Table 9.28. Template Patterns for Numeric Formatting

Pattern	Description
`9`	digit position (can be dropped if insignificant)
`0`	digit position (will not be dropped, even if insignificant)
`.` (period)	decimal point
`,` (comma)	group (thousands) separator
`PR`	negative value in angle brackets
`S`	sign anchored to number (uses locale)
`L`	currency symbol (uses locale)
`D`	decimal point (uses locale)
`G`	group separator (uses locale)
`MI`	minus sign in specified position (if number < 0)
`PL`	plus sign in specified position (if number > 0)
`SG`	plus/minus sign in specified position
`RN`	Roman numeral (input between 1 and 3999)
`TH` or `th`	ordinal number suffix
`V`	shift specified number of digits (see notes)
`EEEE`	exponent for scientific notation

Usage notes for numeric formatting:

- `0` specifies a digit position that will always be printed, even if it contains a leading/trailing zero. `9` also specifies a digit position, but if it is a leading zero then it will be replaced by a space, while if it is a trailing zero and fill mode is specified then it will be deleted. (For `to_number()`, these two pattern characters are equivalent.)
- If the format provides fewer fractional digits than the number being formatted, `to_char()` will round the number to the specified number of fractional digits.
- The pattern characters `S`, `L`, `D`, and `G` represent the sign, currency symbol, decimal point, and thousands separator characters defined by the current locale (see lc_monetary and lc_numeric). The pattern characters period and comma represent those exact characters, with the meanings of decimal point and thousands separator, regardless of locale.
- If no explicit provision is made for a sign in `to_char()`'s pattern, one column will be reserved for the sign, and it will be anchored to (appear just left of) the number. If `S` appears just left of some `9`'s, it will likewise be anchored to the number.
- A sign formatted using `SG`, `PL`, or `MI` is not anchored to the number; for example, `to_char(-12, 'MI9999')` produces `'- 12'` but `to_char(-12, 'S9999')` produces `' -12'`. (The Oracle implementation does not allow the use of `MI` before `9`, but rather requires that `9` precede `MI`.)

- `TH` does not convert values less than zero and does not convert fractional numbers.
- `PL`, `SG`, and `TH` are Postgres Pro extensions.
- In `to_number`, if non-data template patterns such as `L` or `TH` are used, the corresponding number of input characters are skipped, whether or not they match the template pattern, unless they are data characters (that is, digits, sign, decimal point, or comma). For example, `TH` would skip two non-data characters.
- `V` with `to_char` multiplies the input values by `10^n`, where *n* is the number of digits following `V`. `V` with `to_number` divides in a similar manner. `to_char` and `to_number` do not support the use of `V` combined with a decimal point (e.g., `99.9V99` is not allowed).
- `EEEE` (scientific notation) cannot be used in combination with any of the other formatting patterns or modifiers other than digit and decimal point patterns, and must be at the end of the format string (e.g., `9.99EEEE` is a valid pattern).

Certain modifiers can be applied to any template pattern to alter its behavior. For example, `FM99.99` is the `99.99` pattern with the `FM` modifier. Table 9.29 shows the modifier patterns for numeric formatting.

Table 9.29. Template Pattern Modifiers for Numeric Formatting

Modifier	Description	Example
`FM` prefix	fill mode (suppress trailing zeroes and padding blanks)	`FM99.99`
`TH` suffix	upper case ordinal number suffix	`999TH`
`th` suffix	lower case ordinal number suffix	`999th`

Table 9.30 shows some examples of the use of the `to_char` function.

Table 9.30. `to_char` Examples

Expression	Result
`to_char(current_timestamp, 'Day, DD  HH12:MI:SS')`	`'Tuesday  , 06  05:39:18'`
`to_char(current_timestamp, 'FMDay, FMDD  HH12:MI:SS')`	`'Tuesday, 6  05:39:18'`
`to_char(-0.1, '99.99')`	`'  -.10'`
`to_char(-0.1, 'FM9.99')`	`'-.1'`
`to_char(-0.1, 'FM90.99')`	`'-0.1'`
`to_char(0.1, '0.9')`	`' 0.1'`
`to_char(12, '9990999.9')`	`'    0012.0'`
`to_char(12, 'FM9990999.9')`	`'0012.'`
`to_char(485, '999')`	`' 485'`
`to_char(-485, '999')`	`'-485'`
`to_char(485, '9 9 9')`	`' 4 8 5'`
`to_char(1485, '9,999')`	`' 1,485'`
`to_char(1485, '9G999')`	`' 1 485'`
`to_char(148.5, '999.999')`	`' 148.500'`
`to_char(148.5, 'FM999.999')`	`'148.5'`
`to_char(148.5, 'FM999.990')`	`'148.500'`
`to_char(148.5, '999D999')`	`' 148,500'`
`to_char(3148.5, '9G999D999')`	`' 3 148,500'`

Expression	Result
to_char(-485, '999S')	'485-'
to_char(-485, '999MI')	'485-'
to_char(485, '999MI')	'485 '
to_char(485, 'FM999MI')	'485'
to_char(485, 'PL999')	'+485'
to_char(485, 'SG999')	'+485'
to_char(-485, 'SG999')	'-485'
to_char(-485, '9SG99')	'4-85'
to_char(-485, '999PR')	'<485>'
to_char(485, 'L999')	'DM 485'
to_char(485, 'RN')	' CDLXXXV'
to_char(485, 'FMRN')	'CDLXXXV'
to_char(5.2, 'FMRN')	'V'
to_char(482, '999th')	' 482nd'
to_char(485, '"Good number:"999')	'Good number: 485'
to_char(485.8, '"Pre:"999" Post:" .999')	'Pre: 485 Post: .800'
to_char(12, '99V999')	' 12000'
to_char(12.4, '99V999')	' 12400'
to_char(12.45, '99V9')	' 125'
to_char(0.0004859, '9.99EEEE')	' 4.86e-04'

9.9. Date/Time Functions and Operators

Table 9.32 shows the available functions for date/time value processing, with details appearing in the following subsections. Table 9.31 illustrates the behaviors of the basic arithmetic operators (+, *, etc.). For formatting functions, refer to Section 9.8. You should be familiar with the background information on date/time data types from Section 8.5.

In addition, the usual comparison operators shown in Table 9.1 are available for the date/time types. Dates and timestamps (with or without time zone) are all comparable, while times (with or without time zone) and intervals can only be compared to other values of the same data type. When comparing a timestamp without time zone to a timestamp with time zone, the former value is assumed to be given in the time zone specified by the TimeZone configuration parameter, and is rotated to UTC for comparison to the latter value (which is already in UTC internally). Similarly, a date value is assumed to represent midnight in the TimeZone zone when comparing it to a timestamp.

All the functions and operators described below that take time or timestamp inputs actually come in two variants: one that takes time with time zone or timestamp with time zone, and one that takes time without time zone or timestamp without time zone. For brevity, these variants are not shown separately. Also, the + and * operators come in commutative pairs (for example both date + integer and integer + date); we show only one of each such pair.

Table 9.31. Date/Time Operators

Operator Description Example(s)
date + integer → date

Operator **Description** **Example(s)**
Add a number of days to a date `date '2001-09-28' + 7 → 2001-10-05`

`date + interval → timestamp`
Add an interval to a date
`date '2001-09-28' + interval '1 hour' → 2001-09-28 01:00:00`

`date + time → timestamp`
Add a time-of-day to a date
`date '2001-09-28' + time '03:00' → 2001-09-28 03:00:00`

`interval + interval → interval`
Add intervals
`interval '1 day' + interval '1 hour' → 1 day 01:00:00`

`timestamp + interval → timestamp`
Add an interval to a timestamp
`timestamp '2001-09-28 01:00' + interval '23 hours' → 2001-09-29 00:00:00`

`time + interval → time`
Add an interval to a time
`time '01:00' + interval '3 hours' → 04:00:00`

`- interval → interval`
Negate an interval
`- interval '23 hours' → -23:00:00`

`date - date → integer`
Subtract dates, producing the number of days elapsed
`date '2001-10-01' - date '2001-09-28' → 3`

`date - integer → date`
Subtract a number of days from a date
`date '2001-10-01' - 7 → 2001-09-24`

`date - interval → timestamp`
Subtract an interval from a date
`date '2001-09-28' - interval '1 hour' → 2001-09-27 23:00:00`

`time - time → interval`
Subtract times
`time '05:00' - time '03:00' → 02:00:00`

`time - interval → time`
Subtract an interval from a time
`time '05:00' - interval '2 hours' → 03:00:00`

`timestamp - interval → timestamp`
Subtract an interval from a timestamp
`timestamp '2001-09-28 23:00' - interval '23 hours' → 2001-09-28 00:00:00`

`interval - interval → interval`
Subtract intervals
`interval '1 day' - interval '1 hour' → 1 day -01:00:00`

`timestamp - timestamp → interval`

Operator Description Example(s)
Subtract timestamps (converting 24-hour intervals into days, similarly to `justify_hours()`) `timestamp '2001-09-29 03:00' - timestamp '2001-07-27 12:00'` → `63 days 15:00:00`

`interval * double precision → interval`
Multiply an interval by a scalar
`interval '1 second' * 900` → `00:15:00`
`interval '1 day' * 21` → `21 days`
`interval '1 hour' * 3.5` → `03:30:00`

`interval / double precision → interval`
Divide an interval by a scalar
`interval '1 hour' / 1.5` → `00:40:00`

Table 9.32. Date/Time Functions

Function Description Example(s)

`age ( timestamp, timestamp ) → interval`
Subtract arguments, producing a "symbolic" result that uses years and months, rather than just days
`age(timestamp '2001-04-10', timestamp '1957-06-13')` → `43 years 9 mons 27 days`

`age ( timestamp ) → interval`
Subtract argument from `current_date` (at midnight)
`age(timestamp '1957-06-13')` → `62 years 6 mons 10 days`

`clock_timestamp ( ) → timestamp with time zone`
Current date and time (changes during statement execution); see Section 9.9.5
`clock_timestamp()` → `2019-12-23 14:39:53.662522-05`

`current_date → date`
Current date; see Section 9.9.5
`current_date` → `2019-12-23`

`current_time → time with time zone`
Current time of day; see Section 9.9.5
`current_time` → `14:39:53.662522-05`

`current_time ( integer ) → time with time zone`
Current time of day, with limited precision; see Section 9.9.5
`current_time(2)` → `14:39:53.66-05`

`current_timestamp → timestamp with time zone`
Current date and time (start of current transaction); see Section 9.9.5
`current_timestamp` → `2019-12-23 14:39:53.662522-05`

`current_timestamp ( integer ) → timestamp with time zone`
Current date and time (start of current transaction), with limited precision; see Section 9.9.5
`current_timestamp(0)` → `2019-12-23 14:39:53-05`

`date_bin ( interval, timestamp, timestamp ) → timestamp` Bin input into specified interval aligned with specified origin; see Section 9.9.3

Function **Description** **Example(s)**
`date_bin('15 minutes', timestamp '2001-02-16 20:38:40', timestamp '2001-02-16 20:05:00')` → `2001-02-16 20:35:00`

`date_part ( text, timestamp )` → `double precision`
Get timestamp subfield (equivalent to `extract`); see Section 9.9.1
`date_part('hour', timestamp '2001-02-16 20:38:40')` → `20`

`date_part ( text, interval )` → `double precision`
Get interval subfield (equivalent to `extract`); see Section 9.9.1
`date_part('month', interval '2 years 3 months')` → `3`

`date_trunc ( text, timestamp )` → `timestamp`
Truncate to specified precision; see Section 9.9.2
`date_trunc('hour', timestamp '2001-02-16 20:38:40')` → `2001-02-16 20:00:00`

`date_trunc ( text, timestamp with time zone, text )` → `timestamp with time zone`
Truncate to specified precision in the specified time zone; see Section 9.9.2
`date_trunc('day', timestamptz '2001-02-16 20:38:40+00', 'Australia/Sydney')` → `2001-02-16 13:00:00+00`

`date_trunc ( text, interval )` → `interval`
Truncate to specified precision; see Section 9.9.2
`date_trunc('hour', interval '2 days 3 hours 40 minutes')` → `2 days 03:00:00`

`extract ( field from timestamp )` → `numeric`
Get timestamp subfield; see Section 9.9.1
`extract(hour from timestamp '2001-02-16 20:38:40')` → `20`

`extract ( field from interval )` → `numeric`
Get interval subfield; see Section 9.9.1
`extract(month from interval '2 years 3 months')` → `3`

`isfinite ( date )` → `boolean`
Test for finite date (not +/-infinity)
`isfinite(date '2001-02-16')` → `true`

`isfinite ( timestamp )` → `boolean`
Test for finite timestamp (not +/-infinity)
`isfinite(timestamp 'infinity')` → `false`

`isfinite ( interval )` → `boolean`
Test for finite interval (currently always true)
`isfinite(interval '4 hours')` → `true`

`justify_days ( interval )` → `interval`
Adjust interval, converting 30-day time periods to months
`justify_days(interval '1 year 65 days')` → `1 year 2 mons 5 days`

`justify_hours ( interval )` → `interval`
Adjust interval, converting 24-hour time periods to days
`justify_hours(interval '50 hours 10 minutes')` → `2 days 02:10:00`

`justify_interval ( interval )` → `interval`
Adjust interval using `justify_days` and `justify_hours`, with additional sign adjustments
`justify_interval(interval '1 mon -1 hour')` → `29 days 23:00:00`

Function **Description** **Example(s)**

`localtime` → `time`
Current time of day; see Section 9.9.5
`localtime` → `14:39:53.662522`

`localtime` (`integer`) → `time`
Current time of day, with limited precision; see Section 9.9.5
`localtime(0)` → `14:39:53`

`localtimestamp` → `timestamp`
Current date and time (start of current transaction); see Section 9.9.5
`localtimestamp` → `2019-12-23 14:39:53.662522`

`localtimestamp` (`integer`) → `timestamp`
Current date and time (start of current transaction), with limited precision; see Section 9.9.5
`localtimestamp(2)` → `2019-12-23 14:39:53.66`

`make_date` (*year* `int`, *month* `int`, *day* `int`) → `date`
Create date from year, month and day fields (negative years signify BC)
`make_date(2013, 7, 15)` → `2013-07-15`

`make_interval` ([*years* `int` [, *months* `int` [, *weeks* `int` [, *days* `int` [, *hours* `int` [, *mins* `int` [, *secs* `double precision`]]]]]]) → `interval`
Create interval from years, months, weeks, days, hours, minutes and seconds fields, each of which can default to zero
`make_interval(days => 10)` → `10 days`

`make_time` (*hour* `int`, *min* `int`, *sec* `double precision`) → `time`
Create time from hour, minute and seconds fields
`make_time(8, 15, 23.5)` → `08:15:23.5`

`make_timestamp` (*year* `int`, *month* `int`, *day* `int`, *hour* `int`, *min* `int`, *sec* `double precision`) → `timestamp`
Create timestamp from year, month, day, hour, minute and seconds fields (negative years signify BC)
`make_timestamp(2013, 7, 15, 8, 15, 23.5)` → `2013-07-15 08:15:23.5`

`make_timestamptz` (*year* `int`, *month* `int`, *day* `int`, *hour* `int`, *min* `int`, *sec* `double precision` [, *timezone* `text`]) → `timestamp with time zone`
Create timestamp with time zone from year, month, day, hour, minute and seconds fields (negative years signify BC). If *timezone* is not specified, the current time zone is used; the examples assume the session time zone is `Europe/London`
`make_timestamptz(2013, 7, 15, 8, 15, 23.5)` → `2013-07-15 08:15:23.5+01`
`make_timestamptz(2013, 7, 15, 8, 15, 23.5, 'America/New_York')` → `2013-07-15 13:15:23.5+01`

`now` ( ) → `timestamp with time zone`
Current date and time (start of current transaction); see Section 9.9.5
`now()` → `2019-12-23 14:39:53.662522-05`

`statement_timestamp` ( ) → `timestamp with time zone`
Current date and time (start of current statement); see Section 9.9.5
`statement_timestamp()` → `2019-12-23 14:39:53.662522-05`

`timeofday` ( ) → `text` Current date and time (like `clock_timestamp` , but as a `text` string); see Section 9.9.5

Function **Description** **Example(s)**
`timeofday()` → `Mon Dec 23 14:39:53.662522 2019 EST`

`transaction_timestamp ( )` → `timestamp with time zone`
Current date and time (start of current transaction); see Section 9.9.5
`transaction_timestamp()` → `2019-12-23 14:39:53.662522-05`

`to_timestamp ( double precision )` → `timestamp with time zone`
Convert Unix epoch (seconds since 1970-01-01 00:00:00+00) to timestamp with time zone
`to_timestamp(1284352323)` → `2010-09-13 04:32:03+00`

In addition to these functions, the SQL `OVERLAPS` operator is supported:

```
(start1, end1) OVERLAPS (start2, end2)
(start1, length1) OVERLAPS (start2, length2)
```

This expression yields true when two time periods (defined by their endpoints) overlap, false when they do not overlap. The endpoints can be specified as pairs of dates, times, or time stamps; or as a date, time, or time stamp followed by an interval. When a pair of values is provided, either the start or the end can be written first; `OVERLAPS` automatically takes the earlier value of the pair as the start. Each time period is considered to represent the half-open interval *start* <= *time* < *end*, unless *start* and *end* are equal in which case it represents that single time instant. This means for instance that two time periods with only an endpoint in common do not overlap.

```
SELECT (DATE '2001-02-16', DATE '2001-12-21') OVERLAPS
       (DATE '2001-10-30', DATE '2002-10-30');
Result: true
SELECT (DATE '2001-02-16', INTERVAL '100 days') OVERLAPS
       (DATE '2001-10-30', DATE '2002-10-30');
Result: false
SELECT (DATE '2001-10-29', DATE '2001-10-30') OVERLAPS
       (DATE '2001-10-30', DATE '2001-10-31');
Result: false
SELECT (DATE '2001-10-30', DATE '2001-10-30') OVERLAPS
       (DATE '2001-10-30', DATE '2001-10-31');
Result: true
```

When adding an `interval` value to (or subtracting an `interval` value from) a `timestamp with time zone` value, the days component advances or decrements the date of the `timestamp with time zone` by the indicated number of days, keeping the time of day the same. Across daylight saving time changes (when the session time zone is set to a time zone that recognizes DST), this means `interval '1 day'` does not necessarily equal `interval '24 hours'`. For example, with the session time zone set to `America/Denver`:

```
SELECT timestamp with time zone '2005-04-02 12:00:00-07' + interval '1 day';
Result: 2005-04-03 12:00:00-06
SELECT timestamp with time zone '2005-04-02 12:00:00-07' + interval '24 hours';
Result: 2005-04-03 13:00:00-06
```

This happens because an hour was skipped due to a change in daylight saving time at `2005-04-03 02:00:00` in time zone `America/Denver`.

Note there can be ambiguity in the `months` field returned by `age` because different months have different numbers of days. Postgres Pro's approach uses the month from the earlier of the two dates when calculating partial months. For example, `age('2004-06-01', '2004-04-30')` uses April to yield `1 mon 1 day`, while using May would yield `1 mon 2 days` because May has 31 days, while April has only 30.

Subtraction of dates and timestamps can also be complex. One conceptually simple way to perform subtraction is to convert each value to a number of seconds using `EXTRACT(EPOCH FROM ...)`, then

subtract the results; this produces the number of *seconds* between the two values. This will adjust for the number of days in each month, timezone changes, and daylight saving time adjustments. Subtraction of date or timestamp values with the "-" operator returns the number of days (24-hours) and hours/minutes/seconds between the values, making the same adjustments. The `age` function returns years, months, days, and hours/minutes/seconds, performing field-by-field subtraction and then adjusting for negative field values. The following queries illustrate the differences in these approaches. The sample results were produced with `timezone = 'US/Eastern'`; there is a daylight saving time change between the two dates used:

```
SELECT EXTRACT(EPOCH FROM timestamptz '2013-07-01 12:00:00') -
       EXTRACT(EPOCH FROM timestamptz '2013-03-01 12:00:00');
Result: 10537200.000000
SELECT (EXTRACT(EPOCH FROM timestamptz '2013-07-01 12:00:00') -
        EXTRACT(EPOCH FROM timestamptz '2013-03-01 12:00:00'))
        / 60 / 60 / 24;
Result: 121.9583333333333333
SELECT timestamptz '2013-07-01 12:00:00' - timestamptz '2013-03-01 12:00:00';
Result: 121 days 23:00:00
SELECT age(timestamptz '2013-07-01 12:00:00', timestamptz '2013-03-01 12:00:00');
Result: 4 mons
```

9.9.1. EXTRACT, date_part

`EXTRACT(`*`field`* `FROM` *`source`*`)`

The `extract` function retrieves subfields such as year or hour from date/time values. *`source`* must be a value expression of type `timestamp`, `date`, `time`, or `interval`. (Timestamps and times can be with or without time zone.) *`field`* is an identifier or string that selects what field to extract from the source value. Not all fields are valid for every input data type; for example, fields smaller than a day cannot be extracted from a `date`, while fields of a day or more cannot be extracted from a `time`. The `extract` function returns values of type `numeric`.

The following are valid field names:

`century`

The century; for `interval` values, the year field divided by 100

```
SELECT EXTRACT(CENTURY FROM TIMESTAMP '2000-12-16 12:21:13');
Result: 20
SELECT EXTRACT(CENTURY FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 21
SELECT EXTRACT(CENTURY FROM DATE '0001-01-01 AD');
Result: 1
SELECT EXTRACT(CENTURY FROM DATE '0001-12-31 BC');
Result: -1
SELECT EXTRACT(CENTURY FROM INTERVAL '2001 years');
Result: 20
```

`day`

The day of the month (1-31); for `interval` values, the number of days

```
SELECT EXTRACT(DAY FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 16
SELECT EXTRACT(DAY FROM INTERVAL '40 days 1 minute');
Result: 40
```

`decade`

The year field divided by 10

```
SELECT EXTRACT(DECADE FROM TIMESTAMP '2001-02-16 20:38:40');
```

```
Result: 200
```

`dow`

The day of the week as Sunday (`0`) to Saturday (`6`)

```
SELECT EXTRACT(DOW FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 5
```

Note that `extract`'s day of the week numbering differs from that of the `to_char(..., 'D')` function.

`doy`

The day of the year (1-365/366)

```
SELECT EXTRACT(DOY FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 47
```

`epoch`

For `timestamp with time zone` values, the number of seconds since 1970-01-01 00:00:00 UTC (negative for timestamps before that); for `date` and `timestamp` values, the nominal number of seconds since 1970-01-01 00:00:00, without regard to timezone or daylight-savings rules; for `interval` values, the total number of seconds in the interval

```
SELECT EXTRACT(EPOCH FROM TIMESTAMP WITH TIME ZONE '2001-02-16 20:38:40.12-08');
Result: 982384720.120000
SELECT EXTRACT(EPOCH FROM TIMESTAMP '2001-02-16 20:38:40.12');
Result: 982355920.120000
SELECT EXTRACT(EPOCH FROM INTERVAL '5 days 3 hours');
Result: 442800.000000
```

You can convert an epoch value back to a `timestamp with time zone` with `to_timestamp`:

```
SELECT to_timestamp(982384720.12);
Result: 2001-02-17 04:38:40.12+00
```

Beware that applying `to_timestamp` to an epoch extracted from a `date` or `timestamp` value could produce a misleading result: the result will effectively assume that the original value had been given in UTC, which might not be the case.

`hour`

The hour field (0-23 in timestamps, unrestricted in intervals)

```
SELECT EXTRACT(HOUR FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 20
```

`isodow`

The day of the week as Monday (`1`) to Sunday (`7`)

```
SELECT EXTRACT(ISODOW FROM TIMESTAMP '2001-02-18 20:38:40');
Result: 7
```

This is identical to `dow` except for Sunday. This matches the ISO 8601 day of the week numbering.

`isoyear`

The ISO 8601 week-numbering year that the date falls in

```
SELECT EXTRACT(ISOYEAR FROM DATE '2006-01-01');
Result: 2005
SELECT EXTRACT(ISOYEAR FROM DATE '2006-01-02');
```

```
Result: 2006
```

Each ISO 8601 week-numbering year begins with the Monday of the week containing the 4th of January, so in early January or late December the ISO year may be different from the Gregorian year. See the `week` field for more information.

`julian`

The *Julian Date* corresponding to the date or timestamp. Timestamps that are not local midnight result in a fractional value. See Section B.7 for more information.

```
SELECT EXTRACT(JULIAN FROM DATE '2006-01-01');
Result: 2453737
SELECT EXTRACT(JULIAN FROM TIMESTAMP '2006-01-01 12:00');
Result: 2453737.50000000000000000000
```

`microseconds`

The seconds field, including fractional parts, multiplied by 1 000 000; note that this includes full seconds

```
SELECT EXTRACT(MICROSECONDS FROM TIME '17:12:28.5');
Result: 28500000
```

`millennium`

The millennium; for `interval` values, the year field divided by 1000

```
SELECT EXTRACT(MILLENNIUM FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 3
SELECT EXTRACT(MILLENNIUM FROM INTERVAL '2001 years');
Result: 2
```

Years in the 1900s are in the second millennium. The third millennium started January 1, 2001.

`milliseconds`

The seconds field, including fractional parts, multiplied by 1000. Note that this includes full seconds.

```
SELECT EXTRACT(MILLISECONDS FROM TIME '17:12:28.5');
Result: 28500.000
```

`minute`

The minutes field (0–59)

```
SELECT EXTRACT(MINUTE FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 38
```

`month`

The number of the month within the year (1–12); for `interval` values, the number of months modulo 12 (0–11)

```
SELECT EXTRACT(MONTH FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 2
SELECT EXTRACT(MONTH FROM INTERVAL '2 years 3 months');
Result: 3
SELECT EXTRACT(MONTH FROM INTERVAL '2 years 13 months');
Result: 1
```

`quarter`

The quarter of the year (1–4) that the date is in

```
SELECT EXTRACT(QUARTER FROM TIMESTAMP '2001-02-16 20:38:40');
```

```
Result: 1
```

second

The seconds field, including any fractional seconds

```
SELECT EXTRACT(SECOND FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 40.000000
SELECT EXTRACT(SECOND FROM TIME '17:12:28.5');
Result: 28.500000
```

timezone

The time zone offset from UTC, measured in seconds. Positive values correspond to time zones east of UTC, negative values to zones west of UTC. (Technically, Postgres Pro does not use UTC because leap seconds are not handled.)

timezone_hour

The hour component of the time zone offset

timezone_minute

The minute component of the time zone offset

week

The number of the ISO 8601 week-numbering week of the year. By definition, ISO weeks start on Mondays and the first week of a year contains January 4 of that year. In other words, the first Thursday of a year is in week 1 of that year.

In the ISO week-numbering system, it is possible for early-January dates to be part of the 52nd or 53rd week of the previous year, and for late-December dates to be part of the first week of the next year. For example, `2005-01-01` is part of the 53rd week of year 2004, and `2006-01-01` is part of the 52nd week of year 2005, while `2012-12-31` is part of the first week of 2013. It's recommended to use the `isoyear` field together with `week` to get consistent results.

```
SELECT EXTRACT(WEEK FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 7
```

year

The year field. Keep in mind there is no `0 AD`, so subtracting `BC` years from `AD` years should be done with care.

```
SELECT EXTRACT(YEAR FROM TIMESTAMP '2001-02-16 20:38:40');
Result: 2001
```

When processing an `interval` value, the `extract` function produces field values that match the interpretation used by the interval output function. This can produce surprising results if one starts with a non-normalized interval representation, for example:

```
SELECT INTERVAL '80 minutes';
Result: 01:20:00
SELECT EXTRACT(MINUTES FROM INTERVAL '80 minutes');
Result: 20
```

Note

When the input value is +/-Infinity, `extract` returns +/-Infinity for monotonically-increasing fields (`epoch`, `julian`, `year`, `isoyear`, `decade`, `century`, and `millennium`). For other fields, NULL is returned. Postgres Pro versions before 9.6 returned zero for all cases of infinite input.

The `extract` function is primarily intended for computational processing. For formatting date/time values for display, see Section 9.8.

The `date_part` function is modeled on the traditional Ingres equivalent to the SQL-standard function `extract`:

`date_part('field', source)`

Note that here the *`field`* parameter needs to be a string value, not a name. The valid field names for `date_part` are the same as for `extract`. For historical reasons, the `date_part` function returns values of type `double precision`. This can result in a loss of precision in certain uses. Using `extract` is recommended instead.

```
SELECT date_part('day', TIMESTAMP '2001-02-16 20:38:40');
Result: 16
SELECT date_part('hour', INTERVAL '4 hours 3 minutes');
Result: 4
```

9.9.2. date_trunc

The function `date_trunc` is conceptually similar to the `trunc` function for numbers.

`date_trunc(field, source [, time_zone ])`

`source` is a value expression of type `timestamp`, `timestamp with time zone`, or `interval`. (Values of type `date` and `time` are cast automatically to `timestamp` or `interval`, respectively.) *`field`* selects to which precision to truncate the input value. The return value is likewise of type `timestamp`, `timestamp with time zone`, or `interval`, and it has all fields that are less significant than the selected one set to zero (or one, for day and month).

Valid values for *`field`* are:

```
microseconds
milliseconds
second
minute
hour
day
week
month
quarter
year
decade
century
millennium
```

When the input value is of type `timestamp with time zone`, the truncation is performed with respect to a particular time zone; for example, truncation to `day` produces a value that is midnight in that zone. By default, truncation is done with respect to the current TimeZone setting, but the optional *`time_zone`* argument can be provided to specify a different time zone. The time zone name can be specified in any of the ways described in Section 8.5.3.

A time zone cannot be specified when processing `timestamp without time zone` or `interval` inputs. These are always taken at face value.

Examples (assuming the local time zone is `America/New_York`):

```
SELECT date_trunc('hour', TIMESTAMP '2001-02-16 20:38:40');
Result: 2001-02-16 20:00:00
SELECT date_trunc('year', TIMESTAMP '2001-02-16 20:38:40');
Result: 2001-01-01 00:00:00
```

```
SELECT date_trunc('day', TIMESTAMP WITH TIME ZONE '2001-02-16 20:38:40+00');
Result: 2001-02-16 00:00:00-05
SELECT date_trunc('day', TIMESTAMP WITH TIME ZONE '2001-02-16 20:38:40+00', 'Australia/
Sydney');
Result: 2001-02-16 08:00:00-05
SELECT date_trunc('hour', INTERVAL '3 days 02:47:33');
Result: 3 days 02:00:00
```

9.9.3. date_bin

The function date_bin "bins" the input timestamp into the specified interval (the *stride*) aligned with a specified origin.

```
date_bin(stride, source, origin)
```

source is a value expression of type timestamp or timestamp with time zone. (Values of type date are cast automatically to timestamp.) *stride* is a value expression of type interval. The return value is likewise of type timestamp or timestamp with time zone, and it marks the beginning of the bin into which the *source* is placed.

Examples:

```
SELECT date_bin('15 minutes', TIMESTAMP '2020-02-11 15:44:17', TIMESTAMP '2001-01-01');
Result: 2020-02-11 15:30:00
SELECT date_bin('15 minutes', TIMESTAMP '2020-02-11 15:44:17', TIMESTAMP '2001-01-01
 00:02:30');
Result: 2020-02-11 15:32:30
```

In the case of full units (1 minute, 1 hour, etc.), it gives the same result as the analogous date_trunc call, but the difference is that date_bin can truncate to an arbitrary interval.

The *stride* interval must be greater than zero and cannot contain units of month or larger.

9.9.4. AT TIME ZONE

The AT TIME ZONE operator converts time stamp *without* time zone to/from time stamp *with* time zone, and time with time zone values to different time zones. Table 9.33 shows its variants.

Table 9.33. AT TIME ZONE Variants

Operator Description Example(s)
timestamp without time zone AT TIME ZONE *zone* → timestamp with time zone Converts given time stamp *without* time zone to time stamp *with* time zone, assuming the given value is in the named time zone. timestamp '2001-02-16 20:38:40' at time zone 'America/Denver' → 2001-02-17 03:38:40+00
timestamp with time zone AT TIME ZONE *zone* → timestamp without time zone Converts given time stamp *with* time zone to time stamp *without* time zone, as the time would appear in that zone. timestamp with time zone '2001-02-16 20:38:40-05' at time zone 'America/Denver' → 2001-02-16 18:38:40
time with time zone AT TIME ZONE *zone* → time with time zone Converts given time *with* time zone to a new time zone. Since no date is supplied, this uses the currently active UTC offset for the named destination zone. time with time zone '05:34:17-05' at time zone 'UTC' → 10:34:17+00

In these expressions, the desired time zone *zone* can be specified either as a text value (e.g., 'America/Los_Angeles') or as an interval (e.g., INTERVAL '-08:00'). In the text case, a time zone name can be specified in any of the ways described in Section 8.5.3. The interval case is only useful for zones that have fixed offsets from UTC, so it is not very common in practice.

Examples (assuming the current TimeZone setting is America/Los_Angeles):

```
SELECT TIMESTAMP '2001-02-16 20:38:40' AT TIME ZONE 'America/Denver';
Result: 2001-02-16 19:38:40-08
SELECT TIMESTAMP WITH TIME ZONE '2001-02-16 20:38:40-05' AT TIME ZONE 'America/Denver';
Result: 2001-02-16 18:38:40
SELECT TIMESTAMP '2001-02-16 20:38:40' AT TIME ZONE 'Asia/Tokyo' AT TIME ZONE 'America/
Chicago';
Result: 2001-02-16 05:38:40
```

The first example adds a time zone to a value that lacks it, and displays the value using the current TimeZone setting. The second example shifts the time stamp with time zone value to the specified time zone, and returns the value without a time zone. This allows storage and display of values different from the current TimeZone setting. The third example converts Tokyo time to Chicago time.

The function timezone(*zone*, *timestamp*) is equivalent to the SQL-conforming construct *timestamp* AT TIME ZONE *zone*.

9.9.5. Current Date/Time

Postgres Pro provides a number of functions that return values related to the current date and time. These SQL-standard functions all return values based on the start time of the current transaction:

```
CURRENT_DATE
CURRENT_TIME
CURRENT_TIMESTAMP
CURRENT_TIME(precision)
CURRENT_TIMESTAMP(precision)
LOCALTIME
LOCALTIMESTAMP
LOCALTIME(precision)
LOCALTIMESTAMP(precision)
```

CURRENT_TIME and CURRENT_TIMESTAMP deliver values with time zone; LOCALTIME and LOCALTIMESTAMP deliver values without time zone.

CURRENT_TIME, CURRENT_TIMESTAMP, LOCALTIME, and LOCALTIMESTAMP can optionally take a precision parameter, which causes the result to be rounded to that many fractional digits in the seconds field. Without a precision parameter, the result is given to the full available precision.

Some examples:

```
SELECT CURRENT_TIME;
Result: 14:39:53.662522-05
SELECT CURRENT_DATE;
Result: 2019-12-23
SELECT CURRENT_TIMESTAMP;
Result: 2019-12-23 14:39:53.662522-05
SELECT CURRENT_TIMESTAMP(2);
Result: 2019-12-23 14:39:53.66-05
SELECT LOCALTIMESTAMP;
Result: 2019-12-23 14:39:53.662522
```

Since these functions return the start time of the current transaction, their values do not change during the transaction. This is considered a feature: the intent is to allow a single transaction to have a consistent

notion of the “current” time, so that multiple modifications within the same transaction bear the same time stamp.

> **Note**
>
> Other database systems might advance these values more frequently.

Postgres Pro also provides functions that return the start time of the current statement, as well as the actual current time at the instant the function is called. The complete list of non-SQL-standard time functions is:

```
transaction_timestamp()
statement_timestamp()
clock_timestamp()
timeofday()
now()
```

`transaction_timestamp()` is equivalent to `CURRENT_TIMESTAMP`, but is named to clearly reflect what it returns. `statement_timestamp()` returns the start time of the current statement (more specifically, the time of receipt of the latest command message from the client). `statement_timestamp()` and `transaction_timestamp()` return the same value during the first command of a transaction, but might differ during subsequent commands. `clock_timestamp()` returns the actual current time, and therefore its value changes even within a single SQL command. `timeofday()` is a historical Postgres Pro function. Like `clock_timestamp()`, it returns the actual current time, but as a formatted `text` string rather than a `timestamp with time zone` value. `now()` is a traditional Postgres Pro equivalent to `transaction_timestamp()`.

All the date/time data types also accept the special literal value `now` to specify the current date and time (again, interpreted as the transaction start time). Thus, the following three all return the same result:

```
SELECT CURRENT_TIMESTAMP;
SELECT now();
SELECT TIMESTAMP 'now';  -- but see tip below
```

> **Tip**
>
> Do not use the third form when specifying a value to be evaluated later, for example in a `DEFAULT` clause for a table column. The system will convert `now` to a `timestamp` as soon as the constant is parsed, so that when the default value is needed, the time of the table creation would be used! The first two forms will not be evaluated until the default value is used, because they are function calls. Thus they will give the desired behavior of defaulting to the time of row insertion. (See also Section 8.5.1.4.)

9.9.6. Delaying Execution

The following functions are available to delay execution of the server process:

```
pg_sleep ( double precision )
pg_sleep_for ( interval )
pg_sleep_until ( timestamp with time zone )
```

`pg_sleep` makes the current session's process sleep until the given number of seconds have elapsed. Fractional-second delays can be specified. `pg_sleep_for` is a convenience function to allow the sleep time to be specified as an `interval`. `pg_sleep_until` is a convenience function for when a specific wake-up time is desired. For example:

```
SELECT pg_sleep(1.5);
SELECT pg_sleep_for('5 minutes');
SELECT pg_sleep_until('tomorrow 03:00');
```

> **Note**
>
> The effective resolution of the sleep interval is platform-specific; 0.01 seconds is a common value. The sleep delay will be at least as long as specified. It might be longer depending on factors such as server load. In particular, `pg_sleep_until` is not guaranteed to wake up exactly at the specified time, but it will not wake up any earlier.

> **Warning**
>
> Make sure that your session does not hold more locks than necessary when calling `pg_sleep` or its variants. Otherwise other sessions might have to wait for your sleeping process, slowing down the entire system.

9.10. Enum Support Functions

For enum types (described in Section 8.7), there are several functions that allow cleaner programming without hard-coding particular values of an enum type. These are listed in Table 9.34. The examples assume an enum type created as:

```
CREATE TYPE rainbow AS ENUM ('red', 'orange', 'yellow', 'green', 'blue', 'purple');
```

Table 9.34. Enum Support Functions

Function **Description** **Example(s)**

`enum_first ( anyenum ) → anyenum`
Returns the first value of the input enum type.
`enum_first(null::rainbow) → red`

`enum_last ( anyenum ) → anyenum`
Returns the last value of the input enum type.
`enum_last(null::rainbow) → purple`

`enum_range ( anyenum ) → anyarray`
Returns all values of the input enum type in an ordered array.
`enum_range(null::rainbow) → {red,orange,yellow,green,blue,purple}`

`enum_range ( anyenum, anyenum ) → anyarray`
Returns the range between the two given enum values, as an ordered array. The values must be from the same enum type. If the first parameter is null, the result will start with the first value of the enum type. If the second parameter is null, the result will end with the last value of the enum type.
`enum_range('orange'::rainbow, 'green'::rainbow) → {orange,yellow,green}`
`enum_range(NULL, 'green'::rainbow) → {red,orange,yellow,green}`
`enum_range('orange'::rainbow, NULL) → {orange,yellow,green,blue,purple}`

Notice that except for the two-argument form of `enum_range`, these functions disregard the specific value passed to them; they care only about its declared data type. Either null or a specific value of the type can be passed, with the same result. It is more common to apply these functions to a table column or function argument than to a hardwired type name as used in the examples.

9.11. Geometric Functions and Operators

The geometric types `point`, `box`, `lseg`, `line`, `path`, `polygon`, and `circle` have a large set of native support functions and operators, shown in Table 9.35, Table 9.36, and Table 9.37.

Table 9.35. Geometric Operators

Operator **Description** **Example(s)**
geometric_type + point → *geometric_type* Adds the coordinates of the second point to those of each point of the first argument, thus performing translation. Available for point, box, path, circle. box '(1,1),(0,0)' + point '(2,0)' → (3,1),(2,0)
path + path → path Concatenates two open paths (returns NULL if either path is closed). path '[(0,0),(1,1)]' + path '[(2,2),(3,3),(4,4)]' → [(0,0),(1,1),(2,2),(3,3),(4,4)]
geometric_type - point → *geometric_type* Subtracts the coordinates of the second point from those of each point of the first argument, thus performing translation. Available for point, box, path, circle. box '(1,1),(0,0)' - point '(2,0)' → (-1,1),(-2,0)
geometric_type * point → *geometric_type* Multiplies each point of the first argument by the second point (treating a point as being a complex number represented by real and imaginary parts, and performing standard complex multiplication). If one interprets the second point as a vector, this is equivalent to scaling the object's size and distance from the origin by the length of the vector, and rotating it counterclockwise around the origin by the vector's angle from the *x* axis. Available for point, box,[a] path, circle. path '((0,0),(1,0),(1,1))' * point '(3.0,0)' → ((0,0),(3,0),(3,3)) path '((0,0),(1,0),(1,1))' * point(cosd(45), sind(45)) → ((0,0),(0.7071067811865475,0.7071067811865475),(0,1.414213562373095))
geometric_type / point → *geometric_type* Divides each point of the first argument by the second point (treating a point as being a complex number represented by real and imaginary parts, and performing standard complex division). If one interprets the second point as a vector, this is equivalent to scaling the object's size and distance from the origin down by the length of the vector, and rotating it clockwise around the origin by the vector's angle from the *x* axis. Available for point, box,[a] path, circle. path '((0,0),(1,0),(1,1))' / point '(2.0,0)' → ((0,0),(0.5,0),(0.5,0.5)) path '((0,0),(1,0),(1,1))' / point(cosd(45), sind(45)) → ((0,0),(0.7071067811865476,-0.7071067811865476),(1.4142135623730951,0))
@-@ *geometric_type* → double precision Computes the total length. Available for lseg, path. @-@ path '[(0,0),(1,0),(1,1)]' → 2
@@ *geometric_type* → point Computes the center point. Available for box, lseg, polygon, circle. @@ box '(2,2),(0,0)' → (1,1)
# *geometric_type* → integer Returns the number of points. Available for path, polygon. # path '((1,0),(0,1),(-1,0))' → 3
geometric_type # *geometric_type* → point

Operator **Description** **Example(s)**
Computes the point of intersection, or NULL if there is none. Available for `lseg`, `line`. `lseg '[(0,0),(1,1)]' # lseg '[(1,0),(0,1)]'` → `(0.5,0.5)`

`box # box` → `box`
Computes the intersection of two boxes, or NULL if there is none.
`box '(2,2),(-1,-1)' # box '(1,1),(-2,-2)'` → `(1,1),(-1,-1)`

geometric_type `##` *geometric_type* → `point` Computes the closest point to the first object on the second object. Available for these pairs of types: (`point`, `box`), (`point`, `lseg`), (`point`, `line`), (`lseg`, `box`), (`lseg`, `lseg`), (`line`, `lseg`). `point '(0,0)' ## lseg '[(2,0),(0,2)]'` → `(1,1)`
geometric_type `<->` *geometric_type* → `double precision` Computes the distance between the objects. Available for all geometric types except `polygon`, for all combinations of `point` with another geometric type, and for these additional pairs of types: (`box`, `lseg`), (`lseg`, `line`), (`polygon`, `circle`) (and the commutator cases). `circle '<(0,0),1>' <-> circle '<(5,0),1>'` → `3`
geometric_type `@>` *geometric_type* → `boolean` Does first object contain second? Available for these pairs of types: (`box`, `point`), (`box`, `box`), (`path`, `point`), (`polygon`, `point`), (`polygon`, `polygon`), (`circle`, `point`), (`circle`, `circle`). `circle '<(0,0),2>' @> point '(1,1)'` → `t`
geometric_type `<@` *geometric_type* → `boolean` Is first object contained in or on second? Available for these pairs of types: (`point`, `box`), (`point`, `lseg`), (`point`, `line`), (`point`, `path`), (`point`, `polygon`), (`point`, `circle`), (`box`, `box`), (`lseg`, `box`), (`lseg`, `line`), (`polygon`, `polygon`), (`circle`, `circle`). `point '(1,1)' <@ circle '<(0,0),2>'` → `t`
geometric_type `&&` *geometric_type* → `boolean` Do these objects overlap? (One point in common makes this true.) Available for `box`, `polygon`, `circle`. `box '(1,1),(0,0)' && box '(2,2),(0,0)'` → `t`
geometric_type `<<` *geometric_type* → `boolean` Is first object strictly left of second? Available for `point`, `box`, `polygon`, `circle`. `circle '<(0,0),1>' << circle '<(5,0),1>'` → `t`
geometric_type `>>` *geometric_type* → `boolean` Is first object strictly right of second? Available for `point`, `box`, `polygon`, `circle`. `circle '<(5,0),1>' >> circle '<(0,0),1>'` → `t`
geometric_type `&<` *geometric_type* → `boolean` Does first object not extend to the right of second? Available for `box`, `polygon`, `circle`. `box '(1,1),(0,0)' &< box '(2,2),(0,0)'` → `t`
geometric_type `&>` *geometric_type* → `boolean` Does first object not extend to the left of second? Available for `box`, `polygon`, `circle`. `box '(3,3),(0,0)' &> box '(2,2),(0,0)'` → `t`
geometric_type `<<|` *geometric_type* → `boolean` Is first object strictly below second? Available for `point`, `box`, `polygon`, `circle`. `box '(3,3),(0,0)' <<| box '(5,5),(3,4)'` → `t`
geometric_type `|>>` *geometric_type* → `boolean`

Operator **Description** **Example(s)**
Is first object strictly above second? Available for `point`, `box`, `polygon`, `circle`. `box '(5,5),(3,4)' |>> box '(3,3),(0,0)'` → `t`
geometric_type `&<|` *geometric_type* → `boolean` Does first object not extend above second? Available for `box`, `polygon`, `circle`. `box '(1,1),(0,0)' &<| box '(2,2),(0,0)'` → `t`
geometric_type `|&>` *geometric_type* → `boolean` Does first object not extend below second? Available for `box`, `polygon`, `circle`. `box '(3,3),(0,0)' |&> box '(2,2),(0,0)'` → `t`

`box <^ box` → `boolean`
Is first object below second (allows edges to touch)?
`box '((1,1),(0,0))' <^ box '((2,2),(1,1))'` → `t`

`box >^ box` → `boolean`
Is first object above second (allows edges to touch)?
`box '((2,2),(1,1))' >^ box '((1,1),(0,0))'` → `t`

geometric_type `?#` *geometric_type* → `boolean` Do these objects intersect? Available for these pairs of types: (`box`, `box`), (`lseg`, `box`), (`lseg`, `lseg`), (`lseg`, `line`), (`line`, `box`), (`line`, `line`), (`path`, `path`). `lseg '[(-1,0),(1,0)]' ?# box '(2,2),(-2,-2)'` → `t`

`?- line` → `boolean`
`?- lseg` → `boolean`
Is line horizontal?
`?- lseg '[(-1,0),(1,0)]'` → `t`

`point ?- point` → `boolean`
Are points horizontally aligned (that is, have same y coordinate)?
`point '(1,0)' ?- point '(0,0)'` → `t`

`?| line` → `boolean`
`?| lseg` → `boolean`
Is line vertical?
`?| lseg '[(-1,0),(1,0)]'` → `f`

`point ?| point` → `boolean`
Are points vertically aligned (that is, have same x coordinate)?
`point '(0,1)' ?| point '(0,0)'` → `t`

`line ?-| line` → `boolean`
`lseg ?-| lseg` → `boolean`
Are lines perpendicular?
`lseg '[(0,0),(0,1)]' ?-| lseg '[(0,0),(1,0)]'` → `t`

`line ?|| line` → `boolean`
`lseg ?|| lseg` → `boolean`
Are lines parallel?
`lseg '[(-1,0),(1,0)]' ?|| lseg '[(-1,2),(1,2)]'` → `t`

geometric_type `~=` *geometric_type* → `boolean` Are these objects the same? Available for `point`, `box`, `polygon`, `circle`.

Operator Description Example(s)
`polygon '((0,0),(1,1))' ~= polygon '((1,1),(0,0))'` → `t`

[a] "Rotating" a box with these operators only moves its corner points: the box is still considered to have sides parallel to the axes. Hence the box's size is not preserved, as a true rotation would do.

Caution

Note that the "same as" operator, `~=`, represents the usual notion of equality for the `point`, `box`, `polygon`, and `circle` types. Some of the geometric types also have an `=` operator, but `=` compares for equal *areas* only. The other scalar comparison operators (`<=` and so on), where available for these types, likewise compare areas.

Note

Before Postgres Pro 14, the point is strictly below/above comparison operators `point <<| point` and `point |>> point` were respectively called `<^` and `>^`. These names are still available, but are deprecated and will eventually be removed.

Table 9.36. Geometric Functions

Function Description Example(s)

`area ( geometric_type ) → double precision`
Computes area. Available for `box`, `path`, `circle`. A `path` input must be closed, else NULL is returned. Also, if the `path` is self-intersecting, the result may be meaningless.
`area(box '(2,2),(0,0)')` → `4`

`center ( geometric_type ) → point`
Computes center point. Available for `box`, `circle`.
`center(box '(1,2),(0,0)')` → `(0.5,1)`

`diagonal ( box ) → lseg`
Extracts box's diagonal as a line segment (same as `lseg(box)`).
`diagonal(box '(1,2),(0,0)')` → `[(1,2),(0,0)]`

`diameter ( circle ) → double precision`
Computes diameter of circle.
`diameter(circle '<(0,0),2>')` → `4`

`height ( box ) → double precision`
Computes vertical size of box.
`height(box '(1,2),(0,0)')` → `2`

`isclosed ( path ) → boolean`
Is path closed?
`isclosed(path '((0,0),(1,1),(2,0))')` → `t`

`isopen ( path ) → boolean`
Is path open?
`isopen(path '[(0,0),(1,1),(2,0)]')` → `t`

`length ( geometric_type ) → double precision` Computes the total length. Available for `lseg`, `path`.

Function **Description** **Example(s)**
`length(path '((-1,0),(1,0))')` → `4`

`npoints ( geometric_type ) → integer`
Returns the number of points. Available for `path`, `polygon`.
`npoints(path '[(0,0),(1,1),(2,0)]')` → `3`

`pclose ( path ) → path`
Converts path to closed form.
`pclose(path '[(0,0),(1,1),(2,0)]')` → `((0,0),(1,1),(2,0))`

`popen ( path ) → path`
Converts path to open form.
`popen(path '((0,0),(1,1),(2,0))')` → `[(0,0),(1,1),(2,0)]`

`radius ( circle ) → double precision`
Computes radius of circle.
`radius(circle '<(0,0),2>')` → `2`

`slope ( point, point ) → double precision`
Computes slope of a line drawn through the two points.
`slope(point '(0,0)', point '(2,1)')` → `0.5`

`width ( box ) → double precision`
Computes horizontal size of box.
`width(box '(1,2),(0,0)')` → `1`

Table 9.37. Geometric Type Conversion Functions

Function **Description** **Example(s)**

`box ( circle ) → box`
Computes box inscribed within the circle.
`box(circle '<(0,0),2>')` → `(1.414213562373095,1.414213562373095),(-1.414213562373095,-1.414213562373095)`

`box ( point ) → box`
Converts point to empty box.
`box(point '(1,0)')` → `(1,0),(1,0)`

`box ( point, point ) → box`
Converts any two corner points to box.
`box(point '(0,1)', point '(1,0)')` → `(1,1),(0,0)`

`box ( polygon ) → box`
Computes bounding box of polygon.
`box(polygon '((0,0),(1,1),(2,0))')` → `(2,1),(0,0)`

`bound_box ( box, box ) → box`
Computes bounding box of two boxes.
`bound_box(box '(1,1),(0,0)', box '(4,4),(3,3)')` → `(4,4),(0,0)`

`circle ( box ) → circle`
Computes smallest circle enclosing box.
`circle(box '(1,1),(0,0)')` → `<(0.5,0.5),0.7071067811865476>`

Function
Description
Example(s)

`circle ( point, double precision ) → circle`
Constructs circle from center and radius.
`circle(point '(0,0)', 2.0)` → `<(0,0),2>`

`circle ( polygon ) → circle`
Converts polygon to circle. The circle's center is the mean of the positions of the polygon's points, and the radius is the average distance of the polygon's points from that center.
`circle(polygon '((0,0),(1,3),(2,0))')` → `<(1,1),1.6094757082487299>`

`line ( point, point ) → line`
Converts two points to the line through them.
`line(point '(-1,0)', point '(1,0)')` → `{0,-1,0}`

`lseg ( box ) → lseg`
Extracts box's diagonal as a line segment.
`lseg(box '(1,0),(-1,0)')` → `[(1,0),(-1,0)]`

`lseg ( point, point ) → lseg`
Constructs line segment from two endpoints.
`lseg(point '(-1,0)', point '(1,0)')` → `[(-1,0),(1,0)]`

`path ( polygon ) → path`
Converts polygon to a closed path with the same list of points.
`path(polygon '((0,0),(1,1),(2,0))')` → `((0,0),(1,1),(2,0))`

`point ( double precision, double precision ) → point`
Constructs point from its coordinates.
`point(23.4, -44.5)` → `(23.4,-44.5)`

`point ( box ) → point`
Computes center of box.
`point(box '(1,0),(-1,0)')` → `(0,0)`

`point ( circle ) → point`
Computes center of circle.
`point(circle '<(0,0),2>')` → `(0,0)`

`point ( lseg ) → point`
Computes center of line segment.
`point(lseg '[(-1,0),(1,0)]')` → `(0,0)`

`point ( polygon ) → point`
Computes center of polygon (the mean of the positions of the polygon's points).
`point(polygon '((0,0),(1,1),(2,0))')` → `(1,0.3333333333333333)`

`polygon ( box ) → polygon`
Converts box to a 4-point polygon.
`polygon(box '(1,1),(0,0)')` → `((0,0),(0,1),(1,1),(1,0))`

`polygon ( circle ) → polygon`
Converts circle to a 12-point polygon.
`polygon(circle '<(0,0),2>')` → `((-2,0),(-1.7320508075688774,`
`0.9999999999999999),(-1.0000000000000002,1.7320508075688772),(`
`-1.2246063538223773e-16,2),(0.9999999999999996,1.7320508075688774),`
`(1.732050807568877,1.0000000000000007),(2,2.4492127076447545e-16),`

Function Description Example(s)
(1.7320508075688776,-0.9999999999999994),(1.0000000000000009, -1.7320508075688767),(3.673819061467132e-16,-2),(-0.9999999999999987, -1.732050807568878),(-1.7320508075688767,-1.0000000000000009))
polygon (integer, circle) → polygon Converts circle to an *n*-point polygon. polygon(4, circle '<(3,0),1>') → ((2,0),(3,1),(4, 1.2246063538223773e-16),(3,-1))
polygon (path) → polygon Converts closed path to a polygon with the same list of points. polygon(path '((0,0),(1,1),(2,0))') → ((0,0),(1,1),(2,0))

It is possible to access the two component numbers of a `point` as though the point were an array with indexes 0 and 1. For example, if `t.p` is a `point` column then `SELECT p[0] FROM t` retrieves the X coordinate and `UPDATE t SET p[1] = ...` changes the Y coordinate. In the same way, a value of type `box` or `lseg` can be treated as an array of two `point` values.

9.12. Network Address Functions and Operators

The IP network address types, `cidr` and `inet`, support the usual comparison operators shown in Table 9.1 as well as the specialized operators and functions shown in Table 9.38 and Table 9.39.

Any `cidr` value can be cast to `inet` implicitly; therefore, the operators and functions shown below as operating on `inet` also work on `cidr` values. (Where there are separate functions for `inet` and `cidr`, it is because the behavior should be different for the two cases.) Also, it is permitted to cast an `inet` value to `cidr`. When this is done, any bits to the right of the netmask are silently zeroed to create a valid `cidr` value.

Table 9.38. IP Address Operators

Operator Description Example(s)
inet << inet → boolean Is subnet strictly contained by subnet? This operator, and the next four, test for subnet inclusion. They consider only the network parts of the two addresses (ignoring any bits to the right of the netmasks) and determine whether one network is identical to or a subnet of the other. inet '192.168.1.5' << inet '192.168.1/24' → t inet '192.168.0.5' << inet '192.168.1/24' → f inet '192.168.1/24' << inet '192.168.1/24' → f
inet <<= inet → boolean Is subnet contained by or equal to subnet? inet '192.168.1/24' <<= inet '192.168.1/24' → t
inet >> inet → boolean Does subnet strictly contain subnet? inet '192.168.1/24' >> inet '192.168.1.5' → t
inet >>= inet → boolean Does subnet contain or equal subnet? inet '192.168.1/24' >>= inet '192.168.1/24' → t
inet && inet → boolean

Operator Description Example(s)

Does either subnet contain or equal the other?
`inet '192.168.1/24' && inet '192.168.1.80/28'` → `t`
`inet '192.168.1/24' && inet '192.168.2.0/28'` → `f`

`~ inet` → `inet`
Computes bitwise NOT.
`~ inet '192.168.1.6'` → `63.87.254.249`

`inet & inet` → `inet`
Computes bitwise AND.
`inet '192.168.1.6' & inet '0.0.0.255'` → `0.0.0.6`

`inet | inet` → `inet`
Computes bitwise OR.
`inet '192.168.1.6' | inet '0.0.0.255'` → `192.168.1.255`

`inet + bigint` → `inet`
Adds an offset to an address.
`inet '192.168.1.6' + 25` → `192.168.1.31`

`bigint + inet` → `inet`
Adds an offset to an address.
`200 + inet '::ffff:fff0:1'` → `::ffff:255.240.0.201`

`inet - bigint` → `inet`
Subtracts an offset from an address.
`inet '192.168.1.43' - 36` → `192.168.1.7`

`inet - inet` → `bigint`
Computes the difference of two addresses.
`inet '192.168.1.43' - inet '192.168.1.19'` → `24`
`inet '::1' - inet '::ffff:1'` → `-4294901760`

Table 9.39. IP Address Functions

Function Description Example(s)

`abbrev ( inet )` → `text`
Creates an abbreviated display format as text. (The result is the same as the `inet` output function produces; it is "abbreviated" only in comparison to the result of an explicit cast to `text`, which for historical reasons will never suppress the netmask part.)
`abbrev(inet '10.1.0.0/32')` → `10.1.0.0`

`abbrev ( cidr )` → `text`
Creates an abbreviated display format as text. (The abbreviation consists of dropping all-zero octets to the right of the netmask; more examples are in Table 8.22.)
`abbrev(cidr '10.1.0.0/16')` → `10.1/16`

`broadcast ( inet )` → `inet`
Computes the broadcast address for the address's network.
`broadcast(inet '192.168.1.5/24')` → `192.168.1.255/24`

`family ( inet )` → `integer`

Function **Description** **Example(s)**
Returns the address's family: `4` for IPv4, `6` for IPv6. `family(inet '::1')` → `6`

`host ( inet ) → text`
Returns the IP address as text, ignoring the netmask.
`host(inet '192.168.1.0/24')` → `192.168.1.0`

`hostmask ( inet ) → inet`
Computes the host mask for the address's network.
`hostmask(inet '192.168.23.20/30')` → `0.0.0.3`

`inet_merge ( inet, inet ) → cidr`
Computes the smallest network that includes both of the given networks.
`inet_merge(inet '192.168.1.5/24', inet '192.168.2.5/24')` → `192.168.0.0/22`

`inet_same_family ( inet, inet ) → boolean`
Tests whether the addresses belong to the same IP family.
`inet_same_family(inet '192.168.1.5/24', inet '::1')` → `f`

`masklen ( inet ) → integer`
Returns the netmask length in bits.
`masklen(inet '192.168.1.5/24')` → `24`

`netmask ( inet ) → inet`
Computes the network mask for the address's network.
`netmask(inet '192.168.1.5/24')` → `255.255.255.0`

`network ( inet ) → cidr`
Returns the network part of the address, zeroing out whatever is to the right of the netmask. (This is equivalent to casting the value to `cidr`.)
`network(inet '192.168.1.5/24')` → `192.168.1.0/24`

`set_masklen ( inet, integer ) → inet`
Sets the netmask length for an `inet` value. The address part does not change.
`set_masklen(inet '192.168.1.5/24', 16)` → `192.168.1.5/16`

`set_masklen ( cidr, integer ) → cidr`
Sets the netmask length for a `cidr` value. Address bits to the right of the new netmask are set to zero.
`set_masklen(cidr '192.168.1.0/24', 16)` → `192.168.0.0/16`

`text ( inet ) → text`
Returns the unabbreviated IP address and netmask length as text. (This has the same result as an explicit cast to `text`.)
`text(inet '192.168.1.5')` → `192.168.1.5/32`

> **Tip**
>
> The `abbrev`, `host`, and `text` functions are primarily intended to offer alternative display formats for IP addresses.

The MAC address types, `macaddr` and `macaddr8`, support the usual comparison operators shown in Table 9.1 as well as the specialized functions shown in Table 9.40. In addition, they support the bitwise logical operators `~`, `&` and `|` (NOT, AND and OR), just as shown above for IP addresses.

Table 9.40. MAC Address Functions

Function Description Example(s)

`trunc ( macaddr ) → macaddr`
Sets the last 3 bytes of the address to zero. The remaining prefix can be associated with a particular manufacturer (using data not included in Postgres Pro).
`trunc(macaddr '12:34:56:78:90:ab') → 12:34:56:00:00:00`

`trunc ( macaddr8 ) → macaddr8`
Sets the last 5 bytes of the address to zero. The remaining prefix can be associated with a particular manufacturer (using data not included in Postgres Pro).
`trunc(macaddr8 '12:34:56:78:90:ab:cd:ef') → 12:34:56:00:00:00:00:00`

`macaddr8_set7bit ( macaddr8 ) → macaddr8`
Sets the 7th bit of the address to one, creating what is known as modified EUI-64, for inclusion in an IPv6 address.
`macaddr8_set7bit(macaddr8 '00:34:56:ab:cd:ef') → 02:34:56:ff:fe:ab:cd:ef`

9.13. Text Search Functions and Operators

Table 9.41, Table 9.42 and Table 9.43 summarize the functions and operators that are provided for full text searching. See Chapter 12 for a detailed explanation of Postgres Pro's text search facility.

Table 9.41. Text Search Operators

Operator Description Example(s)

`tsvector @@ tsquery → boolean`
`tsquery @@ tsvector → boolean`
Does `tsvector` match `tsquery`? (The arguments can be given in either order.)
`to_tsvector('fat cats ate rats') @@ to_tsquery('cat & rat') → t`

`text @@ tsquery → boolean`
Does text string, after implicit invocation of `to_tsvector()`, match `tsquery`?
`'fat cats ate rats' @@ to_tsquery('cat & rat') → t`

`tsvector @@@ tsquery → boolean`
`tsquery @@@ tsvector → boolean`
This is a deprecated synonym for `@@`.
`to_tsvector('fat cats ate rats') @@@ to_tsquery('cat & rat') → t`

`tsvector || tsvector → tsvector`
Concatenates two `tsvector`s. If both inputs contain lexeme positions, the second input's positions are adjusted accordingly.
`'a:1 b:2'::tsvector || 'c:1 d:2 b:3'::tsvector → 'a':1 'b':2,5 'c':3 'd':4`

`tsquery && tsquery → tsquery`
ANDs two `tsquery`s together, producing a query that matches documents that match both input queries.
`'fat | rat'::tsquery && 'cat'::tsquery → ( 'fat' | 'rat' ) & 'cat'`

`tsquery || tsquery → tsquery` ORs two `tsquery`s together, producing a query that matches documents that match either input query.

Operator Description Example(s)
`'fat | rat'::tsquery || 'cat'::tsquery` → `'fat' | 'rat' | 'cat'`

`!! tsquery` → `tsquery`
Negates a `tsquery`, producing a query that matches documents that do not match the input query.
`!! 'cat'::tsquery` → `!'cat'`

`tsquery <-> tsquery` → `tsquery`
Constructs a phrase query, which matches if the two input queries match at successive lexemes.
`to_tsquery('fat') <-> to_tsquery('rat')` → `'fat' <-> 'rat'`

`tsquery @> tsquery` → `boolean`
Does first `tsquery` contain the second? (This considers only whether all the lexemes appearing in one query appear in the other, ignoring the combining operators.)
`'cat'::tsquery @> 'cat & rat'::tsquery` → `f`

`tsquery <@ tsquery` → `boolean`
Is first `tsquery` contained in the second? (This considers only whether all the lexemes appearing in one query appear in the other, ignoring the combining operators.)
`'cat'::tsquery <@ 'cat & rat'::tsquery` → `t`
`'cat'::tsquery <@ '!cat & rat'::tsquery` → `t`

In addition to these specialized operators, the usual comparison operators shown in Table 9.1 are available for types `tsvector` and `tsquery`. These are not very useful for text searching but allow, for example, unique indexes to be built on columns of these types.

Table 9.42. Text Search Functions

Function Description Example(s)

`array_to_tsvector ( text[] )` → `tsvector`
Converts an array of lexemes to a `tsvector`. The given strings are used as-is without further processing.
`array_to_tsvector('{fat,cat,rat}'::text[])` → `'cat' 'fat' 'rat'`

`get_current_ts_config ( )` → `regconfig`
Returns the OID of the current default text search configuration (as set by default_text_search_config).
`get_current_ts_config()` → `english`

`length ( tsvector )` → `integer`
Returns the number of lexemes in the `tsvector`.
`length('fat:2,4 cat:3 rat:5A'::tsvector)` → `3`

`numnode ( tsquery )` → `integer`
Returns the number of lexemes plus operators in the `tsquery`.
`numnode('(fat & rat) | cat'::tsquery)` → `5`

`plainto_tsquery ( [ config regconfig, ] query text )` → `tsquery`
Converts text to a `tsquery`, normalizing words according to the specified or default configuration. Any punctuation in the string is ignored (it does not determine query operators). The resulting query matches documents containing all non-stopwords in the text.
`plainto_tsquery('english', 'The Fat Rats')` → `'fat' & 'rat'`

Function
Description
Example(s)

`phraseto_tsquery ( [ config regconfig, ] query text ) → tsquery`

Converts text to a `tsquery`, normalizing words according to the specified or default configuration. Any punctuation in the string is ignored (it does not determine query operators). The resulting query matches phrases containing all non-stopwords in the text.

```
phraseto_tsquery('english', 'The Fat Rats')    → 'fat' <-> 'rat'
phraseto_tsquery('english', 'The Cat and Rats')    → 'cat' <2> 'rat'
```

`websearch_to_tsquery ( [ config regconfig, ] query text ) → tsquery`

Converts text to a `tsquery`, normalizing words according to the specified or default configuration. Quoted word sequences are converted to phrase tests. The word “or” is understood as producing an OR operator, and a dash produces a NOT operator; other punctuation is ignored. This approximates the behavior of some common web search tools.

```
websearch_to_tsquery('english', '"fat rat" or cat dog')    → 'fat' <-> 'rat' |
'cat' & 'dog'
```

`querytree ( tsquery ) → text`

Produces a representation of the indexable portion of a `tsquery`. A result that is empty or just `T` indicates a non-indexable query.

```
querytree('foo & ! bar'::tsquery)  → 'foo'
```

`setweight ( vector tsvector, weight "char" ) → tsvector`

Assigns the specified *weight* to each element of the *vector*.

```
setweight('fat:2,4 cat:3 rat:5B'::tsvector, 'A')    → 'cat':3A 'fat':2A,4A
'rat':5A
```

`setweight ( vector tsvector, weight "char", lexemes text[] ) → tsvector`

Assigns the specified *weight* to elements of the *vector* that are listed in *lexemes*.

```
setweight('fat:2,4 cat:3 rat:5,6B'::tsvector, 'A', '{cat,rat}')      → 'cat':3A
'fat':2,4 'rat':5A,6A
```

`strip ( tsvector ) → tsvector`

Removes positions and weights from the `tsvector`.

```
strip('fat:2,4 cat:3 rat:5A'::tsvector)   → 'cat' 'fat' 'rat'
```

`to_tsquery ( [ config regconfig, ] query text ) → tsquery`

Converts text to a `tsquery`, normalizing words according to the specified or default configuration. The words must be combined by valid `tsquery` operators.

```
to_tsquery('english', 'The & Fat & Rats')    → 'fat' & 'rat'
```

`to_tsvector ( [ config regconfig, ] document text ) → tsvector`

Converts text to a `tsvector`, normalizing words according to the specified or default configuration. Position information is included in the result.

```
to_tsvector('english', 'The Fat Rats')    → 'fat':2 'rat':3
```

`to_tsvector ( [ config regconfig, ] document json ) → tsvector`

`to_tsvector ( [ config regconfig, ] document jsonb ) → tsvector`

Converts each string value in the JSON document to a `tsvector`, normalizing words according to the specified or default configuration. The results are then concatenated in document order to produce the output. Position information is generated as though one stopword exists between each pair of string values. (Beware that “document order” of the fields of a JSON object is implementation-dependent when the input is `jsonb`; observe the difference in the examples.)

Function
Description
Example(s)

`to_tsvector('english', '{"aa": "The Fat Rats", "b": "dog"}'::json)` → `'dog':5 'fat':2 'rat':3`

`to_tsvector('english', '{"aa": "The Fat Rats", "b": "dog"}'::jsonb)` → `'dog':1 'fat':4 'rat':5`

`json_to_tsvector` ([*config* regconfig,] *document* json, *filter* jsonb) → tsvector

`jsonb_to_tsvector` ([*config* regconfig,] *document* jsonb, *filter* jsonb) → tsvector

Selects each item in the JSON document that is requested by the *filter* and converts each one to a `tsvector`, normalizing words according to the specified or default configuration. The results are then concatenated in document order to produce the output. Position information is generated as though one stopword exists between each pair of selected items. (Beware that "document order" of the fields of a JSON object is implementation-dependent when the input is `jsonb`.) The *filter* must be a `jsonb` array containing zero or more of these keywords: `"string"` (to include all string values), `"numeric"` (to include all numeric values), `"boolean"` (to include all boolean values), `"key"` (to include all keys), or `"all"` (to include all the above). As a special case, the *filter* can also be a simple JSON value that is one of these keywords.

`json_to_tsvector('english', '{"a": "The Fat Rats", "b": 123}'::json, '["string", "numeric"]')` → `'123':5 'fat':2 'rat':3`

`json_to_tsvector('english', '{"cat": "The Fat Rats", "dog": 123}'::json, '"all"')` → `'123':9 'cat':1 'dog':7 'fat':4 'rat':5`

`ts_delete` (*vector* tsvector, *lexeme* text) → tsvector

Removes any occurrence of the given *lexeme* from the *vector*.

`ts_delete('fat:2,4 cat:3 rat:5A'::tsvector, 'fat')` → `'cat':3 'rat':5A`

`ts_delete` (*vector* tsvector, *lexemes* text[]) → tsvector

Removes any occurrences of the lexemes in *lexemes* from the *vector*.

`ts_delete('fat:2,4 cat:3 rat:5A'::tsvector, ARRAY['fat','rat'])` → `'cat':3`

`ts_filter` (*vector* tsvector, *weights* "char"[]) → tsvector

Selects only elements with the given *weights* from the *vector*.

`ts_filter('fat:2,4 cat:3b,7c rat:5A'::tsvector, '{a,b}')` → `'cat':3B 'rat':5A`

`ts_headline` ([*config* regconfig,] *document* text, *query* tsquery [, *options* text]) → text

Displays, in an abbreviated form, the match(es) for the *query* in the *document*, which must be raw text not a `tsvector`. Words in the document are normalized according to the specified or default configuration before matching to the query. Use of this function is discussed in Section 12.3.4, which also describes the available *options*.

`ts_headline('The fat cat ate the rat.', 'cat')` → `The fat <b>cat</b> ate the rat.`

`ts_headline` ([*config* regconfig,] *document* json, *query* tsquery [, *options* text]) → text

`ts_headline` ([*config* regconfig,] *document* jsonb, *query* tsquery [, *options* text]) → text

Displays, in an abbreviated form, match(es) for the *query* that occur in string values within the JSON *document*. See Section 12.3.4 for more details.

`ts_headline('{"cat":"raining cats and dogs"}'::jsonb, 'cat')` → `{"cat": "raining <b>cats</b> and dogs"}`

`ts_rank` ([*weights* real[],] *vector* tsvector, *query* tsquery [, *normalization* integer]) → real

Computes a score showing how well the *vector* matches the *query*. See Section 12.3.3 for details.

Function **Description** **Example(s)**
`ts_rank(to_tsvector('raining cats and dogs'), 'cat')` → `0.06079271`

`ts_rank_cd` ([*weights* `real[]`,] *vector* `tsvector`, *query* `tsquery` [, *normalization* `integer`]) → `real`
Computes a score showing how well the *vector* matches the *query*, using a cover density algorithm. See Section 12.3.3 for details.
`ts_rank_cd(to_tsvector('raining cats and dogs'), 'cat')` → `0.1`

`ts_rewrite` (*query* `tsquery`, *target* `tsquery`, *substitute* `tsquery`) → `tsquery`
Replaces occurrences of *target* with *substitute* within the *query*. See Section 12.4.2.1 for details.
`ts_rewrite('a & b'::tsquery, 'a'::tsquery, 'foo|bar'::tsquery)` → `'b' & ( 'foo' | 'bar' )`

`ts_rewrite` (*query* `tsquery`, *select* `text`) → `tsquery`
Replaces portions of the *query* according to target(s) and substitute(s) obtained by executing a `SELECT` command. See Section 12.4.2.1 for details.
`SELECT ts_rewrite('a & b'::tsquery, 'SELECT t,s FROM aliases')` → `'b' & ( 'foo' | 'bar' )`

`tsquery_phrase` (*query1* `tsquery`, *query2* `tsquery`) → `tsquery`
Constructs a phrase query that searches for matches of *query1* and *query2* at successive lexemes (same as `<->` operator).
`tsquery_phrase(to_tsquery('fat'), to_tsquery('cat'))` → `'fat' <-> 'cat'`

`tsquery_phrase` (*query1* `tsquery`, *query2* `tsquery`, *distance* `integer`) → `tsquery`
Constructs a phrase query that searches for matches of *query1* and *query2* that occur exactly *distance* lexemes apart.
`tsquery_phrase(to_tsquery('fat'), to_tsquery('cat'), 10)` → `'fat' <10> 'cat'`

`tsvector_to_array` (`tsvector`) → `text[]`
Converts a `tsvector` to an array of lexemes.
`tsvector_to_array('fat:2,4 cat:3 rat:5A'::tsvector)` → `{cat,fat,rat}`

`unnest` (`tsvector`) → `setof record` (*lexeme* `text`, *positions* `smallint[]`, *weights* `text`)
Expands a `tsvector` into a set of rows, one per lexeme.
`select * from unnest('cat:3 fat:2,4 rat:5A'::tsvector)` →
`lexeme | positions | weights`
`--------+-----------+---------`
`cat | {3} | {D}`
`fat | {2,4} | {D,D}`
`rat | {5} | {A}`

> **Note**
>
> All the text search functions that accept an optional `regconfig` argument will use the configuration specified by default_text_search_config when that argument is omitted.

The functions in Table 9.43 are listed separately because they are not usually used in everyday text searching operations. They are primarily helpful for development and debugging of new text search configurations.

Table 9.43. Text Search Debugging Functions

Function Description Example(s)

`ts_debug ( [ config regconfig, ] document text ) → setof record ( alias text, description text, token text, dictionaries regdictionary[], dictionary regdictionary, lexemes text[] )`
Extracts and normalizes tokens from the *document* according to the specified or default text search configuration, and returns information about how each token was processed. See Section 12.8.1 for details.
`ts_debug('english', 'The Brightest supernovaes') → (asciiword,"Word, all ASCII",The,{english_stem},english_stem,{}) ...`

`ts_lexize ( dict regdictionary, token text ) → text[]`
Returns an array of replacement lexemes if the input token is known to the dictionary, or an empty array if the token is known to the dictionary but it is a stop word, or NULL if it is not a known word. See Section 12.8.3 for details.
`ts_lexize('english_stem', 'stars') → {star}`

`ts_parse ( parser_name text, document text ) → setof record ( tokid integer, token text )`
Extracts tokens from the *document* using the named parser. See Section 12.8.2 for details.
`ts_parse('default', 'foo - bar') → (1,foo) ...`

`ts_parse ( parser_oid oid, document text ) → setof record ( tokid integer, token text )`
Extracts tokens from the *document* using a parser specified by OID. See Section 12.8.2 for details.
`ts_parse(3722, 'foo - bar') → (1,foo) ...`

`ts_token_type ( parser_name text ) → setof record ( tokid integer, alias text, description text )`
Returns a table that describes each type of token the named parser can recognize. See Section 12.8.2 for details.
`ts_token_type('default') → (1,asciiword,"Word, all ASCII") ...`

`ts_token_type ( parser_oid oid ) → setof record ( tokid integer, alias text, description text )`
Returns a table that describes each type of token a parser specified by OID can recognize. See Section 12.8.2 for details.
`ts_token_type(3722) → (1,asciiword,"Word, all ASCII") ...`

`ts_stat ( sqlquery text [, weights text ] ) → setof record ( word text, ndoc integer, nentry integer )`
Executes the *sqlquery*, which must return a single `tsvector` column, and returns statistics about each distinct lexeme contained in the data. See Section 12.4.4 for details.
`ts_stat('SELECT vector FROM apod') → (foo,10,15) ...`

9.14. UUID Functions

Postgres Pro includes one function to generate a UUID:

```
gen_random_uuid () → uuid
```

This function returns a version 4 (random) UUID. This is the most commonly used type of UUID and is appropriate for most applications.

The uuid-ossp module provides additional functions that implement other standard algorithms for generating UUIDs.

Postgres Pro also provides the usual comparison operators shown in Table 9.1 for UUIDs.

9.15. XML Functions

The functions and function-like expressions described in this section operate on values of type `xml`. See Section 8.13 for information about the `xml` type. The function-like expressions `xmlparse` and `xmlserialize` for converting to and from type `xml` are documented there, not in this section.

Use of most of these functions requires Postgres Pro to have been built with `configure --with-libxml`.

9.15.1. Producing XML Content

A set of functions and function-like expressions is available for producing XML content from SQL data. As such, they are particularly suitable for formatting query results into XML documents for processing in client applications.

9.15.1.1. `xmlcomment`

```
xmlcomment ( text ) → xml
```

The function `xmlcomment` creates an XML value containing an XML comment with the specified text as content. The text cannot contain "`--`" or end with a "`-`", otherwise the resulting construct would not be a valid XML comment. If the argument is null, the result is null.

Example:

```
SELECT xmlcomment('hello');

  xmlcomment
--------------
 <!--hello-->
```

9.15.1.2. `xmlconcat`

```
xmlconcat ( xml [, ...] ) → xml
```

The function `xmlconcat` concatenates a list of individual XML values to create a single value containing an XML content fragment. Null values are omitted; the result is only null if there are no nonnull arguments.

Example:

```
SELECT xmlconcat('<abc/>', '<bar>foo</bar>');

      xmlconcat
----------------------
 <abc/><bar>foo</bar>
```

XML declarations, if present, are combined as follows. If all argument values have the same XML version declaration, that version is used in the result, else no version is used. If all argument values have the standalone declaration value "yes", then that value is used in the result. If all argument values have a standalone declaration value and at least one is "no", then that is used in the result. Else the result will have no standalone declaration. If the result is determined to require a standalone declaration but no version declaration, a version declaration with version 1.0 will be used because XML requires an XML declaration to contain a version declaration. Encoding declarations are ignored and removed in all cases.

Example:

```
SELECT xmlconcat('<?xml version="1.1"?><foo/>', '<?xml version="1.1" standalone="no"?
><bar/>');
```

```
             xmlconcat
----------------------------------
 <?xml version="1.1"?><foo/><bar/>
```

9.15.1.3. xmlelement

```
xmlelement ( NAME name [, XMLATTRIBUTES ( attvalue [ AS attname ] [, ...] ) ]
 [, content [, ...]] ) → xml
```

The `xmlelement` expression produces an XML element with the given name, attributes, and content. The *name* and *attname* items shown in the syntax are simple identifiers, not values. The *attvalue* and *content* items are expressions, which can yield any Postgres Pro data type. The argument(s) within `XMLATTRIBUTES` generate attributes of the XML element; the *content* value(s) are concatenated to form its content.

Examples:

```
SELECT xmlelement(name foo);

 xmlelement
------------
 <foo/>

SELECT xmlelement(name foo, xmlattributes('xyz' as bar));

    xmlelement
------------------
 <foo bar="xyz"/>

SELECT xmlelement(name foo, xmlattributes(current_date as bar), 'cont', 'ent');

             xmlelement
-------------------------------------
 <foo bar="2007-01-26">content</foo>
```

Element and attribute names that are not valid XML names are escaped by replacing the offending characters by the sequence _x*HHHH*_, where *HHHH* is the character's Unicode codepoint in hexadecimal notation. For example:

```
SELECT xmlelement(name "foo$bar", xmlattributes('xyz' as "a&b"));

            xmlelement
----------------------------------
 <foo_x0024_bar a_x0026_b="xyz"/>
```

An explicit attribute name need not be specified if the attribute value is a column reference, in which case the column's name will be used as the attribute name by default. In other cases, the attribute must be given an explicit name. So this example is valid:

```
CREATE TABLE test (a xml, b xml);
SELECT xmlelement(name test, xmlattributes(a, b)) FROM test;
```

But these are not:

```
SELECT xmlelement(name test, xmlattributes('constant'), a, b) FROM test;
SELECT xmlelement(name test, xmlattributes(func(a, b))) FROM test;
```

Element content, if specified, will be formatted according to its data type. If the content is itself of type `xml`, complex XML documents can be constructed. For example:

```
SELECT xmlelement(name foo, xmlattributes('xyz' as bar),
                            xmlelement(name abc),
                            xmlcomment('test'),
                            xmlelement(name xyz));

                  xmlelement
----------------------------------------------
 <foo bar="xyz"><abc/><!--test--><xyz/></foo>
```

Content of other types will be formatted into valid XML character data. This means in particular that the characters <, >, and & will be converted to entities. Binary data (data type `bytea`) will be represented in base64 or hex encoding, depending on the setting of the configuration parameter xmlbinary. The particular behavior for individual data types is expected to evolve in order to align the Postgres Pro mappings with those specified in SQL:2006 and later, as discussed in Section D.3.1.3.

9.15.1.4. xmlforest

```
xmlforest ( content [ AS name ] [, ...] ) → xml
```

The `xmlforest` expression produces an XML forest (sequence) of elements using the given names and content. As for `xmlelement`, each *name* must be a simple identifier, while the *content* expressions can have any data type.

Examples:

```
SELECT xmlforest('abc' AS foo, 123 AS bar);

          xmlforest
------------------------------
 <foo>abc</foo><bar>123</bar>


SELECT xmlforest(table_name, column_name)
FROM information_schema.columns
WHERE table_schema = 'pg_catalog';

                                xmlforest
----------------------------------------------------------------------
 <table_name>pg_authid</table_name><column_name>rolname</column_name>
 <table_name>pg_authid</table_name><column_name>rolsuper</column_name>
 ...
```

As seen in the second example, the element name can be omitted if the content value is a column reference, in which case the column name is used by default. Otherwise, a name must be specified.

Element names that are not valid XML names are escaped as shown for `xmlelement` above. Similarly, content data is escaped to make valid XML content, unless it is already of type `xml`.

Note that XML forests are not valid XML documents if they consist of more than one element, so it might be useful to wrap `xmlforest` expressions in `xmlelement`.

9.15.1.5. xmlpi

```
xmlpi ( NAME name [, content ] ) → xml
```

The `xmlpi` expression creates an XML processing instruction. As for `xmlelement`, the *name* must be a simple identifier, while the *content* expression can have any data type. The *content*, if present, must not contain the character sequence `?>`.

Example:

```
SELECT xmlpi(name php, 'echo "hello world";');

            xmlpi
-----------------------------
 <?php echo "hello world";?>
```

9.15.1.6. xmlroot

```
xmlroot ( xml, VERSION {text|NO VALUE} [, STANDALONE {YES|NO|NO VALUE} ] ) → xml
```

The `xmlroot` expression alters the properties of the root node of an XML value. If a version is specified, it replaces the value in the root node's version declaration; if a standalone setting is specified, it replaces the value in the root node's standalone declaration.

```
SELECT xmlroot(xmlparse(document '<?xml version="1.1"?><content>abc</content>'),
               version '1.0', standalone yes);

                xmlroot
----------------------------------------
 <?xml version="1.0" standalone="yes"?>
 <content>abc</content>
```

9.15.1.7. xmlagg

```
xmlagg ( xml ) → xml
```

The function `xmlagg` is, unlike the other functions described here, an aggregate function. It concatenates the input values to the aggregate function call, much like `xmlconcat` does, except that concatenation occurs across rows rather than across expressions in a single row. See Section 9.21 for additional information about aggregate functions.

Example:

```
CREATE TABLE test (y int, x xml);
INSERT INTO test VALUES (1, '<foo>abc</foo>');
INSERT INTO test VALUES (2, '<bar/>');
SELECT xmlagg(x) FROM test;
        xmlagg
----------------------
 <foo>abc</foo><bar/>
```

To determine the order of the concatenation, an `ORDER BY` clause may be added to the aggregate call as described in Section 4.2.7. For example:

```
SELECT xmlagg(x ORDER BY y DESC) FROM test;
        xmlagg
----------------------
 <bar/><foo>abc</foo>
```

The following non-standard approach used to be recommended in previous versions, and may still be useful in specific cases:

```
SELECT xmlagg(x) FROM (SELECT * FROM test ORDER BY y DESC) AS tab;
        xmlagg
----------------------
 <bar/><foo>abc</foo>
```

9.15.2. XML Predicates

The expressions described in this section check properties of `xml` values.

9.15.2.1. IS DOCUMENT

```
xml IS DOCUMENT → boolean
```

The expression IS DOCUMENT returns true if the argument XML value is a proper XML document, false if it is not (that is, it is a content fragment), or null if the argument is null. See Section 8.13 about the difference between documents and content fragments.

9.15.2.2. IS NOT DOCUMENT

```
xml IS NOT DOCUMENT → boolean
```

The expression IS NOT DOCUMENT returns false if the argument XML value is a proper XML document, true if it is not (that is, it is a content fragment), or null if the argument is null.

9.15.2.3. XMLEXISTS

```
XMLEXISTS ( text PASSING [BY {REF|VALUE}] xml [BY {REF|VALUE}] ) → boolean
```

The function xmlexists evaluates an XPath 1.0 expression (the first argument), with the passed XML value as its context item. The function returns false if the result of that evaluation yields an empty node-set, true if it yields any other value. The function returns null if any argument is null. A nonnull value passed as the context item must be an XML document, not a content fragment or any non-XML value.

Example:

```
SELECT xmlexists('//town[text() = ''Toronto'']' PASSING BY VALUE
 '<towns><town>Toronto</town><town>Ottawa</town></towns>');

 xmlexists
------------
 t
(1 row)
```

The BY REF and BY VALUE clauses are accepted in Postgres Pro, but are ignored, as discussed in Section D.3.2.

In the SQL standard, the xmlexists function evaluates an expression in the XML Query language, but Postgres Pro allows only an XPath 1.0 expression, as discussed in Section D.3.1.

9.15.2.4. xml_is_well_formed

```
xml_is_well_formed ( text ) → boolean
xml_is_well_formed_document ( text ) → boolean
xml_is_well_formed_content ( text ) → boolean
```

These functions check whether a text string represents well-formed XML, returning a Boolean result. xml_is_well_formed_document checks for a well-formed document, while xml_is_well_formed_content checks for well-formed content. xml_is_well_formed does the former if the xmloption configuration parameter is set to DOCUMENT, or the latter if it is set to CONTENT. This means that xml_is_well_formed is useful for seeing whether a simple cast to type xml will succeed, whereas the other two functions are useful for seeing whether the corresponding variants of XMLPARSE will succeed.

Examples:

```
SET xmloption TO DOCUMENT;
SELECT xml_is_well_formed('<>');
 xml_is_well_formed
--------------------
```

```
 f
(1 row)

SELECT xml_is_well_formed('<abc/>');
 xml_is_well_formed
--------------------
 t
(1 row)

SET xmloption TO CONTENT;
SELECT xml_is_well_formed('abc');
 xml_is_well_formed
--------------------
 t
(1 row)

SELECT xml_is_well_formed_document('<pg:foo xmlns:pg="http://postgresql.org/
stuff">bar</pg:foo>');
 xml_is_well_formed_document
-----------------------------
 t
(1 row)

SELECT xml_is_well_formed_document('<pg:foo xmlns:pg="http://postgresql.org/
stuff">bar</my:foo>');
 xml_is_well_formed_document
-----------------------------
 f
(1 row)
```

The last example shows that the checks include whether namespaces are correctly matched.

9.15.3. Processing XML

To process values of data type `xml`, Postgres Pro offers the functions `xpath` and `xpath_exists`, which evaluate XPath 1.0 expressions, and the `XMLTABLE` table function.

9.15.3.1. `xpath`

`xpath ( *xpath* text, *xml* xml [, *nsarray* text[] ] ) → xml[]`

The function `xpath` evaluates the XPath 1.0 expression *`xpath`* (given as text) against the XML value *`xml`*. It returns an array of XML values corresponding to the node-set produced by the XPath expression. If the XPath expression returns a scalar value rather than a node-set, a single-element array is returned.

The second argument must be a well formed XML document. In particular, it must have a single root node element.

The optional third argument of the function is an array of namespace mappings. This array should be a two-dimensional `text` array with the length of the second axis being equal to 2 (i.e., it should be an array of arrays, each of which consists of exactly 2 elements). The first element of each array entry is the namespace name (alias), the second the namespace URI. It is not required that aliases provided in this array be the same as those being used in the XML document itself (in other words, both in the XML document and in the `xpath` function context, aliases are *local*).

Example:

```
SELECT xpath('/my:a/text()', '<my:a xmlns:my="http://example.com">test</my:a>',
             ARRAY[ARRAY['my', 'http://example.com']]);
```

```
 xpath
--------
 {test}
(1 row)
```

To deal with default (anonymous) namespaces, do something like this:

```
SELECT xpath('//mydefns:b/text()', '<a xmlns="http://example.com"><b>test</b></a>',
             ARRAY[ARRAY['mydefns', 'http://example.com']]);

 xpath
--------
 {test}
(1 row)
```

9.15.3.2. xpath_exists

```
xpath_exists ( xpath text, xml xml [, nsarray text[] ] ) → boolean
```

The function `xpath_exists` is a specialized form of the `xpath` function. Instead of returning the individual XML values that satisfy the XPath 1.0 expression, this function returns a Boolean indicating whether the query was satisfied or not (specifically, whether it produced any value other than an empty node-set). This function is equivalent to the `XMLEXISTS` predicate, except that it also offers support for a namespace mapping argument.

Example:

```
SELECT xpath_exists('/my:a/text()', '<my:a xmlns:my="http://example.com">test</my:a>',
                    ARRAY[ARRAY['my', 'http://example.com']]);

 xpath_exists
--------------
 t
(1 row)
```

9.15.3.3. xmltable

```
XMLTABLE (
    [ XMLNAMESPACES ( namespace_uri AS namespace_name [, ...] ), ]
    row_expression PASSING [BY {REF|VALUE}] document_expression [BY {REF|VALUE}]
    COLUMNS name { type [PATH column_expression] [DEFAULT default_expression] [NOT NULL
 | NULL]
                   | FOR ORDINALITY }
            [, ...]
) → setof record
```

The `xmltable` expression produces a table based on an XML value, an XPath filter to extract rows, and a set of column definitions. Although it syntactically resembles a function, it can only appear as a table in a query's `FROM` clause.

The optional `XMLNAMESPACES` clause gives a comma-separated list of namespace definitions, where each *`namespace_uri`* is a `text` expression and each *`namespace_name`* is a simple identifier. It specifies the XML namespaces used in the document and their aliases. A default namespace specification is not currently supported.

The required *`row_expression`* argument is an XPath 1.0 expression (given as `text`) that is evaluated, passing the XML value *`document_expression`* as its context item, to obtain a set of XML nodes. These nodes are what `xmltable` transforms into output rows. No rows will be produced if the *`document_ex-`*

pression is null, nor if the *row_expression* produces an empty node-set or any value other than a node-set.

document_expression provides the context item for the *row_expression*. It must be a well-formed XML document; fragments/forests are not accepted. The BY REF and BY VALUE clauses are accepted but ignored, as discussed in Section D.3.2.

In the SQL standard, the xmltable function evaluates expressions in the XML Query language, but Postgres Pro allows only XPath 1.0 expressions, as discussed in Section D.3.1.

The required COLUMNS clause specifies the column(s) that will be produced in the output table. See the syntax summary above for the format. A name is required for each column, as is a data type (unless FOR ORDINALITY is specified, in which case type integer is implicit). The path, default and nullability clauses are optional.

A column marked FOR ORDINALITY will be populated with row numbers, starting with 1, in the order of nodes retrieved from the *row_expression*'s result node-set. At most one column may be marked FOR ORDINALITY.

> **Note**
>
> XPath 1.0 does not specify an order for nodes in a node-set, so code that relies on a particular order of the results will be implementation-dependent. Details can be found in Section D.3.1.2.

The *column_expression* for a column is an XPath 1.0 expression that is evaluated for each row, with the current node from the *row_expression* result as its context item, to find the value of the column. If no *column_expression* is given, then the column name is used as an implicit path.

If a column's XPath expression returns a non-XML value (which is limited to string, boolean, or double in XPath 1.0) and the column has a Postgres Pro type other than xml, the column will be set as if by assigning the value's string representation to the Postgres Pro type. (If the value is a boolean, its string representation is taken to be 1 or 0 if the output column's type category is numeric, otherwise true or false.)

If a column's XPath expression returns a non-empty set of XML nodes and the column's Postgres Pro type is xml, the column will be assigned the expression result exactly, if it is of document or content form. [1]

A non-XML result assigned to an xml output column produces content, a single text node with the string value of the result. An XML result assigned to a column of any other type may not have more than one node, or an error is raised. If there is exactly one node, the column will be set as if by assigning the node's string value (as defined for the XPath 1.0 string function) to the Postgres Pro type.

The string value of an XML element is the concatenation, in document order, of all text nodes contained in that element and its descendants. The string value of an element with no descendant text nodes is an empty string (not NULL). Any xsi:nil attributes are ignored. Note that the whitespace-only text() node between two non-text elements is preserved, and that leading whitespace on a text() node is not flattened. The XPath 1.0 string function may be consulted for the rules defining the string value of other XML node types and non-XML values.

The conversion rules presented here are not exactly those of the SQL standard, as discussed in Section D.3.1.3.

If the path expression returns an empty node-set (typically, when it does not match) for a given row, the column will be set to NULL, unless a *default_expression* is specified; then the value resulting from evaluating that expression is used.

[1] A result containing more than one element node at the top level, or non-whitespace text outside of an element, is an example of content form. An XPath result can be of neither form, for example if it returns an attribute node selected from the element that contains it. Such a result will be put into content form with each such disallowed node replaced by its string value, as defined for the XPath 1.0 string function.

A *default_expression*, rather than being evaluated immediately when xmltable is called, is evaluated each time a default is needed for the column. If the expression qualifies as stable or immutable, the repeat evaluation may be skipped. This means that you can usefully use volatile functions like nextval in *default_expression*.

Columns may be marked NOT NULL. If the *column_expression* for a NOT NULL column does not match anything and there is no DEFAULT or the *default_expression* also evaluates to null, an error is reported.

Examples:

```
CREATE TABLE xmldata AS SELECT
xml $$
<ROWS>
  <ROW id="1">
    <COUNTRY_ID>AU</COUNTRY_ID>
    <COUNTRY_NAME>Australia</COUNTRY_NAME>
  </ROW>
  <ROW id="5">
    <COUNTRY_ID>JP</COUNTRY_ID>
    <COUNTRY_NAME>Japan</COUNTRY_NAME>
    <PREMIER_NAME>Shinzo Abe</PREMIER_NAME>
    <SIZE unit="sq_mi">145935</SIZE>
  </ROW>
  <ROW id="6">
    <COUNTRY_ID>SG</COUNTRY_ID>
    <COUNTRY_NAME>Singapore</COUNTRY_NAME>
    <SIZE unit="sq_km">697</SIZE>
  </ROW>
</ROWS>
$$ AS data;

SELECT xmltable.*
  FROM xmldata,
       XMLTABLE('//ROWS/ROW'
                PASSING data
                COLUMNS id int PATH '@id',
                        ordinality FOR ORDINALITY,
                        "COUNTRY_NAME" text,
                        country_id text PATH 'COUNTRY_ID',
                        size_sq_km float PATH 'SIZE[@unit = "sq_km"]',
                        size_other text PATH
                             'concat(SIZE[@unit!="sq_km"], " ", SIZE[@unit!="sq_km"]/
@unit)',
                        premier_name text PATH 'PREMIER_NAME' DEFAULT 'not specified');

 id | ordinality | COUNTRY_NAME | country_id | size_sq_km |  size_other  | premier_name

----+------------+--------------+------------+------------+--------------
+---------------
  1 |          1 | Australia    | AU         |            |              | not
 specified
  5 |          2 | Japan        | JP         |            | 145935 sq_mi | Shinzo Abe
  6 |          3 | Singapore    | SG         |        697 |              | not
 specified
```

The following example shows concatenation of multiple text() nodes, usage of the column name as XPath filter, and the treatment of whitespace, XML comments and processing instructions:

```
CREATE TABLE xmlelements AS SELECT
xml $$
```

```
  <root>
   <element>  Hello<!-- xyxxz -->2a2<?aaaaa?> <!--x-->  bbb<x>xxx</x>CC  </element>
  </root>
$$ AS data;

SELECT xmltable.*
  FROM xmlelements, XMLTABLE('/root' PASSING data COLUMNS element text);
         element
-------------------------
   Hello2a2   bbbxxxCC
```

The following example illustrates how the `XMLNAMESPACES` clause can be used to specify a list of namespaces used in the XML document as well as in the XPath expressions:

```
WITH xmldata(data) AS (VALUES ('
<example xmlns="http://example.com/myns" xmlns:B="http://example.com/b">
 <item foo="1" B:bar="2"/>
 <item foo="3" B:bar="4"/>
 <item foo="4" B:bar="5"/>
</example>'::xml)
)
SELECT xmltable.*
  FROM XMLTABLE(XMLNAMESPACES('http://example.com/myns' AS x,
                              'http://example.com/b' AS "B"),
              '/x:example/x:item'
                 PASSING (SELECT data FROM xmldata)
                 COLUMNS foo int PATH '@foo',
                   bar int PATH '@B:bar');
 foo | bar
-----+-----
   1 |   2
   3 |   4
   4 |   5
(3 rows)
```

9.15.4. Mapping Tables to XML

The following functions map the contents of relational tables to XML values. They can be thought of as XML export functionality:

```
table_to_xml ( table regclass, nulls boolean,
               tableforest boolean, targetns text ) → xml
query_to_xml ( query text, nulls boolean,
               tableforest boolean, targetns text ) → xml
cursor_to_xml ( cursor refcursor, count integer, nulls boolean,
                tableforest boolean, targetns text ) → xml
```

`table_to_xml` maps the content of the named table, passed as parameter *table*. The `regclass` type accepts strings identifying tables using the usual notation, including optional schema qualification and double quotes (see Section 8.19 for details). `query_to_xml` executes the query whose text is passed as parameter *query* and maps the result set. `cursor_to_xml` fetches the indicated number of rows from the cursor specified by the parameter *cursor*. This variant is recommended if large tables have to be mapped, because the result value is built up in memory by each function.

If *tableforest* is false, then the resulting XML document looks like this:

```
<tablename>
  <row>
    <columnname1>data</columnname1>
```

```
    <columnname2>data</columnname2>
  </row>

  <row>
    ...
  </row>

  ...
</tablename>
```

If *tableforest* is true, the result is an XML content fragment that looks like this:

```
<tablename>
  <columnname1>data</columnname1>
  <columnname2>data</columnname2>
</tablename>

<tablename>
  ...
</tablename>

...
```

If no table name is available, that is, when mapping a query or a cursor, the string `table` is used in the first format, `row` in the second format.

The choice between these formats is up to the user. The first format is a proper XML document, which will be important in many applications. The second format tends to be more useful in the `cursor_to_xml` function if the result values are to be reassembled into one document later on. The functions for producing XML content discussed above, in particular `xmlelement`, can be used to alter the results to taste.

The data values are mapped in the same way as described for the function `xmlelement` above.

The parameter *nulls* determines whether null values should be included in the output. If true, null values in columns are represented as:

```
<columnname xsi:nil="true"/>
```

where `xsi` is the XML namespace prefix for XML Schema Instance. An appropriate namespace declaration will be added to the result value. If false, columns containing null values are simply omitted from the output.

The parameter *targetns* specifies the desired XML namespace of the result. If no particular namespace is wanted, an empty string should be passed.

The following functions return XML Schema documents describing the mappings performed by the corresponding functions above:

```
table_to_xmlschema ( table regclass, nulls boolean,
                     tableforest boolean, targetns text ) → xml
query_to_xmlschema ( query text, nulls boolean,
                     tableforest boolean, targetns text ) → xml
cursor_to_xmlschema ( cursor refcursor, nulls boolean,
                      tableforest boolean, targetns text ) → xml
```

It is essential that the same parameters are passed in order to obtain matching XML data mappings and XML Schema documents.

The following functions produce XML data mappings and the corresponding XML Schema in one document (or forest), linked together. They can be useful where self-contained and self-describing results are wanted:

```
table_to_xml_and_xmlschema ( table regclass, nulls boolean,
                             tableforest boolean, targetns text ) → xml
query_to_xml_and_xmlschema ( query text, nulls boolean,
                             tableforest boolean, targetns text ) → xml
```

In addition, the following functions are available to produce analogous mappings of entire schemas or the entire current database:

```
schema_to_xml ( schema name, nulls boolean,
                tableforest boolean, targetns text ) → xml
schema_to_xmlschema ( schema name, nulls boolean,
                      tableforest boolean, targetns text ) → xml
schema_to_xml_and_xmlschema ( schema name, nulls boolean,
                              tableforest boolean, targetns text ) → xml

database_to_xml ( nulls boolean,
                  tableforest boolean, targetns text ) → xml
database_to_xmlschema ( nulls boolean,
                        tableforest boolean, targetns text ) → xml
database_to_xml_and_xmlschema ( nulls boolean,
                                tableforest boolean, targetns text ) → xml
```

These functions ignore tables that are not readable by the current user. The database-wide functions additionally ignore schemas that the current user does not have `USAGE` (lookup) privilege for.

Note that these potentially produce a lot of data, which needs to be built up in memory. When requesting content mappings of large schemas or databases, it might be worthwhile to consider mapping the tables separately instead, possibly even through a cursor.

The result of a schema content mapping looks like this:

```
<schemaname>

table1-mapping

table2-mapping

...

</schemaname>
```

where the format of a table mapping depends on the *tableforest* parameter as explained above.

The result of a database content mapping looks like this:

```
<dbname>

<schema1name>
  ...
</schema1name>

<schema2name>
  ...
</schema2name>

...

</dbname>
```

where the schema mapping is as above.

As an example of using the output produced by these functions, Example 9.1 shows an XSLT stylesheet that converts the output of `table_to_xml_and_xmlschema` to an HTML document containing a tabular rendition of the table data. In a similar manner, the results from these functions can be converted into other XML-based formats.

Example 9.1. XSLT Stylesheet for Converting SQL/XML Output to HTML

```
<?xml version="1.0"?>
<xsl:stylesheet version="1.0"
    xmlns:xsl="http://www.w3.org/1999/XSL/Transform"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema"
    xmlns="http://www.w3.org/1999/xhtml"
>

  <xsl:output method="xml"
      doctype-system="http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd"
      doctype-public="-//W3C/DTD XHTML 1.0 Strict//EN"
      indent="yes"/>

  <xsl:template match="/*">
    <xsl:variable name="schema" select="//xsd:schema"/>
    <xsl:variable name="tabletypename"
                  select="$schema/xsd:element[@name=name(current())]/@type"/>
    <xsl:variable name="rowtypename"
                  select="$schema/xsd:complexType[@name=$tabletypename]/xsd:sequence/
xsd:element[@name='row']/@type"/>

    <html>
      <head>
        <title><xsl:value-of select="name(current())"/></title>
      </head>
      <body>
        <table>
          <tr>
            <xsl:for-each select="$schema/xsd:complexType[@name=$rowtypename]/
xsd:sequence/xsd:element/@name">
              <th><xsl:value-of select="."/></th>
            </xsl:for-each>
          </tr>

          <xsl:for-each select="row">
            <tr>
              <xsl:for-each select="*">
                <td><xsl:value-of select="."/></td>
              </xsl:for-each>
            </tr>
          </xsl:for-each>
        </table>
      </body>
    </html>
  </xsl:template>

</xsl:stylesheet>
```

9.16. JSON Functions and Operators

This section describes:

- functions and operators for processing and creating JSON data
- the SQL/JSON path language

To learn more about the SQL/JSON standard, see sqltr-19075-6. For details on JSON types supported in Postgres Pro, see Section 8.14.

9.16.1. Processing and Creating JSON Data

> **Note**
>
> Functions manipulating JSONB do not accept the `'\u0000'` character. To handle this, you can specify a unicode character in the unicode_nul_character_replacement_in_jsonb configuration parameter to replace this character on the fly.

Table 9.44 shows the operators that are available for use with JSON data types (see Section 8.14). In addition, the usual comparison operators shown in Table 9.1 are available for `jsonb`, though not for `json`. The comparison operators follow the ordering rules for B-tree operations outlined in Section 8.14.4. See also Section 9.21 for the aggregate function `json_agg` which aggregates record values as JSON, the aggregate function `json_object_agg` which aggregates pairs of values into a JSON object, and their `jsonb` equivalents, `jsonb_agg` and `jsonb_object_agg`.

Table 9.44. `json` and `jsonb` Operators

Operator Description Example(s)

`json -> integer → json`
`jsonb -> integer → jsonb`
Extracts *n*'th element of JSON array (array elements are indexed from zero, but negative integers count from the end).
`'[{"a":"foo"},{"b":"bar"},{"c":"baz"}]'::json -> 2 → {"c":"baz"}`
`'[{"a":"foo"},{"b":"bar"},{"c":"baz"}]'::json -> -3 → {"a":"foo"}`

`json -> text → json`
`jsonb -> text → jsonb`
Extracts JSON object field with the given key.
`'{"a": {"b":"foo"}}'::json -> 'a' → {"b":"foo"}`

`json ->> integer → text`
`jsonb ->> integer → text`
Extracts *n*'th element of JSON array, as `text`.
`'[1,2,3]'::json ->> 2 → 3`

`json ->> text → text`
`jsonb ->> text → text`
Extracts JSON object field with the given key, as `text`.
`'{"a":1,"b":2}'::json ->> 'b' → 2`

`json #> text[] → json`
`jsonb #> text[] → jsonb`
Extracts JSON sub-object at the specified path, where path elements can be either field keys or array indexes.
`'{"a": {"b": ["foo","bar"]}}'::json #> '{a,b,1}' → "bar"`

Operator Description Example(s)

`json #>> text[]` → `text`
`jsonb #>> text[]` → `text`
Extracts JSON sub-object at the specified path as `text`.
`'{"a": {"b": ["foo","bar"]}}'::json #>> '{a,b,1}'` → `bar`

> **Note**
>
> The field/element/path extraction operators return NULL, rather than failing, if the JSON input does not have the right structure to match the request; for example if no such key or array element exists.

Some further operators exist only for `jsonb`, as shown in Table 9.45. Section 8.14.4 describes how these operators can be used to effectively search indexed `jsonb` data.

Table 9.45. Additional `jsonb` Operators

Operator Description Example(s)

`jsonb @> jsonb` → `boolean`
Does the first JSON value contain the second? (See Section 8.14.3 for details about containment.)
`'{"a":1, "b":2}'::jsonb @> '{"b":2}'::jsonb` → `t`

`jsonb <@ jsonb` → `boolean`
Is the first JSON value contained in the second?
`'{"b":2}'::jsonb <@ '{"a":1, "b":2}'::jsonb` → `t`

`jsonb ? text` → `boolean`
Does the text string exist as a top-level key or array element within the JSON value?
`'{"a":1, "b":2}'::jsonb ? 'b'` → `t`
`'["a", "b", "c"]'::jsonb ? 'b'` → `t`

`jsonb ?| text[]` → `boolean`
Do any of the strings in the text array exist as top-level keys or array elements?
`'{"a":1, "b":2, "c":3}'::jsonb ?| array['b', 'd']` → `t`

`jsonb ?& text[]` → `boolean`
Do all of the strings in the text array exist as top-level keys or array elements?
`'["a", "b", "c"]'::jsonb ?& array['a', 'b']` → `t`

`jsonb || jsonb` → `jsonb`
Concatenates two `jsonb` values. Concatenating two arrays generates an array containing all the elements of each input. Concatenating two objects generates an object containing the union of their keys, taking the second object's value when there are duplicate keys. All other cases are treated by converting a non-array input into a single-element array, and then proceeding as for two arrays. Does not operate recursively: only the top-level array or object structure is merged.
`'["a", "b"]'::jsonb || '["a", "d"]'::jsonb` → `["a", "b", "a", "d"]`
`'{"a": "b"}'::jsonb || '{"c": "d"}'::jsonb` → `{"a": "b", "c": "d"}`
`'[1, 2]'::jsonb || '3'::jsonb` → `[1, 2, 3]`

Operator Description Example(s)

`'{"a": "b"}'::jsonb || '42'::jsonb` → `[{"a": "b"}, 42]`
To append an array to another array as a single entry, wrap it in an additional layer of array, for example:
`'[1, 2]'::jsonb || jsonb_build_array('[3, 4]'::jsonb)` → `[1, 2, [3, 4]]`

`jsonb - text` → `jsonb`
Deletes a key (and its value) from a JSON object, or matching string value(s) from a JSON array.
`'{"a": "b", "c": "d"}'::jsonb - 'a'` → `{"c": "d"}`
`'["a", "b", "c", "b"]'::jsonb - 'b'` → `["a", "c"]`

`jsonb - text[]` → `jsonb`
Deletes all matching keys or array elements from the left operand.
`'{"a": "b", "c": "d"}'::jsonb - '{a,c}'::text[]` → `{}`

`jsonb - integer` → `jsonb`
Deletes the array element with specified index (negative integers count from the end). Throws an error if JSON value is not an array.
`'["a", "b"]'::jsonb - 1` → `["a"]`

`jsonb #- text[]` → `jsonb`
Deletes the field or array element at the specified path, where path elements can be either field keys or array indexes.
`'["a", {"b":1}]'::jsonb #- '{1,b}'` → `["a", {}]`

`jsonb @? jsonpath` → `boolean`
Does JSON path return any item for the specified JSON value?
`'{"a":[1,2,3,4,5]}'::jsonb @? '$.a[*] ? (@ > 2)'` → `t`

`jsonb @@ jsonpath` → `boolean`
Returns the result of a JSON path predicate check for the specified JSON value. Only the first item of the result is taken into account. If the result is not Boolean, then `NULL` is returned.
`'{"a":[1,2,3,4,5]}'::jsonb @@ '$.a[*] > 2'` → `t`

> **Note**
>
> The `jsonpath` operators `@?` and `@@` suppress the following errors: missing object field or array element, unexpected JSON item type, datetime and numeric errors. The `jsonpath`-related functions described below can also be told to suppress these types of errors. This behavior might be helpful when searching JSON document collections of varying structure.

Table 9.46 shows the functions that are available for constructing `json` and `jsonb` values.

Table 9.46. JSON Creation Functions

Function Description Example(s)

`to_json ( anyelement )` → `json`
`to_jsonb ( anyelement )` → `jsonb`
Converts any SQL value to `json` or `jsonb`. Arrays and composites are converted recursively to arrays and objects (multidimensional arrays become arrays of arrays in JSON). Otherwise, if

Function **Description** **Example(s)**

there is a cast from the SQL data type to `json`, the cast function will be used to perform the conversion;[a] otherwise, a scalar JSON value is produced. For any scalar other than a number, a Boolean, or a null value, the text representation will be used, with escaping as necessary to make it a valid JSON string value.
`to_json('Fred said "Hi."'::text)` → `"Fred said \"Hi.\""`
`to_jsonb(row(42, 'Fred said "Hi."'::text))` → `{"f1": 42, "f2": "Fred said \"Hi.\""}`

`array_to_json ( anyarray [, boolean ] )` → `json`
Converts an SQL array to a JSON array. The behavior is the same as `to_json` except that line feeds will be added between top-level array elements if the optional boolean parameter is true.
`array_to_json('{{1,5},{99,100}}'::int[])` → `[[1,5],[99,100]]`

`row_to_json ( record [, boolean ] )` → `json`
Converts an SQL composite value to a JSON object. The behavior is the same as `to_json` except that line feeds will be added between top-level elements if the optional boolean parameter is true.
`row_to_json(row(1,'foo'))` → `{"f1":1,"f2":"foo"}`

`json_build_array ( VARIADIC "any" )` → `json`
`jsonb_build_array ( VARIADIC "any" )` → `jsonb`
Builds a possibly-heterogeneously-typed JSON array out of a variadic argument list. Each argument is converted as per `to_json` or `to_jsonb`.
`json_build_array(1, 2, 'foo', 4, 5)` → `[1, 2, "foo", 4, 5]`

`json_build_object ( VARIADIC "any" )` → `json`
`jsonb_build_object ( VARIADIC "any" )` → `jsonb`
Builds a JSON object out of a variadic argument list. By convention, the argument list consists of alternating keys and values. Key arguments are coerced to text; value arguments are converted as per `to_json` or `to_jsonb`.
`json_build_object('foo', 1, 2, row(3,'bar'))` → `{"foo" : 1, "2" : {"f1":3,"f2":"bar"}}`

`json_object ( text[] )` → `json`
`jsonb_object ( text[] )` → `jsonb`
Builds a JSON object out of a text array. The array must have either exactly one dimension with an even number of members, in which case they are taken as alternating key/value pairs, or two dimensions such that each inner array has exactly two elements, which are taken as a key/value pair. All values are converted to JSON strings.
`json_object('{a, 1, b, "def", c, 3.5}')` → `{"a" : "1", "b" : "def", "c" : "3.5"}`
`json_object('{{a, 1}, {b, "def"}, {c, 3.5}}')` → `{"a" : "1", "b" : "def", "c" : "3.5"}`

`json_object ( keys text[], values text[] )` → `json`
`jsonb_object ( keys text[], values text[] )` → `jsonb`
This form of `json_object` takes keys and values pairwise from separate text arrays. Otherwise it is identical to the one-argument form.
`json_object('{a,b}', '{1,2}')` → `{"a": "1", "b": "2"}`

[a] For example, the hstore extension has a cast from `hstore` to `json`, so that `hstore` values converted via the JSON creation functions will be represented as JSON objects, not as primitive string values.

Table 9.47 shows the functions that are available for processing `json` and `jsonb` values.

Table 9.47. JSON Processing Functions

Function **Description** **Example(s)**

`json_array_elements ( json ) → setof json`
`jsonb_array_elements ( jsonb ) → setof jsonb`
Expands the top-level JSON array into a set of JSON values.
`select * from json_array_elements('[1,true, [2,false]]') →`
`value`
`-----------`
`1`
`true`
`[2,false]`

`json_array_elements_text ( json ) → setof text`
`jsonb_array_elements_text ( jsonb ) → setof text`
Expands the top-level JSON array into a set of `text` values.
`select * from json_array_elements_text('["foo", "bar"]') →`
`value`
`-----------`
`foo`
`bar`

`json_array_length ( json ) → integer`
`jsonb_array_length ( jsonb ) → integer`
Returns the number of elements in the top-level JSON array.
`json_array_length('[1,2,3,{"f1":1,"f2":[5,6]},4]') → 5`
`jsonb_array_length('[]') → 0`

`json_each ( json ) → setof record ( key text, value json )`
`jsonb_each ( jsonb ) → setof record ( key text, value jsonb )`
Expands the top-level JSON object into a set of key/value pairs.
`select * from json_each('{"a":"foo", "b":"bar"}') →`
`key | value`
`-----+-------`
`a | "foo"`
`b | "bar"`

`json_each_text ( json ) → setof record ( key text, value text )`
`jsonb_each_text ( jsonb ) → setof record ( key text, value text )`
Expands the top-level JSON object into a set of key/value pairs. The returned *value*s will be of type `text`.
`select * from json_each_text('{"a":"foo", "b":"bar"}') →`
`key | value`
`-----+-------`
`a | foo`
`b | bar`

`json_extract_path ( from_json json, VARIADIC path_elems text[] ) → json`
`jsonb_extract_path ( from_json jsonb, VARIADIC path_elems text[] ) → jsonb`
Extracts JSON sub-object at the specified path. (This is functionally equivalent to the `#>` operator, but writing the path out as a variadic list can be more convenient in some cases.)

Function
Description
Example(s)

`json_extract_path('{"f2":{"f3":1},"f4":{"f5":99,"f6":"foo"}}', 'f4', 'f6')` → `"foo"`

`json_extract_path_text` (*from_json* `json`, `VARIADIC` *path_elems* `text[]`) → `text`
`jsonb_extract_path_text` (*from_json* `jsonb`, `VARIADIC` *path_elems* `text[]`) → `text`
Extracts JSON sub-object at the specified path as `text`. (This is functionally equivalent to the `#>>` operator.)
`json_extract_path_text('{"f2":{"f3":1},"f4":{"f5":99,"f6":"foo"}}', 'f4', 'f6')` → `foo`

`json_object_keys` (`json`) → `setof text`
`jsonb_object_keys` (`jsonb`) → `setof text`
Returns the set of keys in the top-level JSON object.

```
select * from json_object_keys('{"f1":"abc","f2":{"f3":"a", "f4":"b"}}')      →

 json_object_keys
------------------
 f1
 f2
```

`json_populate_record` (*base* `anyelement`, *from_json* `json`) → `anyelement`
`jsonb_populate_record` (*base* `anyelement`, *from_json* `jsonb`) → `anyelement`
Expands the top-level JSON object to a row having the composite type of the *base* argument. The JSON object is scanned for fields whose names match column names of the output row type, and their values are inserted into those columns of the output. (Fields that do not correspond to any output column name are ignored.) In typical use, the value of *base* is just `NULL`, which means that any output columns that do not match any object field will be filled with nulls. However, if *base* isn't `NULL` then the values it contains will be used for unmatched columns.
To convert a JSON value to the SQL type of an output column, the following rules are applied in sequence:

- A JSON null value is converted to an SQL null in all cases.
- If the output column is of type `json` or `jsonb`, the JSON value is just reproduced exactly.
- If the output column is a composite (row) type, and the JSON value is a JSON object, the fields of the object are converted to columns of the output row type by recursive application of these rules.
- Likewise, if the output column is an array type and the JSON value is a JSON array, the elements of the JSON array are converted to elements of the output array by recursive application of these rules.
- Otherwise, if the JSON value is a string, the contents of the string are fed to the input conversion function for the column's data type.
- Otherwise, the ordinary text representation of the JSON value is fed to the input conversion function for the column's data type.

While the example below uses a constant JSON value, typical use would be to reference a `json` or `jsonb` column laterally from another table in the query's `FROM` clause. Writing `json_populate_record` in the `FROM` clause is good practice, since all of the extracted columns are available for use without duplicate function calls.

```
create type subrowtype as (d int, e text);  create type myrowtype as (a int,
b text[], c subrowtype);
select * from json_populate_record(null::myrowtype, '{"a": 1, "b": ["2",
"a b"], "c": {"d": 4, "e": "a b c"}, "x": "foo"}')    →

 a |   b       |      c
```

Function
Description
Example(s)

```
---+-----------+-------------
 1 | {2,"a b"} | (4,"a b c")
```

`json_populate_recordset` (*base* `anyelement`, *from_json* `json`) → `setof anyelement`
`jsonb_populate_recordset` (*base* `anyelement`, *from_json* `jsonb`) → `setof anyelement`

Expands the top-level JSON array of objects to a set of rows having the composite type of the *base* argument. Each element of the JSON array is processed as described above for `json[b]_populate_record` .

```
create type twoints as (a int, b int);
select * from json_populate_recordset(null::twoints, '[{"a":1,"b":2},
{"a":3,"b":4}]') →

 a | b
---+---
 1 | 2
 3 | 4
```

`json_to_record` (`json`) → `record`
`jsonb_to_record` (`jsonb`) → `record`

Expands the top-level JSON object to a row having the composite type defined by an `AS` clause. (As with all functions returning `record`, the calling query must explicitly define the structure of the record with an `AS` clause.) The output record is filled from fields of the JSON object, in the same way as described above for `json[b]_populate_record` . Since there is no input record value, unmatched columns are always filled with nulls.

```
create type myrowtype as (a int, b text);
select * from json_to_record('{"a":1,"b":[1,2,3],"c":[1,2,3],
"e":"bar","r": {"a": 123, "b": "a b c"}}') as x(a int, b text, c int[], d
text, r myrowtype) →

 a |    b    |    c    | d |       r
---+---------+---------+---+---------------
 1 | [1,2,3] | {1,2,3} |   | (123,"a b c")
```

`json_to_recordset` (`json`) → `setof record`
`jsonb_to_recordset` (`jsonb`) → `setof record`

Expands the top-level JSON array of objects to a set of rows having the composite type defined by an `AS` clause. (As with all functions returning `record`, the calling query must explicitly define the structure of the record with an `AS` clause.) Each element of the JSON array is processed as described above for `json[b]_populate_record` .

```
select * from json_to_recordset('[{"a":1,"b":"foo"}, {"a":"2",
"c":"bar"}]') as x(a int, b text) →

 a |  b
---+-----
 1 | foo
 2 |
```

`jsonb_set` (*target* `jsonb`, *path* `text[]`, *new_value* `jsonb` [, *create_if_missing* `boolean`]) → `jsonb`

Returns *target* with the item designated by *path* replaced by *new_value* , or with *new_value* added if *create_if_missing* is true (which is the default) and the item designated by *path* does not exist. All earlier steps in the path must exist, or the *target* is returned unchanged. As with the path oriented operators, negative integers that appear in the *path* count from the end of JSON arrays. If the last path step is an array index that is out of range, and

Function
Description
Example(s)

create_if_missing is true, the new value is added at the beginning of the array if the index is negative, or at the end of the array if it is positive.

```
jsonb_set('[{"f1":1,"f2":null},2,null,3]', '{0,f1}', '[2,3,4]',
false) → [{"f1": [2, 3, 4], "f2": null}, 2, null, 3]
jsonb_set('[{"f1":1,"f2":null},2]', '{0,f3}', '[2,3,4]') → [{"f1": 1,
"f2": null, "f3": [2, 3, 4]}, 2]
```

`jsonb_set_lax` (*target* `jsonb`, *path* `text[]`, *new_value* `jsonb` [, *create_if_missing* `boolean` [, *null_value_treatment* `text`]]) → `jsonb`

If *new_value* is not `NULL`, behaves identically to `jsonb_set`. Otherwise behaves according to the value of *null_value_treatment* which must be one of `'raise_exception'`, `'use_json_null'`, `'delete_key'`, or `'return_target'`. The default is `'use_json_null'`.

```
jsonb_set_lax('[{"f1":1,"f2":null},2,null,3]', '{0,f1}', null) →
[{"f1": null, "f2": null}, 2, null, 3]
jsonb_set_lax('[{"f1":99,"f2":null},2]', '{0,f3}', null, true, 're-
turn_target') → [{"f1": 99, "f2": null}, 2]
```

`jsonb_insert` (*target* `jsonb`, *path* `text[]`, *new_value* `jsonb` [, *insert_after* `boolean`]) → `jsonb`

Returns *target* with *new_value* inserted. If the item designated by the *path* is an array element, *new_value* will be inserted before that item if *insert_after* is false (which is the default), or after it if *insert_after* is true. If the item designated by the *path* is an object field, *new_value* will be inserted only if the object does not already contain that key. All earlier steps in the path must exist, or the *target* is returned unchanged. As with the path oriented operators, negative integers that appear in the *path* count from the end of JSON arrays. If the last path step is an array index that is out of range, the new value is added at the beginning of the array if the index is negative, or at the end of the array if it is positive.

```
jsonb_insert('{"a": [0,1,2]}', '{a, 1}', '"new_value"') → {"a": [0,
"new_value", 1, 2]}
jsonb_insert('{"a": [0,1,2]}', '{a, 1}', '"new_value"', true) → {"a":
[0, 1, "new_value", 2]}
```

`json_strip_nulls` (`json`) → `json`

`jsonb_strip_nulls` (`jsonb`) → `jsonb`

Deletes all object fields that have null values from the given JSON value, recursively. Null values that are not object fields are untouched.

```
json_strip_nulls('[{"f1":1, "f2":null}, 2, null, 3]') → [{"f1":1},2,
null,3]
```

`jsonb_path_exists` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `boolean`

Checks whether the JSON path returns any item for the specified JSON value. If the *vars* argument is specified, it must be a JSON object, and its fields provide named values to be substituted into the `jsonpath` expression. If the *silent* argument is specified and is `true`, the function suppresses the same errors as the `@?` and `@@` operators do.

```
jsonb_path_exists('{"a":[1,2,3,4,5]}', '$.a[*] ? (@ >= $min && @ <=
$max)', '{"min":2, "max":4}') → t
```

`jsonb_path_match` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `boolean`

Returns the result of a JSON path predicate check for the specified JSON value. Only the first item of the result is taken into account. If the result is not Boolean, then `NULL` is returned. The optional *vars* and *silent* arguments act the same as for `jsonb_path_exists`.

Function
Description
Example(s)

`jsonb_path_match('{"a":[1,2,3,4,5]}', 'exists($.a[*] ? (@ >= $min && @ <= $max))', '{"min":2, "max":4}')` → `t`

`jsonb_path_query` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `setof jsonb`

Returns all JSON items returned by the JSON path for the specified JSON value. The optional *vars* and *silent* arguments act the same as for `jsonb_path_exists`.

```
select * from jsonb_path_query('{"a":[1,2,3,4,5]}', '$.a[*] ? (@ >= $min && @ <= $max)', '{"min":2, "max":4}')  →

 jsonb_path_query
------------------
 2
 3
 4
```

`jsonb_path_query_array` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `jsonb`

Returns all JSON items returned by the JSON path for the specified JSON value, as a JSON array. The optional *vars* and *silent* arguments act the same as for `jsonb_path_exists`.

`jsonb_path_query_array('{"a":[1,2,3,4,5]}', '$.a[*] ? (@ >= $min && @ <= $max)', '{"min":2, "max":4}')` → `[2, 3, 4]`

`jsonb_path_query_first` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `jsonb`

Returns the first JSON item returned by the JSON path for the specified JSON value. Returns `NULL` if there are no results. The optional *vars* and *silent* arguments act the same as for `jsonb_path_exists`.

`jsonb_path_query_first('{"a":[1,2,3,4,5]}', '$.a[*] ? (@ >= $min && @ <= $max)', '{"min":2, "max":4}')` → `2`

`jsonb_path_exists_tz` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `boolean`

`jsonb_path_match_tz` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `boolean`

`jsonb_path_query_tz` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `setof jsonb`

`jsonb_path_query_array_tz` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `jsonb`

`jsonb_path_query_first_tz` (*target* `jsonb`, *path* `jsonpath` [, *vars* `jsonb` [, *silent* `boolean`]]) → `jsonb`

These functions act like their counterparts described above without the `_tz` suffix, except that these functions support comparisons of date/time values that require timezone-aware conversions. The example below requires interpretation of the date-only value `2015-08-02` as a timestamp with time zone, so the result depends on the current TimeZone setting. Due to this dependency, these functions are marked as stable, which means these functions cannot be used in indexes. Their counterparts are immutable, and so can be used in indexes; but they will throw errors if asked to make such comparisons.

`jsonb_path_exists_tz('["2015-08-01 12:00:00-05"]', '$[*] ? (@.datetime() < "2015-08-02".datetime())')` → `t`

`jsonb_pretty` (`jsonb`) → `text`

Converts the given JSON value to pretty-printed, indented text.

Function Description Example(s)

`jsonb_pretty('[{"f1":1,"f2":null}, 2]')` →
`[`
`  {`
`  "f1": 1,`
`  "f2": null`
`  },`
`  2`
`]`

`json_typeof ( json ) → text`
`jsonb_typeof ( jsonb ) → text`
Returns the type of the top-level JSON value as a text string. Possible types are `object`, `array`, `string`, `number`, `boolean`, and `null`. (The `null` result should not be confused with an SQL NULL; see the examples.)
`json_typeof('-123.4')` → `number`
`json_typeof('null'::json)` → `null`
`json_typeof(NULL::json) IS NULL` → `t`

9.16.2. The SQL/JSON Path Language

SQL/JSON path expressions specify the items to be retrieved from the JSON data, similar to XPath expressions used for SQL access to XML. In Postgres Pro, path expressions are implemented as the `jsonpath` data type and can use any elements described in Section 8.14.7.

JSON query functions and operators pass the provided path expression to the *path engine* for evaluation. If the expression matches the queried JSON data, the corresponding JSON item, or set of items, is returned. Path expressions are written in the SQL/JSON path language and can include arithmetic expressions and functions.

A path expression consists of a sequence of elements allowed by the `jsonpath` data type. The path expression is normally evaluated from left to right, but you can use parentheses to change the order of operations. If the evaluation is successful, a sequence of JSON items is produced, and the evaluation result is returned to the JSON query function that completes the specified computation.

To refer to the JSON value being queried (the *context item*), use the `$` variable in the path expression. It can be followed by one or more accessor operators, which go down the JSON structure level by level to retrieve sub-items of the context item. Each operator that follows deals with the result of the previous evaluation step.

For example, suppose you have some JSON data from a GPS tracker that you would like to parse, such as:

```
{
  "track": {
    "segments": [
      {
        "location":   [ 47.763, 13.4034 ],
        "start time": "2018-10-14 10:05:14",
        "HR": 73
      },
      {
        "location":   [ 47.706, 13.2635 ],
        "start time": "2018-10-14 10:39:21",
        "HR": 135
      }
```

```
    ]
  }
}
```

To retrieve the available track segments, you need to use the `.key` accessor operator to descend through surrounding JSON objects:

```
$.track.segments
```

To retrieve the contents of an array, you typically use the `[*]` operator. For example, the following path will return the location coordinates for all the available track segments:

```
$.track.segments[*].location
```

To return the coordinates of the first segment only, you can specify the corresponding subscript in the `[]` accessor operator. Recall that JSON array indexes are 0-relative:

```
$.track.segments[0].location
```

The result of each path evaluation step can be processed by one or more `jsonpath` operators and methods listed in Section 9.16.2.2. Each method name must be preceded by a dot. For example, you can get the size of an array:

```
$.track.segments.size()
```

More examples of using `jsonpath` operators and methods within path expressions appear below in Section 9.16.2.2.

When defining a path, you can also use one or more *filter expressions* that work similarly to the `WHERE` clause in SQL. A filter expression begins with a question mark and provides a condition in parentheses:

```
? (condition)
```

Filter expressions must be written just after the path evaluation step to which they should apply. The result of that step is filtered to include only those items that satisfy the provided condition. SQL/JSON defines three-valued logic, so the condition can be `true`, `false`, or `unknown`. The `unknown` value plays the same role as SQL `NULL` and can be tested for with the `is unknown` predicate. Further path evaluation steps use only those items for which the filter expression returned `true`.

The functions and operators that can be used in filter expressions are listed in Table 9.49. Within a filter expression, the `@` variable denotes the value being filtered (i.e., one result of the preceding path step). You can write accessor operators after `@` to retrieve component items.

For example, suppose you would like to retrieve all heart rate values higher than 130. You can achieve this using the following expression:

```
$.track.segments[*].HR ? (@ > 130)
```

To get the start times of segments with such values, you have to filter out irrelevant segments before returning the start times, so the filter expression is applied to the previous step, and the path used in the condition is different:

```
$.track.segments[*] ? (@.HR > 130)."start time"
```

You can use several filter expressions in sequence, if required. For example, the following expression selects start times of all segments that contain locations with relevant coordinates and high heart rate values:

```
$.track.segments[*] ? (@.location[1] < 13.4) ? (@.HR > 130)."start time"
```

Using filter expressions at different nesting levels is also allowed. The following example first filters all segments by location, and then returns high heart rate values for these segments, if available:

```
$.track.segments[*] ? (@.location[1] < 13.4).HR ? (@ > 130)
```

You can also nest filter expressions within each other:

```
$.track ? (exists(@.segments[*] ? (@.HR > 130))).segments.size()
```

This expression returns the size of the track if it contains any segments with high heart rate values, or an empty sequence otherwise.

Postgres Pro's implementation of the SQL/JSON path language has the following deviations from the SQL/JSON standard:

- A path expression can be a Boolean predicate, although the SQL/JSON standard allows predicates only in filters. This is necessary for implementation of the `@@` operator. For example, the following `jsonpath` expression is valid in Postgres Pro:

  ```
  $.track.segments[*].HR < 70
  ```

- There are minor differences in the interpretation of regular expression patterns used in `like_regex` filters, as described in Section 9.16.2.3.

9.16.2.1. Strict and Lax Modes

When you query JSON data, the path expression may not match the actual JSON data structure. An attempt to access a non-existent member of an object or element of an array results in a structural error. SQL/JSON path expressions have two modes of handling structural errors:

- lax (default) — the path engine implicitly adapts the queried data to the specified path. Any remaining structural errors are suppressed and converted to empty SQL/JSON sequences.
- strict — if a structural error occurs, an error is raised.

The lax mode facilitates matching of a JSON document structure and path expression if the JSON data does not conform to the expected schema. If an operand does not match the requirements of a particular operation, it can be automatically wrapped as an SQL/JSON array or unwrapped by converting its elements into an SQL/JSON sequence before performing this operation. Besides, comparison operators automatically unwrap their operands in the lax mode, so you can compare SQL/JSON arrays out-of-the-box. An array of size 1 is considered equal to its sole element. Automatic unwrapping is not performed only when:

- The path expression contains `type()` or `size()` methods that return the type and the number of elements in the array, respectively.
- The queried JSON data contain nested arrays. In this case, only the outermost array is unwrapped, while all the inner arrays remain unchanged. Thus, implicit unwrapping can only go one level down within each path evaluation step.

For example, when querying the GPS data listed above, you can abstract from the fact that it stores an array of segments when using the lax mode:

```
lax $.track.segments.location
```

In the strict mode, the specified path must exactly match the structure of the queried JSON document to return an SQL/JSON item, so using this path expression will cause an error. To get the same result as in the lax mode, you have to explicitly unwrap the `segments` array:

```
strict $.track.segments[*].location
```

The `.**` accessor can lead to surprising results when using the lax mode. For instance, the following query selects every `HR` value twice:

```
lax $.**.HR
```

This happens because the `.**` accessor selects both the `segments` array and each of its elements, while the `.HR` accessor automatically unwraps arrays when using the lax mode. To avoid surprising results, we recommend using the `.**` accessor only in the strict mode. The following query selects each `HR` value just once:

```
strict $.**.HR
```

9.16.2.2. SQL/JSON Path Operators and Methods

Table 9.48 shows the operators and methods available in `jsonpath`. Note that while the unary operators and methods can be applied to multiple values resulting from a preceding path step, the binary operators (addition etc.) can only be applied to single values.

Table 9.48. `jsonpath` Operators and Methods

Operator/Method Description Example(s)
number + *number* → *number* Addition `jsonb_path_query('[2]', '$[0] + 3')` → `5`
+ *number* → *number* Unary plus (no operation); unlike addition, this can iterate over multiple values `jsonb_path_query_array('{"x": [2,3,4]}', '+ $.x')` → `[2, 3, 4]`
number - *number* → *number* Subtraction `jsonb_path_query('[2]', '7 - $[0]')` → `5`
- *number* → *number* Negation; unlike subtraction, this can iterate over multiple values `jsonb_path_query_array('{"x": [2,3,4]}', '- $.x')` → `[-2, -3, -4]`
number * *number* → *number* Multiplication `jsonb_path_query('[4]', '2 * $[0]')` → `8`
number / *number* → *number* Division `jsonb_path_query('[8.5]', '$[0] / 2')` → `4.2500000000000000`
number % *number* → *number* Modulo (remainder) `jsonb_path_query('[32]', '$[0] % 10')` → `2`
value . type() → *string* Type of the JSON item (see `json_typeof`) `jsonb_path_query_array('[1, "2", {}]', '$[*].type()')` → `["number", "string", "object"]`
value . size() → *number* Size of the JSON item (number of array elements, or 1 if not an array) `jsonb_path_query('{"m": [11, 15]}', '$.m.size()')` → `2`
value . double() → *number* Approximate floating-point number converted from a JSON number or string `jsonb_path_query('{"len": "1.9"}', '$.len.double() * 2')` → `3.8`
number . ceiling() → *number* Nearest integer greater than or equal to the given number `jsonb_path_query('{"h": 1.3}', '$.h.ceiling()')` → `2`
number . floor() → *number* Nearest integer less than or equal to the given number `jsonb_path_query('{"h": 1.7}', '$.h.floor()')` → `1`

Operator/Method **Description** **Example(s)**
number . abs() → *number* Absolute value of the given number jsonb_path_query('{"z": -0.3}', '$.z.abs()') → 0.3
string . datetime() → *datetime_type* (see note) Date/time value converted from a string jsonb_path_query('["2015-8-1", "2015-08-12"]', '$[*] ? (@.datetime() < "2015-08-2".datetime())') → "2015-8-1"
string . datetime(*template*) → *datetime_type* (see note) Date/time value converted from a string using the specified to_timestamp template jsonb_path_query_array('["12:30", "18:40"]', '$[*].datetime("HH24:MI")') → ["12:30:00", "18:40:00"]
object . keyvalue() → *array* The object's key-value pairs, represented as an array of objects containing three fields: "key", "value", and "id"; "id" is a unique identifier of the object the key-value pair belongs to jsonb_path_query_array('{"x": "20", "y": 32}', '$.keyvalue()') → [{"id": 0, "key": "x", "value": "20"}, {"id": 0, "key": "y", "value": 32}]

Note

The result type of the datetime() and datetime(*template*) methods can be date, timetz, time, timestamptz, or timestamp. Both methods determine their result type dynamically.

The datetime() method sequentially tries to match its input string to the ISO formats for date, timetz, time, timestamptz, and timestamp. It stops on the first matching format and emits the corresponding data type.

The datetime(*template*) method determines the result type according to the fields used in the provided template string.

The datetime() and datetime(*template*) methods use the same parsing rules as the to_timestamp SQL function does (see Section 9.8), with three exceptions. First, these methods don't allow unmatched template patterns. Second, only the following separators are allowed in the template string: minus sign, period, solidus (slash), comma, apostrophe, semicolon, colon and space. Third, separators in the template string must exactly match the input string.

If different date/time types need to be compared, an implicit cast is applied. A date value can be cast to timestamp or timestamptz, timestamp can be cast to timestamptz, and time to timetz. However, all but the first of these conversions depend on the current TimeZone setting, and thus can only be performed within timezone-aware jsonpath functions.

Table 9.49 shows the available filter expression elements.

Table 9.49. jsonpath Filter Expression Elements

Predicate/Value **Description** **Example(s)**
value == *value* → boolean Equality comparison (this, and the other comparison operators, work on all JSON scalar values) jsonb_path_query_array('[1, "a", 1, 3]', '$[*] ? (@ == 1)') → [1, 1]

Predicate/Value **Description** **Example(s)**
`jsonb_path_query_array('[1, "a", 1, 3]', '$[*] ? (@ == "a")')` → `["a"]`

value `!=` *value* → `boolean`
value `<>` *value* → `boolean`
Non-equality comparison
`jsonb_path_query_array('[1, 2, 1, 3]', '$[*] ? (@ != 1)')` → `[2, 3]`
`jsonb_path_query_array('["a", "b", "c"]', '$[*] ? (@ <> "b")')` → `["a", "c"]`

value `<` *value* → `boolean` Less-than comparison `jsonb_path_query_array('[1, 2, 3]', '$[*] ? (@ < 2)')` → `[1]`
value `<=` *value* → `boolean` Less-than-or-equal-to comparison `jsonb_path_query_array('["a", "b", "c"]', '$[*] ? (@ <= "b")')` → `["a", "b"]`
value `>` *value* → `boolean` Greater-than comparison `jsonb_path_query_array('[1, 2, 3]', '$[*] ? (@ > 2)')` → `[3]`
value `>=` *value* → `boolean` Greater-than-or-equal-to comparison `jsonb_path_query_array('[1, 2, 3]', '$[*] ? (@ >= 2)')` → `[2, 3]`

`true` → `boolean`
JSON constant `true`
`jsonb_path_query('[{"name": "John", "parent": false}, {"name": "Chris", "parent": true}]', '$[*] ? (@.parent == true)')` → `{"name": "Chris", "parent": true}`

`false` → `boolean`
JSON constant `false`
`jsonb_path_query('[{"name": "John", "parent": false}, {"name": "Chris", "parent": true}]', '$[*] ? (@.parent == false)')` → `{"name": "John", "parent": false}`

`null` → *value* JSON constant `null` (note that, unlike in SQL, comparison to `null` works normally) `jsonb_path_query('[{"name": "Mary", "job": null}, {"name": "Michael", "job": "driver"}]', '$[*] ? (@.job == null) .name')` → `"Mary"`
boolean `&&` *boolean* → `boolean` Boolean AND `jsonb_path_query('[1, 3, 7]', '$[*] ? (@ > 1 && @ < 5)')` → `3`
boolean `||` *boolean* → `boolean` Boolean OR `jsonb_path_query('[1, 3, 7]', '$[*] ? (@ < 1 || @ > 5)')` → `7`

`!` *boolean* → `boolean`
Boolean NOT
`jsonb_path_query('[1, 3, 7]', '$[*] ? (!(@ < 5))')` → `7`

Predicate/Value **Description** **Example(s)**
boolean `is unknown` → `boolean` Tests whether a Boolean condition is `unknown`. `jsonb_path_query('[-1, 2, 7, "foo"]', '$[*] ? ((@ > 0) is unknown)')` → `"foo"`

string `like_regex` *string* [`flag` *string*] → `boolean`
Tests whether the first operand matches the regular expression given by the second operand, optionally with modifications described by a string of `flag` characters (see Section 9.16.2.3).
`jsonb_path_query_array('["abc", "abd", "aBdC", "abdacb", "babc"]', '$[*] ? (@ like_regex "^ab.*c")')` → `["abc", "abdacb"]`
`jsonb_path_query_array('["abc", "abd", "aBdC", "abdacb", "babc"]', '$[*] ? (@ like_regex "^ab.*c" flag "i")')` → `["abc", "aBdC", "abdacb"]`

string `starts with` *string* → `boolean` Tests whether the second operand is an initial substring of the first operand. `jsonb_path_query('["John Smith", "Mary Stone", "Bob Johnson"]', '$[*] ? (@ starts with "John")')` → `"John Smith"`

`exists (` *path_expression* `)` → `boolean`
Tests whether a path expression matches at least one SQL/JSON item. Returns `unknown` if the path expression would result in an error; the second example uses this to avoid a no-such-key error in strict mode.
`jsonb_path_query('{"x": [1, 2], "y": [2, 4]}', 'strict $.* ? (exists ( @ ? (@[*] > 2)))')` → `[2, 4]`
`jsonb_path_query_array('{"value": 41}', 'strict $ ? (exists ( @.name)) .name')` → `[]`

9.16.2.3. SQL/JSON Regular Expressions

SQL/JSON path expressions allow matching text to a regular expression with the `like_regex` filter. For example, the following SQL/JSON path query would case-insensitively match all strings in an array that start with an English vowel:

```
$[*] ? (@ like_regex "^[aeiou]" flag "i")
```

The optional `flag` string may include one or more of the characters `i` for case-insensitive match, `m` to allow `^` and `$` to match at newlines, `s` to allow `.` to match a newline, and `q` to quote the whole pattern (reducing the behavior to a simple substring match).

The SQL/JSON standard borrows its definition for regular expressions from the `LIKE_REGEX` operator, which in turn uses the XQuery standard. Postgres Pro does not currently support the `LIKE_REGEX` operator. Therefore, the `like_regex` filter is implemented using the POSIX regular expression engine described in Section 9.7.3. This leads to various minor discrepancies from standard SQL/JSON behavior, which are cataloged in Section 9.7.3.8. Note, however, that the flag-letter incompatibilities described there do not apply to SQL/JSON, as it translates the XQuery flag letters to match what the POSIX engine expects.

Keep in mind that the pattern argument of `like_regex` is a JSON path string literal, written according to the rules given in Section 8.14.7. This means in particular that any backslashes you want to use in the regular expression must be doubled. For example, to match string values of the root document that contain only digits:

```
$.* ? (@ like_regex "^\\d+$")
```

9.17. Sequence Manipulation Functions

This section describes functions for operating on *sequence objects*, also called sequence generators or just sequences. Sequence objects are special single-row tables created with CREATE SEQUENCE. Sequence objects are commonly used to generate unique identifiers for rows of a table. The sequence functions, listed in Table 9.50, provide simple, multiuser-safe methods for obtaining successive sequence values from sequence objects.

Table 9.50. Sequence Functions

Function Description
`nextval ( regclass ) → bigint` Advances the sequence object to its next value and returns that value. This is done atomically: even if multiple sessions execute `nextval` concurrently, each will safely receive a distinct sequence value. If the sequence object has been created with default parameters, successive `nextval` calls will return successive values beginning with 1. Other behaviors can be obtained by using appropriate parameters in the CREATE SEQUENCE command. This function requires `USAGE` or `UPDATE` privilege on the sequence.
`setval ( regclass, bigint [, boolean ] ) → bigint` Sets the sequence object's current value, and optionally its `is_called` flag. The two-parameter form sets the sequence's `last_value` field to the specified value and sets its `is_called` field to `true`, meaning that the next `nextval` will advance the sequence before returning a value. The value that will be reported by `currval` is also set to the specified value. In the three-parameter form, `is_called` can be set to either `true` or `false`. `true` has the same effect as the two-parameter form. If it is set to `false`, the next `nextval` will return exactly the specified value, and sequence advancement commences with the following `nextval`. Furthermore, the value reported by `currval` is not changed in this case. For example, `SELECT setval('myseq', 42);` *Next nextval will return 43* `SELECT setval('myseq', 42, true);` *Same as above* `SELECT setval('myseq', 42, false);` *Next nextval will return 42* The result returned by `setval` is just the value of its second argument. This function requires `UPDATE` privilege on the sequence.
`currval ( regclass ) → bigint` Returns the value most recently obtained by `nextval` for this sequence in the current session. (An error is reported if `nextval` has never been called for this sequence in this session.) Because this is returning a session-local value, it gives a predictable answer whether or not other sessions have executed `nextval` since the current session did. This function requires `USAGE` or `SELECT` privilege on the sequence.
`lastval () → bigint` Returns the value most recently returned by `nextval` in the current session. This function is identical to `currval`, except that instead of taking the sequence name as an argument it refers to whichever sequence `nextval` was most recently applied to in the current session. It is an error to call `lastval` if `nextval` has not yet been called in the current session. This function requires `USAGE` or `SELECT` privilege on the last used sequence.

Caution

To avoid blocking concurrent transactions that obtain numbers from the same sequence, the value obtained by `nextval` is not reclaimed for re-use if the calling transaction later aborts. This means that transaction aborts or database crashes can result in gaps in the sequence of assigned values. That can happen without a transaction abort, too. For example an `INSERT` with an `ON CONFLICT` clause will compute the to-be-inserted tuple, including doing any required `nextval` calls, before detecting any conflict that would cause it to follow the `ON CONFLICT` rule instead. Thus, Postgres Pro sequence objects *cannot be used to obtain "gapless" sequences*.

Likewise, sequence state changes made by `setval` are immediately visible to other transactions, and are not undone if the calling transaction rolls back.

If the database cluster crashes before committing a transaction containing a `nextval` or `setval` call, the sequence state change might not have made its way to persistent storage, so that it is uncertain whether the sequence will have its original or updated state after the cluster restarts. This is harmless for usage of the sequence within the database, since other effects of uncommitted transactions will not be visible either. However, if you wish to use a sequence value for persistent outside-the-database purposes, make sure that the `nextval` call has been committed before doing so.

The sequence to be operated on by a sequence function is specified by a `regclass` argument, which is simply the OID of the sequence in the `pg_class` system catalog. You do not have to look up the OID by hand, however, since the `regclass` data type's input converter will do the work for you. See Section 8.19 for details.

9.18. Conditional Expressions

This section describes the SQL-compliant conditional expressions available in Postgres Pro.

Tip

If your needs go beyond the capabilities of these conditional expressions, you might want to consider writing a server-side function in a more expressive programming language.

Note

Although `COALESCE`, `GREATEST`, and `LEAST` are syntactically similar to functions, they are not ordinary functions, and thus cannot be used with explicit `VARIADIC` array arguments.

9.18.1. CASE

The SQL `CASE` expression is a generic conditional expression, similar to if/else statements in other programming languages:

```
CASE WHEN condition THEN result
     [WHEN ...]
     [ELSE result]
END
```

`CASE` clauses can be used wherever an expression is valid. Each *condition* is an expression that returns a `boolean` result. If the condition's result is true, the value of the `CASE` expression is the *result* that follows the condition, and the remainder of the `CASE` expression is not processed. If the condition's result is not true, any subsequent `WHEN` clauses are examined in the same manner. If no `WHEN` *condition* yields true, the value of the `CASE` expression is the *result* of the `ELSE` clause. If the `ELSE` clause is omitted and no condition is true, the result is null.

An example:

```
SELECT * FROM test;

 a
---
 1
 2
 3
```

```
SELECT a,
       CASE WHEN a=1 THEN 'one'
            WHEN a=2 THEN 'two'
            ELSE 'other'
       END
    FROM test;

 a | case
---+-------
 1 | one
 2 | two
 3 | other
```

The data types of all the *result* expressions must be convertible to a single output type. See Section 10.5 for more details.

There is a "simple" form of CASE expression that is a variant of the general form above:

```
CASE expression
    WHEN value THEN result
    [WHEN ...]
    [ELSE result]
END
```

The first *expression* is computed, then compared to each of the *value* expressions in the WHEN clauses until one is found that is equal to it. If no match is found, the *result* of the ELSE clause (or a null value) is returned. This is similar to the switch statement in C.

The example above can be written using the simple CASE syntax:

```
SELECT a,
       CASE a WHEN 1 THEN 'one'
              WHEN 2 THEN 'two'
              ELSE 'other'
       END
    FROM test;

 a | case
---+-------
 1 | one
 2 | two
 3 | other
```

A CASE expression does not evaluate any subexpressions that are not needed to determine the result. For example, this is a possible way of avoiding a division-by-zero failure:

```
SELECT ... WHERE CASE WHEN x <> 0 THEN y/x > 1.5 ELSE false END;
```

> **Note**
>
> As described in Section 4.2.14, there are various situations in which subexpressions of an expression are evaluated at different times, so that the principle that "CASE evaluates only necessary subexpressions" is not ironclad. For example a constant 1/0 subexpression will usually result in a division-by-zero failure at planning time, even if it's within a CASE arm that would never be entered at run time.

9.18.2. COALESCE

```
COALESCE(value [, ...])
```

The COALESCE function returns the first of its arguments that is not null. Null is returned only if all arguments are null. It is often used to substitute a default value for null values when data is retrieved for display, for example:

```
SELECT COALESCE(description, short_description, '(none)') ...
```

This returns description if it is not null, otherwise short_description if it is not null, otherwise (none).

The arguments must all be convertible to a common data type, which will be the type of the result (see Section 10.5 for details).

Like a CASE expression, COALESCE only evaluates the arguments that are needed to determine the result; that is, arguments to the right of the first non-null argument are not evaluated. This SQL-standard function provides capabilities similar to NVL and IFNULL, which are used in some other database systems.

9.18.3. NULLIF

```
NULLIF(value1, value2)
```

The NULLIF function returns a null value if *value1* equals *value2*; otherwise it returns *value1*. This can be used to perform the inverse operation of the COALESCE example given above:

```
SELECT NULLIF(value, '(none)') ...
```

In this example, if value is (none), null is returned, otherwise the value of value is returned.

The two arguments must be of comparable types. To be specific, they are compared exactly as if you had written *value1* = *value2*, so there must be a suitable = operator available.

The result has the same type as the first argument — but there is a subtlety. What is actually returned is the first argument of the implied = operator, and in some cases that will have been promoted to match the second argument's type. For example, NULLIF(1, 2.2) yields numeric, because there is no integer = numeric operator, only numeric = numeric.

9.18.4. GREATEST and LEAST

```
GREATEST(value [, ...])
```

```
LEAST(value [, ...])
```

The GREATEST and LEAST functions select the largest or smallest value from a list of any number of expressions. The expressions must all be convertible to a common data type, which will be the type of the result (see Section 10.5 for details). NULL values in the list are ignored. The result will be NULL only if all the expressions evaluate to NULL.

Note that GREATEST and LEAST are not in the SQL standard, but are a common extension. Some other databases make them return NULL if any argument is NULL, rather than only when all are NULL.

9.19. Array Functions and Operators

Table 9.51 shows the specialized operators available for array types. In addition to those, the usual comparison operators shown in Table 9.1 are available for arrays. The comparison operators compare the array contents element-by-element, using the default B-tree comparison function for the element data type, and sort based on the first difference. In multidimensional arrays the elements are visited in row-major order (last subscript varies most rapidly). If the contents of two arrays are equal but the dimensionality is different, the first difference in the dimensionality information determines the sort order.

Table 9.51. Array Operators

Operator Description Example(s)
anyarray @> anyarray → boolean

Operator Description Example(s)
Does the first array contain the second, that is, does each element appearing in the second array equal some element of the first array? (Duplicates are not treated specially, thus `ARRAY[1]` and `ARRAY[1,1]` are each considered to contain the other.) `ARRAY[1,4,3] @> ARRAY[3,1,3]` → `t`

`anyarray <@ anyarray` → `boolean`
Is the first array contained by the second?
`ARRAY[2,2,7] <@ ARRAY[1,7,4,2,6]` → `t`

`anyarray && anyarray` → `boolean`
Do the arrays overlap, that is, have any elements in common?
`ARRAY[1,4,3] && ARRAY[2,1]` → `t`

`anycompatiblearray || anycompatiblearray` → `anycompatiblearray`
Concatenates the two arrays. Concatenating a null or empty array is a no-op; otherwise the arrays must have the same number of dimensions (as illustrated by the first example) or differ in number of dimensions by one (as illustrated by the second). If the arrays are not of identical element types, they will be coerced to a common type (see Section 10.5).
`ARRAY[1,2,3] || ARRAY[4,5,6,7]` → `{1,2,3,4,5,6,7}`
`ARRAY[1,2,3] || ARRAY[[4,5,6],[7,8,9.9]]` → `{{1,2,3},{4,5,6},{7,8,9.9}}`

`anycompatible || anycompatiblearray` → `anycompatiblearray`
Concatenates an element onto the front of an array (which must be empty or one-dimensional).
`3 || ARRAY[4,5,6]` → `{3,4,5,6}`

`anycompatiblearray || anycompatible` → `anycompatiblearray`
Concatenates an element onto the end of an array (which must be empty or one-dimensional).
`ARRAY[4,5,6] || 7` → `{4,5,6,7}`

See Section 8.15 for more details about array operator behavior. See Section 11.2 for more details about which operators support indexed operations.

Table 9.52 shows the functions available for use with array types. See Section 8.15 for more information and examples of the use of these functions.

Table 9.52. Array Functions

Function Description Example(s)

`array_append ( anycompatiblearray, anycompatible )` → `anycompatiblearray`
Appends an element to the end of an array (same as the `anycompatiblearray || anycompatible` operator).
`array_append(ARRAY[1,2], 3)` → `{1,2,3}`

`array_cat ( anycompatiblearray, anycompatiblearray )` → `anycompatiblearray`
Concatenates two arrays (same as the `anycompatiblearray || anycompatiblearray` operator).
`array_cat(ARRAY[1,2,3], ARRAY[4,5])` → `{1,2,3,4,5}`

`array_dims ( anyarray )` → `text`
Returns a text representation of the array's dimensions.
`array_dims(ARRAY[[1,2,3], [4,5,6]])` → `[1:2][1:3]`

Function
Description
Example(s)

`array_fill ( anyelement, integer[] [, integer[] ] ) → anyarray`
Returns an array filled with copies of the given value, having dimensions of the lengths specified by the second argument. The optional third argument supplies lower-bound values for each dimension (which default to all `1`).
`array_fill(11, ARRAY[2,3])` → `{{11,11,11},{11,11,11}}`
`array_fill(7, ARRAY[3], ARRAY[2])` → `[2:4]={7,7,7}`

`array_length ( anyarray, integer ) → integer`
Returns the length of the requested array dimension. (Produces NULL instead of 0 for empty or missing array dimensions.)
`array_length(array[1,2,3], 1)` → `3`
`array_length(array[]::int[], 1)` → `NULL`
`array_length(array['text'], 2)` → `NULL`

`array_lower ( anyarray, integer ) → integer`
Returns the lower bound of the requested array dimension.
`array_lower('[0:2]={1,2,3}'::integer[], 1)` → `0`

`array_ndims ( anyarray ) → integer`
Returns the number of dimensions of the array.
`array_ndims(ARRAY[[1,2,3], [4,5,6]])` → `2`

`array_position ( anycompatiblearray, anycompatible [, integer ] ) → integer`
Returns the subscript of the first occurrence of the second argument in the array, or `NULL` if it's not present. If the third argument is given, the search begins at that subscript. The array must be one-dimensional. Comparisons are done using `IS NOT DISTINCT FROM` semantics, so it is possible to search for `NULL`.
`array_position(ARRAY['sun', 'mon', 'tue', 'wed', 'thu', 'fri', 'sat'], 'mon')` → `2`

`array_positions ( anycompatiblearray, anycompatible ) → integer[]`
Returns an array of the subscripts of all occurrences of the second argument in the array given as first argument. The array must be one-dimensional. Comparisons are done using `IS NOT DISTINCT FROM` semantics, so it is possible to search for `NULL`. `NULL` is returned only if the array is `NULL`; if the value is not found in the array, an empty array is returned.
`array_positions(ARRAY['A','A','B','A'], 'A')` → `{1,2,4}`

`array_prepend ( anycompatible, anycompatiblearray ) → anycompatiblearray`
Prepends an element to the beginning of an array (same as the `anycompatible || anycompatiblearray` operator).
`array_prepend(1, ARRAY[2,3])` → `{1,2,3}`

`array_remove ( anycompatiblearray, anycompatible ) → anycompatiblearray`
Removes all elements equal to the given value from the array. The array must be one-dimensional. Comparisons are done using `IS NOT DISTINCT FROM` semantics, so it is possible to remove `NULL`s.
`array_remove(ARRAY[1,2,3,2], 2)` → `{1,3}`

`array_replace ( anycompatiblearray, anycompatible, anycompatible ) → anycompatiblearray`
Replaces each array element equal to the second argument with the third argument.
`array_replace(ARRAY[1,2,5,4], 5, 3)` → `{1,2,3,4}`

`array_to_string ( array anyarray, delimiter text [, null_string text ] ) → text`

Function **Description** **Example(s)**
Converts each array element to its text representation, and concatenates those separated by the *delimiter* string. If *null_string* is given and is not NULL, then NULL array entries are represented by that string; otherwise, they are omitted. `array_to_string(ARRAY[1, 2, 3, NULL, 5], ',', '*')` → `1,2,3,*,5`

`array_upper ( anyarray, integer ) → integer`
Returns the upper bound of the requested array dimension.
`array_upper(ARRAY[1,8,3,7], 1)` → `4`

`cardinality ( anyarray ) → integer`
Returns the total number of elements in the array, or 0 if the array is empty.
`cardinality(ARRAY[[1,2],[3,4]])` → `4`

`trim_array ( array anyarray, n integer ) → anyarray`
Trims an array by removing the last *n* elements. If the array is multidimensional, only the first dimension is trimmed.
`trim_array(ARRAY[1,2,3,4,5,6], 2)` → `{1,2,3,4}`

`unnest ( anyarray ) → setof anyelement`
Expands an array into a set of rows. The array's elements are read out in storage order.
`unnest(ARRAY[1,2])` →
`1`
`2`
`unnest(ARRAY[['foo','bar'],['baz','quux']])` →
`foo`
`bar`
`baz`
`quux`

`unnest ( anyarray, anyarray [, ... ] ) → setof anyelement, anyelement [, ... ]`
Expands multiple arrays (possibly of different data types) into a set of rows. If the arrays are not all the same length then the shorter ones are padded with NULLs. This form is only allowed in a query's FROM clause; see Section 7.2.1.4.
`select * from unnest(ARRAY[1,2], ARRAY['foo','bar','baz']) as x(a,b)` →
`a | b`
`---+-----`
`1 | foo`
`2 | bar`
`  | baz`

> **Note**
>
> There are two differences in the behavior of `string_to_array` from pre-9.1 versions of PostgreSQL. First, it will return an empty (zero-element) array rather than NULL when the input string is of zero length. Second, if the delimiter string is NULL, the function splits the input into individual characters, rather than returning NULL as before.

See also Section 9.21 about the aggregate function `array_agg` for use with arrays.

9.20. Range/Multirange Functions and Operators

See Section 8.17 for an overview of range types.

Table 9.53 shows the specialized operators available for range types. Table 9.54 shows the specialized operators available for multirange types. In addition to those, the usual comparison operators shown in Table 9.1 are available for range and multirange types. The comparison operators order first by the range lower bounds, and only if those are equal do they compare the upper bounds. The multirange operators compare each range until one is unequal. This does not usually result in a useful overall ordering, but the operators are provided to allow unique indexes to be constructed on ranges.

Table 9.53. Range Operators

Operator **Description** **Example(s)**

`anyrange @> anyrange → boolean`
Does the first range contain the second?
`int4range(2,4) @> int4range(2,3)  → t`

`anyrange @> anyelement → boolean`
Does the range contain the element?
`'[2011-01-01,2011-03-01)'::tsrange @> '2011-01-10'::timestamp  → t`

`anyrange <@ anyrange → boolean`
Is the first range contained by the second?
`int4range(2,4) <@ int4range(1,7)  → t`

`anyelement <@ anyrange → boolean`
Is the element contained in the range?
`42 <@ int4range(1,7)  → f`

`anyrange && anyrange → boolean`
Do the ranges overlap, that is, have any elements in common?
`int8range(3,7) && int8range(4,12)  → t`

`anyrange << anyrange → boolean`
Is the first range strictly left of the second?
`int8range(1,10) << int8range(100,110)  → t`

`anyrange >> anyrange → boolean`
Is the first range strictly right of the second?
`int8range(50,60) >> int8range(20,30)  → t`

`anyrange &< anyrange → boolean`
Does the first range not extend to the right of the second?
`int8range(1,20) &< int8range(18,20)  → t`

`anyrange &> anyrange → boolean`
Does the first range not extend to the left of the second?
`int8range(7,20) &> int8range(5,10)  → t`

`anyrange -|- anyrange → boolean`
Are the ranges adjacent?
`numrange(1.1,2.2) -|- numrange(2.2,3.3)  → t`

`anyrange + anyrange → anyrange`
Computes the union of the ranges. The ranges must overlap or be adjacent, so that the union is a single range (but see `range_merge()`).
`numrange(5,15) + numrange(10,20)  → [5,20)`

`anyrange * anyrange → anyrange` Computes the intersection of the ranges.

Operator Description Example(s)
`int8range(5,15) * int8range(10,20)` → `[10,15)`

`anyrange - anyrange → anyrange`
Computes the difference of the ranges. The second range must not be contained in the first in such a way that the difference would not be a single range.
`int8range(5,15) - int8range(10,20)` → `[5,10)`

Table 9.54. Multirange Operators

Operator Description Example(s)

`anymultirange @> anymultirange → boolean`
Does the first multirange contain the second?
`'{[2,4)}'::int4multirange @> '{[2,3)}'::int4multirange` → `t`

`anymultirange @> anyrange → boolean`
Does the multirange contain the range?
`'{[2,4)}'::int4multirange @> int4range(2,3)` → `t`

`anymultirange @> anyelement → boolean`
Does the multirange contain the element?
`'{[2011-01-01,2011-03-01)}'::tsmultirange @> '2011-01-10'::timestamp` → `t`

`anyrange @> anymultirange → boolean`
Does the range contain the multirange?
`'[2,4)'::int4range @> '{[2,3)}'::int4multirange` → `t`

`anymultirange <@ anymultirange → boolean`
Is the first multirange contained by the second?
`'{[2,4)}'::int4multirange <@ '{[1,7)}'::int4multirange` → `t`

`anymultirange <@ anyrange → boolean`
Is the multirange contained by the range?
`'{[2,4)}'::int4multirange <@ int4range(1,7)` → `t`

`anyrange <@ anymultirange → boolean`
Is the range contained by the multirange?
`int4range(2,4) <@ '{[1,7)}'::int4multirange` → `t`

`anyelement <@ anymultirange → boolean`
Is the element contained by the multirange?
`4 <@ '{[1,7)}'::int4multirange` → `t`

`anymultirange && anymultirange → boolean`
Do the multiranges overlap, that is, have any elements in common?
`'{[3,7)}'::int8multirange && '{[4,12)}'::int8multirange` → `t`

`anymultirange && anyrange → boolean`
Does the multirange overlap the range?
`'{[3,7)}'::int8multirange && int8range(4,12)` → `t`

`anyrange && anymultirange → boolean`
Does the range overlap the multirange?
`int8range(3,7) && '{[4,12)}'::int8multirange` → `t`

Operator **Description** **Example(s)**

`anymultirange << anymultirange → boolean`
Is the first multirange strictly left of the second?
`'{[1,10)}'::int8multirange << '{[100,110)}'::int8multirange → t`

`anymultirange << anyrange → boolean`
Is the multirange strictly left of the range?
`'{[1,10)}'::int8multirange << int8range(100,110) → t`

`anyrange << anymultirange → boolean`
Is the range strictly left of the multirange?
`int8range(1,10) << '{[100,110)}'::int8multirange → t`

`anymultirange >> anymultirange → boolean`
Is the first multirange strictly right of the second?
`'{[50,60)}'::int8multirange >> '{[20,30)}'::int8multirange → t`

`anymultirange >> anyrange → boolean`
Is the multirange strictly right of the range?
`'{[50,60)}'::int8multirange >> int8range(20,30) → t`

`anyrange >> anymultirange → boolean`
Is the range strictly right of the multirange?
`int8range(50,60) >> '{[20,30)}'::int8multirange → t`

`anymultirange &< anymultirange → boolean`
Does the first multirange not extend to the right of the second?
`'{[1,20)}'::int8multirange &< '{[18,20)}'::int8multirange → t`

`anymultirange &< anyrange → boolean`
Does the multirange not extend to the right of the range?
`'{[1,20)}'::int8multirange &< int8range(18,20) → t`

`anyrange &< anymultirange → boolean`
Does the range not extend to the right of the multirange?
`int8range(1,20) &< '{[18,20)}'::int8multirange → t`

`anymultirange &> anymultirange → boolean`
Does the first multirange not extend to the left of the second?
`'{[7,20)}'::int8multirange &> '{[5,10)}'::int8multirange → t`

`anymultirange &> anyrange → boolean`
Does the multirange not extend to the left of the range?
`'{[7,20)}'::int8multirange &> int8range(5,10) → t`

`anyrange &> anymultirange → boolean`
Does the range not extend to the left of the multirange?
`int8range(7,20) &> '{[5,10)}'::int8multirange → t`

`anymultirange -|- anymultirange → boolean`
Are the multiranges adjacent?
`'{[1.1,2.2)}'::nummultirange -|- '{[2.2,3.3)}'::nummultirange → t`

`anymultirange -|- anyrange → boolean`
Is the multirange adjacent to the range?
`'{[1.1,2.2)}'::nummultirange -|- numrange(2.2,3.3) → t`

Operator Description Example(s)

`anyrange -|- anymultirange → boolean`
Is the range adjacent to the multirange?
`numrange(1.1,2.2) -|- '{[2.2,3.3)}'::nummultirange → t`

`anymultirange + anymultirange → anymultirange`
Computes the union of the multiranges. The multiranges need not overlap or be adjacent.
`'{[5,10)}'::nummultirange + '{[15,20)}'::nummultirange → {[5,10), [15,20)}`

`anymultirange * anymultirange → anymultirange`
Computes the intersection of the multiranges.
`'{[5,15)}'::int8multirange * '{[10,20)}'::int8multirange → {[10,15)}`

`anymultirange - anymultirange → anymultirange`
Computes the difference of the multiranges.
`'{[5,20)}'::int8multirange - '{[10,15)}'::int8multirange → {[5,10), [15, 20)}`

The left-of/right-of/adjacent operators always return false when an empty range or multirange is involved; that is, an empty range is not considered to be either before or after any other range.

Elsewhere empty ranges and multiranges are treated as the additive identity: anything unioned with an empty value is itself. Anything minus an empty value is itself. An empty multirange has exactly the same points as an empty range. Every range contains the empty range. Every multirange contains as many empty ranges as you like.

The range union and difference operators will fail if the resulting range would need to contain two disjoint sub-ranges, as such a range cannot be represented. There are separate operators for union and difference that take multirange parameters and return a multirange, and they do not fail even if their arguments are disjoint. So if you need a union or difference operation for ranges that may be disjoint, you can avoid errors by first casting your ranges to multiranges.

Table 9.55 shows the functions available for use with range types. Table 9.56 shows the functions available for use with multirange types.

Table 9.55. Range Functions

Function Description Example(s)

`lower ( anyrange ) → anyelement`
Extracts the lower bound of the range (`NULL` if the range is empty or the lower bound is infinite).
`lower(numrange(1.1,2.2)) → 1.1`

`upper ( anyrange ) → anyelement`
Extracts the upper bound of the range (`NULL` if the range is empty or the upper bound is infinite).
`upper(numrange(1.1,2.2)) → 2.2`

`isempty ( anyrange ) → boolean`
Is the range empty?
`isempty(numrange(1.1,2.2)) → f`

`lower_inc ( anyrange ) → boolean` Is the range's lower bound inclusive?

Function Description Example(s)
`lower_inc(numrange(1.1,2.2))` → `t`

`upper_inc ( anyrange ) → boolean`
Is the range's upper bound inclusive?
`upper_inc(numrange(1.1,2.2))` → `f`

`lower_inf ( anyrange ) → boolean`
Is the range's lower bound infinite?
`lower_inf('(,)'::daterange)` → `t`

`upper_inf ( anyrange ) → boolean`
Is the range's upper bound infinite?
`upper_inf('(,)'::daterange)` → `t`

`range_merge ( anyrange, anyrange ) → anyrange`
Computes the smallest range that includes both of the given ranges.
`range_merge('[1,2)'::int4range, '[3,4)'::int4range)` → `[1,4)`

Table 9.56. Multirange Functions

Function Description Example(s)

`lower ( anymultirange ) → anyelement`
Extracts the lower bound of the multirange (`NULL` if the multirange is empty or the lower bound is infinite).
`lower('{[1.1,2.2)}'::nummultirange)` → `1.1`

`upper ( anymultirange ) → anyelement`
Extracts the upper bound of the multirange (`NULL` if the multirange is empty or the upper bound is infinite).
`upper('{[1.1,2.2)}'::nummultirange)` → `2.2`

`isempty ( anymultirange ) → boolean`
Is the multirange empty?
`isempty('{[1.1,2.2)}'::nummultirange)` → `f`

`lower_inc ( anymultirange ) → boolean`
Is the multirange's lower bound inclusive?
`lower_inc('{[1.1,2.2)}'::nummultirange)` → `t`

`upper_inc ( anymultirange ) → boolean`
Is the multirange's upper bound inclusive?
`upper_inc('{[1.1,2.2)}'::nummultirange)` → `f`

`lower_inf ( anymultirange ) → boolean`
Is the multirange's lower bound infinite?
`lower_inf('{(,)}'::datemultirange)` → `t`

`upper_inf ( anymultirange ) → boolean`
Is the multirange's upper bound infinite?
`upper_inf('{(,)}'::datemultirange)` → `t`

`range_merge ( anymultirange ) → anyrange` Computes the smallest range that includes the entire multirange.

Function Description Example(s)
`range_merge('{[1,2), [3,4)}'::int4multirange)` → `[1,4)`

`multirange ( anyrange ) → anymultirange`
Returns a multirange containing just the given range.
`multirange('[1,2)'::int4range)` → `{[1,2)}`

`unnest ( anymultirange ) → setof anyrange`
Expands a multirange into a set of ranges. The ranges are read out in storage order (ascending).
`unnest('{[1,2), [3,4)}'::int4multirange)` →
`[1,2)`
`[3,4)`

The `lower_inc`, `upper_inc`, `lower_inf`, and `upper_inf` functions all return false for an empty range or multirange.

9.21. Aggregate Functions

Aggregate functions compute a single result from a set of input values. The built-in general-purpose aggregate functions are listed in Table 9.57 while statistical aggregates are in Table 9.58. The built-in within-group ordered-set aggregate functions are listed in Table 9.59 while the built-in within-group hypothetical-set ones are in Table 9.60. Grouping operations, which are closely related to aggregate functions, are listed in Table 9.61. The special syntax considerations for aggregate functions are explained in Section 4.2.7. Consult Section 2.7 for additional introductory information.

Aggregate functions that support *Partial Mode* are eligible to participate in various optimizations, such as parallel aggregation.

Table 9.57. General-Purpose Aggregate Functions

Function Description	Partial Mode
`array_agg ( anynonarray ) → anyarray` Collects all the input values, including nulls, into an array.	No
`array_agg ( anyarray ) → anyarray` Concatenates all the input arrays into an array of one higher dimension. (The inputs must all have the same dimensionality, and cannot be empty or null.)	No

`avg ( smallint ) → numeric`
`avg ( integer ) → numeric`
`avg ( bigint ) → numeric`
`avg ( numeric ) → numeric`
`avg ( real ) → double precision`
`avg ( double precision ) → double precision`
`avg ( interval ) → interval`
Computes the average (arithmetic mean) of all the non-null input values.
	Yes

`bit_and ( smallint ) → smallint`
`bit_and ( integer ) → integer`
`bit_and ( bigint ) → bigint`
`bit_and ( bit ) → bit`
Computes the bitwise AND of all non-null input values.
	Yes

Function **Description**	**Partial Mode**

`bit_or ( smallint ) → smallint`
`bit_or ( integer ) → integer`
`bit_or ( bigint ) → bigint`
`bit_or ( bit ) → bit`
Computes the bitwise OR of all non-null input values.
	Yes

`bit_xor ( smallint ) → smallint`
`bit_xor ( integer ) → integer`
`bit_xor ( bigint ) → bigint`
`bit_xor ( bit ) → bit`
Computes the bitwise exclusive OR of all non-null input values. Can be useful as a checksum for an unordered set of values.
	Yes

`bool_and ( boolean ) → boolean` Returns true if all non-null input values are true, otherwise false.	Yes
`bool_or ( boolean ) → boolean` Returns true if any non-null input value is true, otherwise false.	Yes
`count ( * ) → bigint` Computes the number of input rows.	Yes
`count ( "any" ) → bigint` Computes the number of input rows in which the input value is not null.	Yes
`every ( boolean ) → boolean` This is the SQL standard's equivalent to `bool_and`.	Yes

`json_agg ( anyelement ) → json`
`jsonb_agg ( anyelement ) → jsonb`
Collects all the input values, including nulls, into a JSON array. Values are converted to JSON as per `to_json` or `to_jsonb`.
	No

`json_object_agg ( key "any", value "any" ) → json`
`jsonb_object_agg ( key "any", value "any" ) → jsonb`
Collects all the key/value pairs into a JSON object. Key arguments are coerced to text; value arguments are converted as per `to_json` or `to_jsonb`. Values can be null, but not keys.
	No

`max ( see text ) → same as input type` Computes the maximum of the non-null input values. Available for any numeric, string, date/time, or enum type, as well as `inet`, `interval`, `money`, `oid`, `pg_lsn`, `tid`, and arrays of any of these types.	Yes
`min ( see text ) → same as input type` Computes the minimum of the non-null input values. Available for any numeric, string, date/time, or enum type, as well as `inet`, `interval`, `money`, `oid`, `pg_lsn`, `tid`, and arrays of any of these types.	Yes
`range_agg ( value anyrange ) → anymultirange` Computes the union of the non-null input values.	No

`range_intersect_agg ( value anyrange ) → anyrange`
`range_intersect_agg ( value anymultirange ) → anymultirange`
Computes the intersection of the non-null input values.
	No

`string_agg ( value text, delimiter text ) → text`	No

Function Description	Partial Mode
`string_agg` (*value* bytea, *delimiter* bytea) → bytea Concatenates the non-null input values into a string. Each value after the first is preceded by the corresponding *delimiter* (if it's not null).	

`sum` (`smallint`) → `bigint`
`sum` (`integer`) → `bigint`
`sum` (`bigint`) → `numeric`
`sum` (`numeric`) → `numeric`
`sum` (`real`) → `real`
`sum` (`double precision`) → `double precision`
`sum` (`interval`) → `interval`
`sum` (`money`) → `money`
Computes the sum of the non-null input values.
	Yes

`xmlagg` (`xml`) → `xml` Concatenates the non-null XML input values (see Section 9.15.1.7).	No

It should be noted that except for `count`, these functions return a null value when no rows are selected. In particular, `sum` of no rows returns null, not zero as one might expect, and `array_agg` returns null rather than an empty array when there are no input rows. The `coalesce` function can be used to substitute zero or an empty array for null when necessary.

The aggregate functions `array_agg`, `json_agg`, `jsonb_agg`, `json_object_agg`, `jsonb_object_agg`, `string_agg`, and `xmlagg`, as well as similar user-defined aggregate functions, produce meaningfully different result values depending on the order of the input values. This ordering is unspecified by default, but can be controlled by writing an `ORDER BY` clause within the aggregate call, as shown in Section 4.2.7. Alternatively, supplying the input values from a sorted subquery will usually work. For example:

```
SELECT xmlagg(x) FROM (SELECT x FROM test ORDER BY y DESC) AS tab;
```

Beware that this approach can fail if the outer query level contains additional processing, such as a join, because that might cause the subquery's output to be reordered before the aggregate is computed.

Note

The boolean aggregates `bool_and` and `bool_or` correspond to the standard SQL aggregates `every` and `any` or `some`. Postgres Pro supports `every`, but not `any` or `some`, because there is an ambiguity built into the standard syntax:

```
SELECT b1 = ANY((SELECT b2 FROM t2 ...)) FROM t1 ...;
```

Here `ANY` can be considered either as introducing a subquery, or as being an aggregate function, if the subquery returns one row with a Boolean value. Thus the standard name cannot be given to these aggregates.

Note

Users accustomed to working with other SQL database management systems might be disappointed by the performance of the `count` aggregate when it is applied to the entire table. A query like:

```
SELECT count(*) FROM sometable;
```

will require effort proportional to the size of the table: Postgres Pro will need to scan either the entire table or the entirety of an index that includes all rows in the table.

Table 9.58 shows aggregate functions typically used in statistical analysis. (These are separated out merely to avoid cluttering the listing of more-commonly-used aggregates.) Functions shown as accepting *numeric_type* are available for all the types `smallint`, `integer`, `bigint`, `numeric`, `real`, and `double precision`. Where the description mentions *N*, it means the number of input rows for which all the input expressions are non-null. In all cases, null is returned if the computation is meaningless, for example when *N* is zero.

Table 9.58. Aggregate Functions for Statistics

Function Description	Partial Mode
`corr ( Y double precision, X double precision ) → double precision` Computes the correlation coefficient.	Yes
`covar_pop ( Y double precision, X double precision ) → double precision` Computes the population covariance.	Yes
`covar_samp ( Y double precision, X double precision ) → double precision` Computes the sample covariance.	Yes
`regr_avgx ( Y double precision, X double precision ) → double precision` Computes the average of the independent variable, `sum( X)/N`.	Yes
`regr_avgy ( Y double precision, X double precision ) → double precision` Computes the average of the dependent variable, `sum( Y)/N`.	Yes
`regr_count ( Y double precision, X double precision ) → bigint` Computes the number of rows in which both inputs are non-null.	Yes
`regr_intercept ( Y double precision, X double precision ) → double precision` Computes the y-intercept of the least-squares-fit linear equation determined by the (*X*, *Y*) pairs.	Yes
`regr_r2 ( Y double precision, X double precision ) → double precision` Computes the square of the correlation coefficient.	Yes
`regr_slope ( Y double precision, X double precision ) → double precision` Computes the slope of the least-squares-fit linear equation determined by the (*X*, *Y*) pairs.	Yes
`regr_sxx ( Y double precision, X double precision ) → double precision` Computes the “sum of squares” of the independent variable, `sum( X^2) - sum( X)^2/N`.	Yes
`regr_sxy ( Y double precision, X double precision ) → double precision` Computes the “sum of products” of independent times dependent variables, `sum( X*Y) - sum( X) * sum( Y)/N`.	Yes
`regr_syy ( Y double precision, X double precision ) → double precision` Computes the “sum of squares” of the dependent variable, `sum( Y^2) - sum( Y)^2/N`.	Yes
`stddev ( numeric_type ) → double precision` for `real` or `double precision`, otherwise `numeric` This is a historical alias for `stddev_samp` .	Yes
`stddev_pop ( numeric_type ) → double precision` for `real` or `double precision`, otherwise `numeric` Computes the population standard deviation of the input values.	Yes
`stddev_samp ( numeric_type ) → double precision` for `real` or `double precision`, otherwise `numeric`	Yes

Function Description	Partial Mode
Computes the sample standard deviation of the input values.	
`variance` (*`numeric_type`*) → `double precision` for `real` or `double precision`, otherwise `numeric` This is a historical alias for `var_samp` .	Yes
`var_pop` (*`numeric_type`*) → `double precision` for `real` or `double precision`, otherwise `numeric` Computes the population variance of the input values (square of the population standard deviation).	Yes
`var_samp` (*`numeric_type`*) → `double precision` for `real` or `double precision`, otherwise `numeric` Computes the sample variance of the input values (square of the sample standard deviation).	Yes

Table 9.59 shows some aggregate functions that use the *ordered-set aggregate* syntax. These functions are sometimes referred to as "inverse distribution" functions. Their aggregated input is introduced by `ORDER BY`, and they may also take a *direct argument* that is not aggregated, but is computed only once. All these functions ignore null values in their aggregated input. For those that take a *`fraction`* parameter, the fraction value must be between 0 and 1; an error is thrown if not. However, a null *`fraction`* value simply produces a null result.

Table 9.59. Ordered-Set Aggregate Functions

Function Description	Partial Mode
`mode` () `WITHIN GROUP` (`ORDER BY anyelement`) → `anyelement` Computes the *mode*, the most frequent value of the aggregated argument (arbitrarily choosing the first one if there are multiple equally-frequent values). The aggregated argument must be of a sortable type.	No

`percentile_cont` (*`fraction`* `double precision`) `WITHIN GROUP` (`ORDER BY double precision`) → `double precision`
`percentile_cont` (*`fraction`* `double precision`) `WITHIN GROUP` (`ORDER BY interval`) → `interval`
Computes the *continuous percentile*, a value corresponding to the specified *`fraction`* within the ordered set of aggregated argument values. This will interpolate between adjacent input items if needed.
	No

`percentile_cont` (*`fractions`* `double precision[]`) `WITHIN GROUP` (`ORDER BY double precision`) → `double precision[]`
`percentile_cont` (*`fractions`* `double precision[]`) `WITHIN GROUP` (`ORDER BY interval`) → `interval[]`
Computes multiple continuous percentiles. The result is an array of the same dimensions as the *`fractions`* parameter, with each non-null element replaced by the (possibly interpolated) value corresponding to that percentile.
	No

`percentile_disc` (*`fraction`* `double precision`) `WITHIN GROUP` (`ORDER BY anyelement`) → `anyelement` Computes the *discrete percentile*, the first value within the ordered set of aggregated argument values whose position in the ordering equals or exceeds the specified *`fraction`*. The aggregated argument must be of a sortable type.	No
`percentile_disc` (*`fractions`* `double precision[]`) `WITHIN GROUP` (`ORDER BY anyelement`) → `anyarray`	No

Function Description	Partial Mode
Computes multiple discrete percentiles. The result is an array of the same dimensions as the *fractions* parameter, with each non-null element replaced by the input value corresponding to that percentile. The aggregated argument must be of a sortable type.	

Each of the "hypothetical-set" aggregates listed in Table 9.60 is associated with a window function of the same name defined in Section 9.22. In each case, the aggregate's result is the value that the associated window function would have returned for the "hypothetical" row constructed from *args*, if such a row had been added to the sorted group of rows represented by the *sorted_args*. For each of these functions, the list of direct arguments given in *args* must match the number and types of the aggregated arguments given in *sorted_args*. Unlike most built-in aggregates, these aggregates are not strict, that is they do not drop input rows containing nulls. Null values sort according to the rule specified in the ORDER BY clause.

Table 9.60. Hypothetical-Set Aggregate Functions

Function Description	Partial Mode
rank (*args*) WITHIN GROUP (ORDER BY *sorted_args*) → bigint Computes the rank of the hypothetical row, with gaps; that is, the row number of the first row in its peer group.	No
dense_rank (*args*) WITHIN GROUP (ORDER BY *sorted_args*) → bigint Computes the rank of the hypothetical row, without gaps; this function effectively counts peer groups.	No
percent_rank (*args*) WITHIN GROUP (ORDER BY *sorted_args*) → double precision Computes the relative rank of the hypothetical row, that is (rank - 1) / (total rows - 1). The value thus ranges from 0 to 1 inclusive.	No
cume_dist (*args*) WITHIN GROUP (ORDER BY *sorted_args*) → double precision Computes the cumulative distribution, that is (number of rows preceding or peers with hypothetical row) / (total rows). The value thus ranges from 1/*N* to 1.	No

Table 9.61. Grouping Operations

Function Description
GROUPING (*group_by_expression(s)*) → integer Returns a bit mask indicating which GROUP BY expressions are not included in the current grouping set. Bits are assigned with the rightmost argument corresponding to the least-significant bit; each bit is 0 if the corresponding expression is included in the grouping criteria of the grouping set generating the current result row, and 1 if it is not included.

The grouping operations shown in Table 9.61 are used in conjunction with grouping sets (see Section 7.2.4) to distinguish result rows. The arguments to the GROUPING function are not actually evaluated, but they must exactly match expressions given in the GROUP BY clause of the associated query level. For example:

```
=> SELECT * FROM items_sold;
 make  | model | sales
-------+-------+-------
 Foo   | GT    |  10
 Foo   | Tour  |  20
 Bar   | City  |  15
 Bar   | Sport |  5
(4 rows)
```

```
=> SELECT make, model, GROUPING(make,model), sum(sales) FROM items_sold GROUP BY
 ROLLUP(make,model);
 make  | model | grouping | sum
-------+-------+----------+-----
 Foo   | GT    |        0 | 10
 Foo   | Tour  |        0 | 20
 Bar   | City  |        0 | 15
 Bar   | Sport |        0 | 5
 Foo   |       |        1 | 30
 Bar   |       |        1 | 20
       |       |        3 | 50
(7 rows)
```

Here, the `grouping` value `0` in the first four rows shows that those have been grouped normally, over both the grouping columns. The value `1` indicates that `model` was not grouped by in the next-to-last two rows, and the value `3` indicates that neither `make` nor `model` was grouped by in the last row (which therefore is an aggregate over all the input rows).

9.22. Window Functions

Window functions provide the ability to perform calculations across sets of rows that are related to the current query row. See Section 3.5 for an introduction to this feature, and Section 4.2.8 for syntax details.

The built-in window functions are listed in Table 9.62. Note that these functions *must* be invoked using window function syntax, i.e., an `OVER` clause is required.

In addition to these functions, any built-in or user-defined ordinary aggregate (i.e., not ordered-set or hypothetical-set aggregates) can be used as a window function; see Section 9.21 for a list of the built-in aggregates. Aggregate functions act as window functions only when an `OVER` clause follows the call; otherwise they act as plain aggregates and return a single row for the entire set.

Table 9.62. General-Purpose Window Functions

Function **Description**
`row_number` () → `bigint` Returns the number of the current row within its partition, counting from 1.
`rank` () → `bigint` Returns the rank of the current row, with gaps; that is, the `row_number` of the first row in its peer group.
`dense_rank` () → `bigint` Returns the rank of the current row, without gaps; this function effectively counts peer groups.
`percent_rank` () → `double precision` Returns the relative rank of the current row, that is (`rank` - 1) / (total partition rows - 1). The value thus ranges from 0 to 1 inclusive.
`cume_dist` () → `double precision` Returns the cumulative distribution, that is (number of partition rows preceding or peers with current row) / (total partition rows). The value thus ranges from 1/*N* to 1.
`ntile` (*num_buckets* `integer`) → `integer` Returns an integer ranging from 1 to the argument value, dividing the partition as equally as possible.
`lag` (*value* `anycompatible` [, *offset* `integer` [, *default* `anycompatible`]]) → `anycompatible` Returns *value* evaluated at the row that is *offset* rows before the current row within the partition; if there is no such row, instead returns *default* (which must be of a type compat-

Function Description
ible with *value*). Both *offset* and *default* are evaluated with respect to the current row. If omitted, *offset* defaults to 1 and *default* to NULL.
lead (*value* anycompatible [, *offset* integer [, *default* anycompatible]]) → anycompatible Returns *value* evaluated at the row that is *offset* rows after the current row within the partition; if there is no such row, instead returns *default* (which must be of a type compatible with *value*). Both *offset* and *default* are evaluated with respect to the current row. If omitted, *offset* defaults to 1 and *default* to NULL.
first_value (*value* anyelement) → anyelement Returns *value* evaluated at the row that is the first row of the window frame.
last_value (*value* anyelement) → anyelement Returns *value* evaluated at the row that is the last row of the window frame.
nth_value (*value* anyelement, *n* integer) → anyelement Returns *value* evaluated at the row that is the *n*'th row of the window frame (counting from 1); returns NULL if there is no such row.

All of the functions listed in Table 9.62 depend on the sort ordering specified by the ORDER BY clause of the associated window definition. Rows that are not distinct when considering only the ORDER BY columns are said to be *peers*. The four ranking functions (including cume_dist) are defined so that they give the same answer for all rows of a peer group.

Note that first_value, last_value, and nth_value consider only the rows within the "window frame", which by default contains the rows from the start of the partition through the last peer of the current row. This is likely to give unhelpful results for last_value and sometimes also nth_value. You can redefine the frame by adding a suitable frame specification (RANGE, ROWS or GROUPS) to the OVER clause. See Section 4.2.8 for more information about frame specifications.

When an aggregate function is used as a window function, it aggregates over the rows within the current row's window frame. An aggregate used with ORDER BY and the default window frame definition produces a "running sum" type of behavior, which may or may not be what's wanted. To obtain aggregation over the whole partition, omit ORDER BY or use ROWS BETWEEN UNBOUNDED PRECEDING AND UNBOUNDED FOLLOWING. Other frame specifications can be used to obtain other effects.

> **Note**
>
> The SQL standard defines a RESPECT NULLS or IGNORE NULLS option for lead, lag, first_value, last_value, and nth_value. This is not implemented in Postgres Pro: the behavior is always the same as the standard's default, namely RESPECT NULLS. Likewise, the standard's FROM FIRST or FROM LAST option for nth_value is not implemented: only the default FROM FIRST behavior is supported. (You can achieve the result of FROM LAST by reversing the ORDER BY ordering.)

9.23. Subquery Expressions

This section describes the SQL-compliant subquery expressions available in Postgres Pro. All of the expression forms documented in this section return Boolean (true/false) results.

9.23.1. EXISTS

```
EXISTS (subquery)
```

The argument of EXISTS is an arbitrary SELECT statement, or *subquery*. The subquery is evaluated to determine whether it returns any rows. If it returns at least one row, the result of EXISTS is "true"; if the subquery returns no rows, the result of EXISTS is "false".

The subquery can refer to variables from the surrounding query, which will act as constants during any one evaluation of the subquery.

The subquery will generally only be executed long enough to determine whether at least one row is returned, not all the way to completion. It is unwise to write a subquery that has side effects (such as calling sequence functions); whether the side effects occur might be unpredictable.

Since the result depends only on whether any rows are returned, and not on the contents of those rows, the output list of the subquery is normally unimportant. A common coding convention is to write all EXISTS tests in the form EXISTS(SELECT 1 WHERE ...). There are exceptions to this rule however, such as subqueries that use INTERSECT.

This simple example is like an inner join on col2, but it produces at most one output row for each tab1 row, even if there are several matching tab2 rows:

```
SELECT col1
FROM tab1
WHERE EXISTS (SELECT 1 FROM tab2 WHERE col2 = tab1.col2);
```

9.23.2. IN

expression IN (*subquery*)

The right-hand side is a parenthesized subquery, which must return exactly one column. The left-hand expression is evaluated and compared to each row of the subquery result. The result of IN is “true” if any equal subquery row is found. The result is “false” if no equal row is found (including the case where the subquery returns no rows).

Note that if the left-hand expression yields null, or if there are no equal right-hand values and at least one right-hand row yields null, the result of the IN construct will be null, not false. This is in accordance with SQL's normal rules for Boolean combinations of null values.

As with EXISTS, it's unwise to assume that the subquery will be evaluated completely.

row_constructor IN (*subquery*)

The left-hand side of this form of IN is a row constructor, as described in Section 4.2.13. The right-hand side is a parenthesized subquery, which must return exactly as many columns as there are expressions in the left-hand row. The left-hand expressions are evaluated and compared row-wise to each row of the subquery result. The result of IN is “true” if any equal subquery row is found. The result is “false” if no equal row is found (including the case where the subquery returns no rows).

As usual, null values in the rows are combined per the normal rules of SQL Boolean expressions. Two rows are considered equal if all their corresponding members are non-null and equal; the rows are unequal if any corresponding members are non-null and unequal; otherwise the result of that row comparison is unknown (null). If all the per-row results are either unequal or null, with at least one null, then the result of IN is null.

9.23.3. NOT IN

expression NOT IN (*subquery*)

The right-hand side is a parenthesized subquery, which must return exactly one column. The left-hand expression is evaluated and compared to each row of the subquery result. The result of NOT IN is “true” if only unequal subquery rows are found (including the case where the subquery returns no rows). The result is “false” if any equal row is found.

Note that if the left-hand expression yields null, or if there are no equal right-hand values and at least one right-hand row yields null, the result of the NOT IN construct will be null, not true. This is in accordance with SQL's normal rules for Boolean combinations of null values.

As with EXISTS, it's unwise to assume that the subquery will be evaluated completely.

row_constructor NOT IN (*subquery*)

The left-hand side of this form of NOT IN is a row constructor, as described in Section 4.2.13. The right-hand side is a parenthesized subquery, which must return exactly as many columns as there are expressions in the left-hand row. The left-hand expressions are evaluated and compared row-wise to each row of the subquery result. The result of NOT IN is "true" if only unequal subquery rows are found (including the case where the subquery returns no rows). The result is "false" if any equal row is found.

As usual, null values in the rows are combined per the normal rules of SQL Boolean expressions. Two rows are considered equal if all their corresponding members are non-null and equal; the rows are unequal if any corresponding members are non-null and unequal; otherwise the result of that row comparison is unknown (null). If all the per-row results are either unequal or null, with at least one null, then the result of NOT IN is null.

9.23.4. ANY/SOME

expression operator ANY (*subquery*)
expression operator SOME (*subquery*)

The right-hand side is a parenthesized subquery, which must return exactly one column. The left-hand expression is evaluated and compared to each row of the subquery result using the given *operator*, which must yield a Boolean result. The result of ANY is "true" if any true result is obtained. The result is "false" if no true result is found (including the case where the subquery returns no rows).

SOME is a synonym for ANY. IN is equivalent to = ANY.

Note that if there are no successes and at least one right-hand row yields null for the operator's result, the result of the ANY construct will be null, not false. This is in accordance with SQL's normal rules for Boolean combinations of null values.

As with EXISTS, it's unwise to assume that the subquery will be evaluated completely.

row_constructor operator ANY (*subquery*)
row_constructor operator SOME (*subquery*)

The left-hand side of this form of ANY is a row constructor, as described in Section 4.2.13. The right-hand side is a parenthesized subquery, which must return exactly as many columns as there are expressions in the left-hand row. The left-hand expressions are evaluated and compared row-wise to each row of the subquery result, using the given *operator*. The result of ANY is "true" if the comparison returns true for any subquery row. The result is "false" if the comparison returns false for every subquery row (including the case where the subquery returns no rows). The result is NULL if no comparison with a subquery row returns true, and at least one comparison returns NULL.

See Section 9.24.5 for details about the meaning of a row constructor comparison.

9.23.5. ALL

expression operator ALL (*subquery*)

The right-hand side is a parenthesized subquery, which must return exactly one column. The left-hand expression is evaluated and compared to each row of the subquery result using the given *operator*, which must yield a Boolean result. The result of ALL is "true" if all rows yield true (including the case where the subquery returns no rows). The result is "false" if any false result is found. The result is NULL if no comparison with a subquery row returns false, and at least one comparison returns NULL.

NOT IN is equivalent to <> ALL.

As with EXISTS, it's unwise to assume that the subquery will be evaluated completely.

row_constructor operator ALL (*subquery*)

The left-hand side of this form of ALL is a row constructor, as described in Section 4.2.13. The right-hand side is a parenthesized subquery, which must return exactly as many columns as there are expressions in the left-hand row. The left-hand expressions are evaluated and compared row-wise to each row of the subquery result, using the given *operator*. The result of ALL is "true" if the comparison returns true for all subquery rows (including the case where the subquery returns no rows). The result is "false" if the

comparison returns false for any subquery row. The result is NULL if no comparison with a subquery row returns false, and at least one comparison returns NULL.

See Section 9.24.5 for details about the meaning of a row constructor comparison.

9.23.6. Single-Row Comparison

row_constructor operator (*subquery*)

The left-hand side is a row constructor, as described in Section 4.2.13. The right-hand side is a parenthesized subquery, which must return exactly as many columns as there are expressions in the left-hand row. Furthermore, the subquery cannot return more than one row. (If it returns zero rows, the result is taken to be null.) The left-hand side is evaluated and compared row-wise to the single subquery result row.

See Section 9.24.5 for details about the meaning of a row constructor comparison.

9.24. Row and Array Comparisons

This section describes several specialized constructs for making multiple comparisons between groups of values. These forms are syntactically related to the subquery forms of the previous section, but do not involve subqueries. The forms involving array subexpressions are Postgres Pro extensions; the rest are SQL-compliant. All of the expression forms documented in this section return Boolean (true/false) results.

9.24.1. IN

expression IN (*value* [, ...])

The right-hand side is a parenthesized list of expressions. The result is “true” if the left-hand expression's result is equal to any of the right-hand expressions. This is a shorthand notation for

```
expression = value1
OR
expression = value2
OR
...
```

Note that if the left-hand expression yields null, or if there are no equal right-hand values and at least one right-hand expression yields null, the result of the IN construct will be null, not false. This is in accordance with SQL's normal rules for Boolean combinations of null values.

9.24.2. NOT IN

expression NOT IN (*value* [, ...])

The right-hand side is a parenthesized list of expressions. The result is “true” if the left-hand expression's result is unequal to all of the right-hand expressions. This is a shorthand notation for

```
expression <> value1
AND
expression <> value2
AND
...
```

Note that if the left-hand expression yields null, or if there are no equal right-hand values and at least one right-hand expression yields null, the result of the NOT IN construct will be null, not true as one might naively expect. This is in accordance with SQL's normal rules for Boolean combinations of null values.

> **Tip**
>
> x NOT IN y is equivalent to NOT (x IN y) in all cases. However, null values are much more likely to trip up the novice when working with NOT IN than when working with IN. It is best to express your condition positively if possible.

9.24.3. ANY/SOME (array)

expression operator ANY (*array expression*)
expression operator SOME (*array expression*)

The right-hand side is a parenthesized expression, which must yield an array value. The left-hand expression is evaluated and compared to each element of the array using the given *operator*, which must yield a Boolean result. The result of ANY is "true" if any true result is obtained. The result is "false" if no true result is found (including the case where the array has zero elements).

If the array expression yields a null array, the result of ANY will be null. If the left-hand expression yields null, the result of ANY is ordinarily null (though a non-strict comparison operator could possibly yield a different result). Also, if the right-hand array contains any null elements and no true comparison result is obtained, the result of ANY will be null, not false (again, assuming a strict comparison operator). This is in accordance with SQL's normal rules for Boolean combinations of null values.

SOME is a synonym for ANY.

9.24.4. ALL (array)

expression operator ALL (*array expression*)

The right-hand side is a parenthesized expression, which must yield an array value. The left-hand expression is evaluated and compared to each element of the array using the given *operator*, which must yield a Boolean result. The result of ALL is "true" if all comparisons yield true (including the case where the array has zero elements). The result is "false" if any false result is found.

If the array expression yields a null array, the result of ALL will be null. If the left-hand expression yields null, the result of ALL is ordinarily null (though a non-strict comparison operator could possibly yield a different result). Also, if the right-hand array contains any null elements and no false comparison result is obtained, the result of ALL will be null, not true (again, assuming a strict comparison operator). This is in accordance with SQL's normal rules for Boolean combinations of null values.

9.24.5. Row Constructor Comparison

row_constructor operator row_constructor

Each side is a row constructor, as described in Section 4.2.13. The two row constructors must have the same number of fields. The given *operator* is applied to each pair of corresponding fields. (Since the fields could be of different types, this means that a different specific operator could be selected for each pair.) All the selected operators must be members of some B-tree operator class, or be the negator of an = member of a B-tree operator class, meaning that row constructor comparison is only possible when the *operator* is =, <>, <, <=, >, or >=, or has semantics similar to one of these.

The = and <> cases work slightly differently from the others. Two rows are considered equal if all their corresponding members are non-null and equal; the rows are unequal if any corresponding members are non-null and unequal; otherwise the result of the row comparison is unknown (null).

For the <, <=, > and >= cases, the row elements are compared left-to-right, stopping as soon as an unequal or null pair of elements is found. If either of this pair of elements is null, the result of the row comparison is unknown (null); otherwise comparison of this pair of elements determines the result. For example, ROW(1,2,NULL) < ROW(1,3,0) yields true, not null, because the third pair of elements are not considered.

> **Note**
>
> Prior to PostgreSQL 8.2, the <, <=, > and >= cases were not handled per SQL specification. A comparison like ROW(a,b) < ROW(c,d) was implemented as a < c AND b < d whereas the correct behavior is equivalent to a < c OR (a = c AND b < d).

row_constructor IS DISTINCT FROM *row_constructor*

This construct is similar to a <> row comparison, but it does not yield null for null inputs. Instead, any null value is considered unequal to (distinct from) any non-null value, and any two nulls are considered equal (not distinct). Thus the result will either be true or false, never null.

row_constructor IS NOT DISTINCT FROM *row_constructor*

This construct is similar to a = row comparison, but it does not yield null for null inputs. Instead, any null value is considered unequal to (distinct from) any non-null value, and any two nulls are considered equal (not distinct). Thus the result will always be either true or false, never null.

9.24.6. Composite Type Comparison

record operator record

The SQL specification requires row-wise comparison to return NULL if the result depends on comparing two NULL values or a NULL and a non-NULL. Postgres Pro does this only when comparing the results of two row constructors (as in Section 9.24.5) or comparing a row constructor to the output of a subquery (as in Section 9.23). In other contexts where two composite-type values are compared, two NULL field values are considered equal, and a NULL is considered larger than a non-NULL. This is necessary in order to have consistent sorting and indexing behavior for composite types.

Each side is evaluated and they are compared row-wise. Composite type comparisons are allowed when the *operator* is =, <>, <, <=, > or >=, or has semantics similar to one of these. (To be specific, an operator can be a row comparison operator if it is a member of a B-tree operator class, or is the negator of the = member of a B-tree operator class.) The default behavior of the above operators is the same as for IS [NOT] DISTINCT FROM for row constructors (see Section 9.24.5).

To support matching of rows which include elements without a default B-tree operator class, the following operators are defined for composite type comparison: *=, *<>, *<, *<=, *>, and *>=. These operators compare the internal binary representation of the two rows. Two rows might have a different binary representation even though comparisons of the two rows with the equality operator is true. The ordering of rows under these comparison operators is deterministic but not otherwise meaningful. These operators are used internally for materialized views and might be useful for other specialized purposes such as replication and B-Tree deduplication (see Section 64.4.3). They are not intended to be generally useful for writing queries, though.

9.25. Set Returning Functions

This section describes functions that possibly return more than one row. The most widely used functions in this class are series generating functions, as detailed in Table 9.63 and Table 9.64. Other, more specialized set-returning functions are described elsewhere in this manual. See Section 7.2.1.4 for ways to combine multiple set-returning functions.

Table 9.63. Series Generating Functions

Function Description
generate_series (*start* integer, *stop* integer [, *step* integer]) → setof integer generate_series (*start* bigint, *stop* bigint [, *step* bigint]) → setof bigint generate_series (*start* numeric, *stop* numeric [, *step* numeric]) → setof numeric Generates a series of values from *start* to *stop*, with a step size of *step*. *step* defaults to 1.
generate_series (*start* timestamp, *stop* timestamp, *step* interval) → setof timestamp generate_series (*start* timestamp with time zone, *stop* timestamp with time zone, *step* interval) → setof timestamp with time zone Generates a series of values from *start* to *stop*, with a step size of *step*.

When *step* is positive, zero rows are returned if *start* is greater than *stop*. Conversely, when *step* is negative, zero rows are returned if *start* is less than *stop*. Zero rows are also returned if any input is NULL. It is an error for *step* to be zero. Some examples follow:

```
SELECT * FROM generate_series(2,4);
 generate_series
-----------------
               2
               3
               4
(3 rows)

SELECT * FROM generate_series(5,1,-2);
 generate_series
-----------------
               5
               3
               1
(3 rows)

SELECT * FROM generate_series(4,3);
 generate_series
-----------------
(0 rows)

SELECT generate_series(1.1, 4, 1.3);
 generate_series
-----------------
             1.1
             2.4
             3.7
(3 rows)

-- this example relies on the date-plus-integer operator:
SELECT current_date + s.a AS dates FROM generate_series(0,14,7) AS s(a);
   dates
------------
 2004-02-05
 2004-02-12
 2004-02-19
(3 rows)

SELECT * FROM generate_series('2008-03-01 00:00'::timestamp,
                              '2008-03-04 12:00', '10 hours');
   generate_series
---------------------
 2008-03-01 00:00:00
 2008-03-01 10:00:00
 2008-03-01 20:00:00
 2008-03-02 06:00:00
 2008-03-02 16:00:00
 2008-03-03 02:00:00
 2008-03-03 12:00:00
 2008-03-03 22:00:00
 2008-03-04 08:00:00
(9 rows)
```

Table 9.64. Subscript Generating Functions

Function Description
generate_subscripts (*array* anyarray, *dim* integer) → setof integer

Function Description
Generates a series comprising the valid subscripts of the *dim*'th dimension of the given array.
`generate_subscripts ( array anyarray, dim integer, reverse boolean ) → setof integer` Generates a series comprising the valid subscripts of the *dim*'th dimension of the given array. When *reverse* is true, returns the series in reverse order.

`generate_subscripts` is a convenience function that generates the set of valid subscripts for the specified dimension of the given array. Zero rows are returned for arrays that do not have the requested dimension, or if any input is `NULL`. Some examples follow:

```
-- basic usage:
SELECT generate_subscripts('{NULL,1,NULL,2}'::int[], 1) AS s;
 s
---
 1
 2
 3
 4
(4 rows)

-- presenting an array, the subscript and the subscripted
-- value requires a subquery:
SELECT * FROM arrays;
         a
--------------------
 {-1,-2}
 {100,200,300}
(2 rows)

SELECT a AS array, s AS subscript, a[s] AS value
FROM (SELECT generate_subscripts(a, 1) AS s, a FROM arrays) foo;
     array     | subscript | value
---------------+-----------+-------
 {-1,-2}       |         1 |    -1
 {-1,-2}       |         2 |    -2
 {100,200,300} |         1 |   100
 {100,200,300} |         2 |   200
 {100,200,300} |         3 |   300
(5 rows)

-- unnest a 2D array:
CREATE OR REPLACE FUNCTION unnest2(anyarray)
RETURNS SETOF anyelement AS $$
select $1[i][j]
   from generate_subscripts($1,1) g1(i),
        generate_subscripts($1,2) g2(j);
$$ LANGUAGE sql IMMUTABLE;
CREATE FUNCTION
SELECT * FROM unnest2(ARRAY[[1,2],[3,4]]);
 unnest2
---------
       1
       2
       3
       4
(4 rows)
```

When a function in the `FROM` clause is suffixed by `WITH ORDINALITY`, a `bigint` column is appended to the function's output column(s), which starts from 1 and increments by 1 for each row of the function's output. This is most useful in the case of set returning functions such as `unnest()`.

```
-- set returning function WITH ORDINALITY:
SELECT * FROM pg_ls_dir('.') WITH ORDINALITY AS t(ls,n);
       ls        | n
-----------------+----
 pg_serial       |  1
 pg_twophase     |  2
 postmaster.opts |  3
 pg_notify       |  4
 postgresql.conf |  5
 pg_tblspc       |  6
 logfile         |  7
 base            |  8
 postmaster.pid  |  9
 pg_ident.conf   | 10
 global          | 11
 pg_xact         | 12
 pg_snapshots    | 13
 pg_multixact    | 14
 PG_VERSION      | 15
 pg_wal          | 16
 pg_hba.conf     | 17
 pg_stat_tmp     | 18
 pg_subtrans     | 19
(19 rows)
```

9.26. System Information Functions and Operators

Table 9.65 shows several functions that extract session and system information.

In addition to the functions listed in this section, there are a number of functions related to the statistics system that also provide system information. See Section 27.2.25 for more information.

Table 9.65. Session Information Functions

Function **Description**

`current_catalog` → `name`
`current_database` () → `name`
Returns the name of the current database. (Databases are called “catalogs” in the SQL standard, so `current_catalog` is the standard's spelling.)

`current_query` () → `text` Returns the text of the currently executing query, as submitted by the client (which might contain more than one statement).
`current_role` → `name` This is equivalent to `current_user`.

`current_schema` → `name`
`current_schema` () → `name`
Returns the name of the schema that is first in the search path (or a null value if the search path is empty). This is the schema that will be used for any tables or other named objects that are created without specifying a target schema.

`current_schemas` (*include_implicit* `boolean`) → `name[]`

Function Description
Returns an array of the names of all schemas presently in the effective search path, in their priority order. (Items in the current search_path setting that do not correspond to existing, searchable schemas are omitted.) If the Boolean argument is `true`, then implicitly-searched system schemas such as `pg_catalog` are included in the result.
`current_user` → `name` Returns the user name of the current execution context.
`inet_client_addr` () → `inet` Returns the IP address of the current client, or `NULL` if the current connection is via a Unix-domain socket.
`inet_client_port` () → `integer` Returns the IP port number of the current client, or `NULL` if the current connection is via a Unix-domain socket.
`inet_server_addr` () → `inet` Returns the IP address on which the server accepted the current connection, or `NULL` if the current connection is via a Unix-domain socket.
`inet_server_port` () → `integer` Returns the IP port number on which the server accepted the current connection, or `NULL` if the current connection is via a Unix-domain socket.
`pg_backend_pid` () → `integer` Returns the process ID of the server process attached to the current session.
`pg_blocking_pids` (`integer`) → `integer[]` Returns an array of the process ID(s) of the sessions that are blocking the server process with the specified process ID from acquiring a lock, or an empty array if there is no such server process or it is not blocked. One server process blocks another if it either holds a lock that conflicts with the blocked process's lock request (hard block), or is waiting for a lock that would conflict with the blocked process's lock request and is ahead of it in the wait queue (soft block). When using parallel queries the result always lists client-visible process IDs (that is, `pg_backend_pid` results) even if the actual lock is held or awaited by a child worker process. As a result of that, there may be duplicated PIDs in the result. Also note that when a prepared transaction holds a conflicting lock, it will be represented by a zero process ID. Frequent calls to this function could have some impact on database performance, because it needs exclusive access to the lock manager's shared state for a short time.
`pg_conf_load_time` () → `timestamp with time zone` Returns the time when the server configuration files were last loaded. If the current session was alive at the time, this will be the time when the session itself re-read the configuration files (so the reading will vary a little in different sessions). Otherwise it is the time when the postmaster process re-read the configuration files.
`pg_current_logfile` ([`text`]) → `text` Returns the path name of the log file currently in use by the logging collector. The path includes the log_directory directory and the individual log file name. The result is `NULL` if the logging collector is disabled. When multiple log files exist, each in a different format, `pg_current_logfile` without an argument returns the path of the file having the first format found in the ordered list: `stderr`, `csvlog`. `NULL` is returned if no log file has any of these formats. To request information about a specific log file format, supply either `csvlog` or `stderr` as the value of the optional parameter. The result is `NULL` if the log format requested is not configured in log_destination. The result reflects the contents of the `current_logfiles` file.
`pg_my_temp_schema` () → `oid`

Function **Description**
Returns the OID of the current session's temporary schema, or zero if it has none (because it has not created any temporary tables).
`pg_is_other_temp_schema` (`oid`) → `boolean` Returns true if the given OID is the OID of another session's temporary schema. (This can be useful, for example, to exclude other sessions' temporary tables from a catalog display.)
`pg_jit_available` () → `boolean` Returns true if a JIT compiler extension is available (see Chapter 31) and the jit configuration parameter is set to `on`.
`pg_listening_channels` () → `setof text` Returns the set of names of asynchronous notification channels that the current session is listening to.
`pg_notification_queue_usage` () → `double precision` Returns the fraction (0–1) of the asynchronous notification queue's maximum size that is currently occupied by notifications that are waiting to be processed. See LISTEN and NOTIFY for more information.
`pg_postmaster_start_time` () → `timestamp with time zone` Returns the time when the server started.
`pg_safe_snapshot_blocking_pids` (`integer`) → `integer[]` Returns an array of the process ID(s) of the sessions that are blocking the server process with the specified process ID from acquiring a safe snapshot, or an empty array if there is no such server process or it is not blocked. A session running a `SERIALIZABLE` transaction blocks a `SERIALIZABLE READ ONLY DEFERRABLE` transaction from acquiring a snapshot until the latter determines that it is safe to avoid taking any predicate locks. See Section 13.2.3 for more information about serializable and deferrable transactions. Frequent calls to this function could have some impact on database performance, because it needs access to the predicate lock manager's shared state for a short time.
`pg_trigger_depth` () → `integer` Returns the current nesting level of Postgres Pro triggers (0 if not called, directly or indirectly, from inside a trigger).
`session_user` → `name` Returns the session user's name.
`user` → `name` This is equivalent to `current_user` .
`version` () → `text` Returns a string describing the PostgreSQL server's version. You can also get this information from server_version, or for a machine-readable version use server_version_num. Software developers should use `server_version_num` (available since 8.2) or `PQserverVersion` instead of parsing the text version.
`pgpro_version` () → `text` Returns a string describing the Postgres Pro server's version.
`pgpro_edition` () → `text` Returns a string describing Postgres Pro edition, i.e. `standard` or `enterprise`.
`pgpro_build` () → `text` Returns the commit ID of Postgres Pro source files.

> **Note**
>
> current_catalog, current_role, current_schema, current_user, session_user, and user have special syntactic status in SQL: they must be called without trailing parentheses. In Postgres Pro, parentheses can optionally be used with current_schema, but not with the others.

The session_user is normally the user who initiated the current database connection; but superusers can change this setting with SET SESSION AUTHORIZATION. The current_user is the user identifier that is applicable for permission checking. Normally it is equal to the session user, but it can be changed with SET ROLE. It also changes during the execution of functions with the attribute SECURITY DEFINER. In Unix parlance, the session user is the "real user" and the current user is the "effective user". current_role and user are synonyms for current_user. (The SQL standard draws a distinction between current_role and current_user, but Postgres Pro does not, since it unifies users and roles into a single kind of entity.)

Table 9.66 lists functions that allow querying object access privileges programmatically. (See Section 5.7 for more information about privileges.) In these functions, the user whose privileges are being inquired about can be specified by name or by OID (pg_authid.oid), or if the name is given as public then the privileges of the PUBLIC pseudo-role are checked. Also, the *user* argument can be omitted entirely, in which case the current_user is assumed. The object that is being inquired about can be specified either by name or by OID, too. When specifying by name, a schema name can be included if relevant. The access privilege of interest is specified by a text string, which must evaluate to one of the appropriate privilege keywords for the object's type (e.g., SELECT). Optionally, WITH GRANT OPTION can be added to a privilege type to test whether the privilege is held with grant option. Also, multiple privilege types can be listed separated by commas, in which case the result will be true if any of the listed privileges is held. (Case of the privilege string is not significant, and extra whitespace is allowed between but not within privilege names.) Some examples:

```
SELECT has_table_privilege('myschema.mytable', 'select');
SELECT has_table_privilege('joe', 'mytable', 'INSERT, SELECT WITH GRANT OPTION');
```

Table 9.66. Access Privilege Inquiry Functions

Function Description
has_any_column_privilege ([*user* name or oid,] *table* text or oid, *privilege* text) → boolean Does user have privilege for any column of table? This succeeds either if the privilege is held for the whole table, or if there is a column-level grant of the privilege for at least one column. Allowable privilege types are SELECT, INSERT, UPDATE, and REFERENCES.
has_column_privilege ([*user* name or oid,] *table* text or oid, *column* text or smallint, *privilege* text) → boolean Does user have privilege for the specified table column? This succeeds either if the privilege is held for the whole table, or if there is a column-level grant of the privilege for the column. The column can be specified by name or by attribute number (pg_attribute .attnum). Allowable privilege types are SELECT, INSERT, UPDATE, and REFERENCES.
has_database_privilege ([*user* name or oid,] *database* text or oid, *privilege* text) → boolean Does user have privilege for database? Allowable privilege types are CREATE, CONNECT, TEMPORARY, and TEMP (which is equivalent to TEMPORARY).
has_foreign_data_wrapper_privilege ([*user* name or oid,] *fdw* text or oid, *privilege* text) → boolean Does user have privilege for foreign-data wrapper? The only allowable privilege type is USAGE.

Function Description

`has_function_privilege` ([*user* `name` or `oid`,] *function* `text` or `oid`, *privilege* `text`) → `boolean`
Does user have privilege for function? The only allowable privilege type is `EXECUTE`.
When specifying a function by name rather than by OID, the allowed input is the same as for the `regprocedure` data type (see Section 8.19). An example is:
`SELECT has_function_privilege('joeuser', 'myfunc(int, text)', 'execute');`

`has_language_privilege` ([*user* `name` or `oid`,] *language* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for language? The only allowable privilege type is `USAGE`.
`has_schema_privilege` ([*user* `name` or `oid`,] *schema* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for schema? Allowable privilege types are `CREATE` and `USAGE`.
`has_sequence_privilege` ([*user* `name` or `oid`,] *sequence* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for sequence? Allowable privilege types are `USAGE`, `SELECT`, and `UPDATE`.
`has_server_privilege` ([*user* `name` or `oid`,] *server* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for foreign server? The only allowable privilege type is `USAGE`.
`has_table_privilege` ([*user* `name` or `oid`,] *table* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for table? Allowable privilege types are `SELECT`, `INSERT`, `UPDATE`, `DELETE`, `TRUNCATE`, `REFERENCES`, and `TRIGGER`.
`has_tablespace_privilege` ([*user* `name` or `oid`,] *tablespace* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for tablespace? The only allowable privilege type is `CREATE`.
`has_type_privilege` ([*user* `name` or `oid`,] *type* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for data type? The only allowable privilege type is `USAGE`. When specifying a type by name rather than by OID, the allowed input is the same as for the `regtype` data type (see Section 8.19).
`pg_has_role` ([*user* `name` or `oid`,] *role* `text` or `oid`, *privilege* `text`) → `boolean` Does user have privilege for role? Allowable privilege types are `MEMBER` and `USAGE`. `MEMBER` denotes direct or indirect membership in the role (that is, the right to do `SET ROLE`), while `USAGE` denotes whether the privileges of the role are immediately available without doing `SET ROLE`. `WITH ADMIN OPTION` or `WITH GRANT OPTION` can be added to either of these privilege types to test whether the `ADMIN` privilege is held (all four spellings test the same thing). This function does not allow the special case of setting *user* to `public`, because the PUBLIC pseudo-role can never be a member of real roles.
`row_security_active` (*table* `text` or `oid`) → `boolean` Is row-level security active for the specified table in the context of the current user and current environment?

Table 9.67 shows the operators available for the `aclitem` type, which is the catalog representation of access privileges. See Section 5.7 for information about how to read access privilege values.

Table 9.67. `aclitem` Operators

Operator Description Example(s)
`aclitem = aclitem → boolean`

Operator Description Example(s)
Are aclitems equal? (Notice that type aclitem lacks the usual set of comparison operators; it has only equality. In turn, aclitem arrays can only be compared for equality.) 'calvin=r*w/hobbes'::aclitem = 'calvin=r*w*/hobbes'::aclitem → f
aclitem[] @> aclitem → boolean Does array contain the specified privileges? (This is true if there is an array entry that matches the aclitem's grantee and grantor, and has at least the specified set of privileges.) '{calvin=r*w/hobbes,hobbes=r*w*/postgres}'::aclitem[] @> 'calvin=r*/hobbes'::aclitem → t
aclitem[] ~ aclitem → boolean This is a deprecated alias for @>. '{calvin=r*w/hobbes,hobbes=r*w*/postgres}'::aclitem[] ~ 'calvin=r*/hobbes'::aclitem → t

Table 9.68 shows some additional functions to manage the aclitem type.

Table 9.68. aclitem Functions

Function Description
acldefault (*type* "char", *ownerId* oid) → aclitem[] Constructs an aclitem array holding the default access privileges for an object of type *type* belonging to the role with OID *ownerId*. This represents the access privileges that will be assumed when an object's ACL entry is null. (The default access privileges are described in Section 5.7.) The *type* parameter must be one of 'c' for COLUMN, 'r' for TABLE and table-like objects, 's' for SEQUENCE, 'd' for DATABASE, 'f' for FUNCTION or PROCEDURE, 'l' for LANGUAGE, 'L' for LARGE OBJECT, 'n' for SCHEMA, 't' for TABLESPACE, 'F' for FOREIGN DATA WRAPPER, 'S' for FOREIGN SERVER, or 'T' for TYPE or DOMAIN.
aclexplode (aclitem[]) → setof record (*grantor* oid, *grantee* oid, *privilege_type* text, *is_grantable* boolean) Returns the aclitem array as a set of rows. If the grantee is the pseudo-role PUBLIC, it is represented by zero in the *grantee* column. Each granted privilege is represented as SELECT, INSERT, etc. Note that each privilege is broken out as a separate row, so only one keyword appears in the *privilege_type* column.
makeaclitem (*grantee* oid, *grantor* oid, *privileges* text, *is_grantable* boolean) → aclitem Constructs an aclitem with the given properties.

Table 9.69 shows functions that determine whether a certain object is *visible* in the current schema search path. For example, a table is said to be visible if its containing schema is in the search path and no table of the same name appears earlier in the search path. This is equivalent to the statement that the table can be referenced by name without explicit schema qualification. Thus, to list the names of all visible tables:

```
SELECT relname FROM pg_class WHERE pg_table_is_visible(oid);
```

For functions and operators, an object in the search path is said to be visible if there is no object of the same name *and argument data type(s)* earlier in the path. For operator classes and families, both the name and the associated index access method are considered.

Table 9.69. Schema Visibility Inquiry Functions

Function Description
`pg_collation_is_visible` (*collation* `oid`) → `boolean` Is collation visible in search path?
`pg_conversion_is_visible` (*conversion* `oid`) → `boolean` Is conversion visible in search path?
`pg_function_is_visible` (*function* `oid`) → `boolean` Is function visible in search path? (This also works for procedures and aggregates.)
`pg_opclass_is_visible` (*opclass* `oid`) → `boolean` Is operator class visible in search path?
`pg_operator_is_visible` (*operator* `oid`) → `boolean` Is operator visible in search path?
`pg_opfamily_is_visible` (*opclass* `oid`) → `boolean` Is operator family visible in search path?
`pg_statistics_obj_is_visible` (*stat* `oid`) → `boolean` Is statistics object visible in search path?
`pg_table_is_visible` (*table* `oid`) → `boolean` Is table visible in search path? (This works for all types of relations, including views, materialized views, indexes, sequences and foreign tables.)
`pg_ts_config_is_visible` (*config* `oid`) → `boolean` Is text search configuration visible in search path?
`pg_ts_dict_is_visible` (*dict* `oid`) → `boolean` Is text search dictionary visible in search path?
`pg_ts_parser_is_visible` (*parser* `oid`) → `boolean` Is text search parser visible in search path?
`pg_ts_template_is_visible` (*template* `oid`) → `boolean` Is text search template visible in search path?
`pg_type_is_visible` (*type* `oid`) → `boolean` Is type (or domain) visible in search path?

All these functions require object OIDs to identify the object to be checked. If you want to test an object by name, it is convenient to use the OID alias types (`regclass`, `regtype`, `regprocedure`, `regoperator`, `regconfig`, or `regdictionary`), for example:

```
SELECT pg_type_is_visible('myschema.widget'::regtype);
```

Note that it would not make much sense to test a non-schema-qualified type name in this way — if the name can be recognized at all, it must be visible.

Table 9.70 lists functions that extract information from the system catalogs.

Table 9.70. System Catalog Information Functions

Function Description
`format_type` (*type* `oid`, *typemod* `integer`) → `text` Returns the SQL name for a data type that is identified by its type OID and possibly a type modifier. Pass NULL for the type modifier if no specific modifier is known.
`pg_get_catalog_foreign_keys` () → `setof record` (*fktable* `regclass`, *fkcols* `text[]`, *pktable* `regclass`, *pkcols* `text[]`, *is_array* `boolean`, *is_opt* `boolean`)

Function **Description**
Returns a set of records describing the foreign key relationships that exist within the Postgres Pro system catalogs. The *fktable* column contains the name of the referencing catalog, and the *fkcols* column contains the name(s) of the referencing column(s). Similarly, the *pktable* column contains the name of the referenced catalog, and the *pkcols* column contains the name(s) of the referenced column(s). If *is_array* is true, the last referencing column is an array, each of whose elements should match some entry in the referenced catalog. If *is_opt* is true, the referencing column(s) are allowed to contain zeroes instead of a valid reference.
pg_get_constraintdef (*constraint* oid [, *pretty* boolean]) → text Reconstructs the creating command for a constraint. (This is a decompiled reconstruction, not the original text of the command.)
pg_get_expr (*expr* pg_node_tree , *relation* oid [, *pretty* boolean]) → text Decompiles the internal form of an expression stored in the system catalogs, such as the default value for a column. If the expression might contain Vars, specify the OID of the relation they refer to as the second parameter; if no Vars are expected, passing zero is sufficient.
pg_get_functiondef (*func* oid) → text Reconstructs the creating command for a function or procedure. (This is a decompiled reconstruction, not the original text of the command.) The result is a complete CREATE OR REPLACE FUNCTION or CREATE OR REPLACE PROCEDURE statement.
pg_get_function_arguments (*func* oid) → text Reconstructs the argument list of a function or procedure, in the form it would need to appear in within CREATE FUNCTION (including default values).
pg_get_function_identity_arguments (*func* oid) → text Reconstructs the argument list necessary to identify a function or procedure, in the form it would need to appear in within commands such as ALTER FUNCTION. This form omits default values.
pg_get_function_result (*func* oid) → text Reconstructs the RETURNS clause of a function, in the form it would need to appear in within CREATE FUNCTION. Returns NULL for a procedure.
pg_get_indexdef (*index* oid [, *column* integer, *pretty* boolean]) → text Reconstructs the creating command for an index. (This is a decompiled reconstruction, not the original text of the command.) If *column* is supplied and is not zero, only the definition of that column is reconstructed.
pg_get_keywords () → setof record (*word* text, *catcode* "char", *barelabel* boolean, *catdesc* text, *baredesc* text) Returns a set of records describing the SQL keywords recognized by the server. The *word* column contains the keyword. The *catcode* column contains a category code: U for an unreserved keyword, C for a keyword that can be a column name, T for a keyword that can be a type or function name, or R for a fully reserved keyword. The *barelabel* column contains true if the keyword can be used as a “bare” column label in SELECT lists, or false if it can only be used after AS. The *catdesc* column contains a possibly-localized string describing the keyword's category. The *baredesc* column contains a possibly-localized string describing the keyword's column label status.
pg_get_ruledef (*rule* oid [, *pretty* boolean]) → text Reconstructs the creating command for a rule. (This is a decompiled reconstruction, not the original text of the command.)
pg_get_serial_sequence (*table* text, *column* text) → text

Function Description
Returns the name of the sequence associated with a column, or NULL if no sequence is associated with the column. If the column is an identity column, the associated sequence is the sequence internally created for that column. For columns created using one of the serial types (`serial`, `smallserial`, `bigserial`), it is the sequence created for that serial column definition. In the latter case, the association can be modified or removed with `ALTER SEQUENCE OWNED BY`. (This function probably should have been called `pg_get_owned_sequence` ; its current name reflects the fact that it has historically been used with serial-type columns.) The first parameter is a table name with optional schema, and the second parameter is a column name. Because the first parameter potentially contains both schema and table names, it is parsed per usual SQL rules, meaning it is lower-cased by default. The second parameter, being just a column name, is treated literally and so has its case preserved. The result is suitably formatted for passing to the sequence functions (see Section 9.17). A typical use is in reading the current value of the sequence for an identity or serial column, for example: `SELECT currval(pg_get_serial_sequence('sometable', 'id'));`
`pg_get_statisticsobjdef ( statobj oid ) → text` Reconstructs the creating command for an extended statistics object. (This is a decompiled reconstruction, not the original text of the command.)
`pg_get_triggerdef ( trigger oid [, pretty boolean ] ) → text` Reconstructs the creating command for a trigger. (This is a decompiled reconstruction, not the original text of the command.)
`pg_get_userbyid ( role oid ) → name` Returns a role's name given its OID.
`pg_get_viewdef ( view oid [, pretty boolean ] ) → text` Reconstructs the underlying `SELECT` command for a view or materialized view. (This is a decompiled reconstruction, not the original text of the command.)
`pg_get_viewdef ( view oid, wrap_column integer ) → text` Reconstructs the underlying `SELECT` command for a view or materialized view. (This is a decompiled reconstruction, not the original text of the command.) In this form of the function, pretty-printing is always enabled, and long lines are wrapped to try to keep them shorter than the specified number of columns.
`pg_get_viewdef ( view text [, pretty boolean ] ) → text` Reconstructs the underlying `SELECT` command for a view or materialized view, working from a textual name for the view rather than its OID. (This is deprecated; use the OID variant instead.)
`pg_index_column_has_property ( index regclass, column integer, property text ) → boolean` Tests whether an index column has the named property. Common index column properties are listed in Table 9.71. (Note that extension access methods can define additional property names for their indexes.) `NULL` is returned if the property name is not known or does not apply to the particular object, or if the OID or column number does not identify a valid object.
`pg_index_has_property ( index regclass, property text ) → boolean` Tests whether an index has the named property. Common index properties are listed in Table 9.72. (Note that extension access methods can define additional property names for their indexes.) `NULL` is returned if the property name is not known or does not apply to the particular object, or if the OID does not identify a valid object.
`pg_indexam_has_property ( am oid, property text ) → boolean`

Function Description
Tests whether an index access method has the named property. Access method properties are listed in Table 9.73. NULL is returned if the property name is not known or does not apply to the particular object, or if the OID does not identify a valid object.
pg_options_to_table (*options_array* text[]) → setof record (*option_name* text, *option_value* text) Returns the set of storage options represented by a value from pg_class .reloptions or pg_attribute .attoptions.
pg_tablespace_databases (*tablespace* oid) → setof oid Returns the set of OIDs of databases that have objects stored in the specified tablespace. If this function returns any rows, the tablespace is not empty and cannot be dropped. To identify the specific objects populating the tablespace, you will need to connect to the database(s) identified by pg_tablespace_databases and query their pg_class catalogs.
pg_tablespace_location (*tablespace* oid) → text Returns the file system path that this tablespace is located in.

pg_typeof ("any") → regtype
Returns the OID of the data type of the value that is passed to it. This can be helpful for troubleshooting or dynamically constructing SQL queries. The function is declared as returning regtype, which is an OID alias type (see Section 8.19); this means that it is the same as an OID for comparison purposes but displays as a type name.
For example:
`SELECT pg_typeof(33);`
` pg_typeof`
`------------`
` integer`
 	
`SELECT typlen FROM pg_type WHERE oid = pg_typeof(33);`
` typlen`
`--------`
`  4`

COLLATION FOR ("any") → text
Returns the name of the collation of the value that is passed to it. The value is quoted and schema-qualified if necessary. If no collation was derived for the argument expression, then NULL is returned. If the argument is not of a collatable data type, then an error is raised.
For example:
`SELECT collation for (description) FROM pg_description LIMIT 1;`
` pg_collation_for`
`-------------------`
` "default"`
 	
`SELECT collation for ('foo' COLLATE "de_DE");`
` pg_collation_for`
`-------------------`
` "de_DE"`

to_regclass (text) → regclass Translates a textual relation name to its OID. A similar result is obtained by casting the string to type regclass (see Section 8.19); however, this function will return NULL rather than throwing an error if the name is not found. Also unlike the cast, this does not accept a numeric OID as input.
to_regcollation (text) → regcollation

Function **Description**
Translates a textual collation name to its OID. A similar result is obtained by casting the string to type `regcollation` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found. Also unlike the cast, this does not accept a numeric OID as input.
`to_regnamespace ( text ) → regnamespace` Translates a textual schema name to its OID. A similar result is obtained by casting the string to type `regnamespace` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found. Also unlike the cast, this does not accept a numeric OID as input.
`to_regoper ( text ) → regoper` Translates a textual operator name to its OID. A similar result is obtained by casting the string to type `regoper` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found or is ambiguous. Also unlike the cast, this does not accept a numeric OID as input.
`to_regoperator ( text ) → regoperator` Translates a textual operator name (with parameter types) to its OID. A similar result is obtained by casting the string to type `regoperator` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found. Also unlike the cast, this does not accept a numeric OID as input.
`to_regproc ( text ) → regproc` Translates a textual function or procedure name to its OID. A similar result is obtained by casting the string to type `regproc` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found or is ambiguous. Also unlike the cast, this does not accept a numeric OID as input.
`to_regprocedure ( text ) → regprocedure` Translates a textual function or procedure name (with argument types) to its OID. A similar result is obtained by casting the string to type `regprocedure` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found. Also unlike the cast, this does not accept a numeric OID as input.
`to_regrole ( text ) → regrole` Translates a textual role name to its OID. A similar result is obtained by casting the string to type `regrole` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found. Also unlike the cast, this does not accept a numeric OID as input.
`to_regtype ( text ) → regtype` Translates a textual type name to its OID. A similar result is obtained by casting the string to type `regtype` (see Section 8.19); however, this function will return `NULL` rather than throwing an error if the name is not found. Also unlike the cast, this does not accept a numeric OID as input.

Most of the functions that reconstruct (decompile) database objects have an optional *`pretty`* flag, which if `true` causes the result to be “pretty-printed”. Pretty-printing suppresses unnecessary parentheses and adds whitespace for legibility. The pretty-printed format is more readable, but the default format is more likely to be interpreted the same way by future versions of Postgres Pro; so avoid using pretty-printed output for dump purposes. Passing `false` for the *`pretty`* parameter yields the same result as omitting the parameter.

Table 9.71. Index Column Properties

Name	Description
`asc`	Does the column sort in ascending order on a forward scan?
`desc`	Does the column sort in descending order on a forward scan?
`nulls_first`	Does the column sort with nulls first on a forward scan?
`nulls_last`	Does the column sort with nulls last on a forward scan?
`orderable`	Does the column possess any defined sort ordering?
`distance_orderable`	Can the column be scanned in order by a "distance" operator, for example `ORDER BY col <-> constant` ?
`returnable`	Can the column value be returned by an index-only scan?
`search_array`	Does the column natively support `col = ANY( array)` searches?
`search_nulls`	Does the column support `IS NULL` and `IS NOT NULL` searches?

Table 9.72. Index Properties

Name	Description
`clusterable`	Can the index be used in a `CLUSTER` command?
`index_scan`	Does the index support plain (non-bitmap) scans?
`bitmap_scan`	Does the index support bitmap scans?
`backward_scan`	Can the scan direction be changed in mid-scan (to support `FETCH BACKWARD` on a cursor without needing materialization)?

Table 9.73. Index Access Method Properties

Name	Description
`can_order`	Does the access method support `ASC`, `DESC` and related keywords in `CREATE INDEX`?
`can_unique`	Does the access method support unique indexes?
`can_multi_col`	Does the access method support indexes with multiple columns?
`can_exclude`	Does the access method support exclusion constraints?
`can_include`	Does the access method support the `INCLUDE` clause of `CREATE INDEX`?

Table 9.74 lists functions related to database object identification and addressing.

Table 9.74. Object Information and Addressing Functions

Function Description	
`pg_describe_object`	(*classid* `oid`, *objid* `oid`, *objsubid* `integer`) → `text`

Function Description
Returns a textual description of a database object identified by catalog OID, object OID, and sub-object ID (such as a column number within a table; the sub-object ID is zero when referring to a whole object). This description is intended to be human-readable, and might be translated, depending on server configuration. This is especially useful to determine the identity of an object referenced in the pg_depend catalog. This function returns NULL values for undefined objects.
pg_identify_object (*classid* oid, *objid* oid, *objsubid* integer) → record (*type* text, *schema* text, *name* text, *identity* text) Returns a row containing enough information to uniquely identify the database object specified by catalog OID, object OID and sub-object ID. This information is intended to be machine-readable, and is never translated. *type* identifies the type of database object; *schema* is the schema name that the object belongs in, or NULL for object types that do not belong to schemas; *name* is the name of the object, quoted if necessary, if the name (along with schema name, if pertinent) is sufficient to uniquely identify the object, otherwise NULL; *identity* is the complete object identity, with the precise format depending on object type, and each name within the format being schema-qualified and quoted as necessary. Undefined objects are identified with NULL values.
pg_identify_object_as_address (*classid* oid, *objid* oid, *objsubid* integer) → record (*type* text, *object_names* text[], *object_args* text[]) Returns a row containing enough information to uniquely identify the database object specified by catalog OID, object OID and sub-object ID. The returned information is independent of the current server, that is, it could be used to identify an identically named object in another server. *type* identifies the type of database object; *object_names* and *object_args* are text arrays that together form a reference to the object. These three values can be passed to pg_get_object_address to obtain the internal address of the object.
pg_get_object_address (*type* text, *object_names* text[], *object_args* text[]) → record (*classid* oid, *objid* oid, *objsubid* integer) Returns a row containing enough information to uniquely identify the database object specified by a type code and object name and argument arrays. The returned values are the ones that would be used in system catalogs such as pg_depend ; they can be passed to other system functions such as pg_describe_object or pg_identify_object . *classid* is the OID of the system catalog containing the object; *objid* is the OID of the object itself, and *objsubid* is the sub-object ID, or zero if none. This function is the inverse of pg_identify_object_as_address . Undefined objects are identified with NULL values.

The functions shown in Table 9.75 extract comments previously stored with the COMMENT command. A null value is returned if no comment could be found for the specified parameters.

Table 9.75. Comment Information Functions

Function Description
col_description (*table* oid, *column* integer) → text Returns the comment for a table column, which is specified by the OID of its table and its column number. (obj_description cannot be used for table columns, since columns do not have OIDs of their own.)
obj_description (*object* oid, *catalog* name) → text Returns the comment for a database object specified by its OID and the name of the containing system catalog. For example, obj_description(123456, 'pg_class') would retrieve the comment for the table with OID 123456.
obj_description (*object* oid) → text

Function Description
Returns the comment for a database object specified by its OID alone. This is *deprecated* since there is no guarantee that OIDs are unique across different system catalogs; therefore, the wrong comment might be returned.
`shobj_description` (*object* `oid`, *catalog* `name`) → `text` Returns the comment for a shared database object specified by its OID and the name of the containing system catalog. This is just like `obj_description` except that it is used for retrieving comments on shared objects (that is, databases, roles, and tablespaces). Some system catalogs are global to all databases within each cluster, and the descriptions for objects in them are stored globally as well.

The functions shown in Table 9.76 provide server transaction information in an exportable form. The main use of these functions is to determine which transactions were committed between two snapshots.

Table 9.76. Transaction ID and Snapshot Information Functions

Function Description
`pg_current_xact_id` () → `xid8` Returns the current transaction's ID. It will assign a new one if the current transaction does not have one already (because it has not performed any database updates).
`pg_current_xact_id_if_assigned` () → `xid8` Returns the current transaction's ID, or `NULL` if no ID is assigned yet. (It's best to use this variant if the transaction might otherwise be read-only, to avoid unnecessary consumption of an XID.)
`pg_xact_status` (`xid8`) → `text` Reports the commit status of a recent transaction. The result is one of `in progress`, `committed`, or `aborted`, provided that the transaction is recent enough that the system retains the commit status of that transaction. If it is old enough that no references to the transaction survive in the system and the commit status information has been discarded, the result is `NULL`. Applications might use this function, for example, to determine whether their transaction committed or aborted after the application and database server become disconnected while a `COMMIT` is in progress. Note that prepared transactions are reported as `in progress`; applications must check `pg_prepared_xacts` if they need to determine whether a transaction ID belongs to a prepared transaction.
`pg_current_snapshot` () → `pg_snapshot` Returns a current *snapshot*, a data structure showing which transaction IDs are now in-progress.
`pg_snapshot_xip` (`pg_snapshot`) → `setof xid8` Returns the set of in-progress transaction IDs contained in a snapshot.
`pg_snapshot_xmax` (`pg_snapshot`) → `xid8` Returns the `xmax` of a snapshot.
`pg_snapshot_xmin` (`pg_snapshot`) → `xid8` Returns the `xmin` of a snapshot.
`pg_visible_in_snapshot` (`xid8`, `pg_snapshot`) → `boolean` Is the given transaction ID *visible* according to this snapshot (that is, was it completed before the snapshot was taken)? Note that this function will not give the correct answer for a subtransaction ID.

In Postgres Pro Enterprise, transaction IDs are implemented as 64-bit counters to prevent transaction ID wraparound. The functions shown in Table 9.76 use a 64-bit type `xid8` that does not wrap around during

the life of an installation, and can be converted to `xid` by casting if required. The data type `pg_snapshot` stores information about transaction ID visibility at a particular moment in time. Its components are described in Table 9.77. `pg_snapshot`'s textual representation is *`xmin`*`:`*`xmax`*`:`*`xip_list`*. For example `10:20:10,14,15` means `xmin=10, xmax=20, xip_list=10, 14, 15`.

Table 9.77. Snapshot Components

Name	Description
`xmin`	Lowest transaction ID that was still active. All transaction IDs less than `xmin` are either committed and visible, or rolled back and dead.
`xmax`	One past the highest completed transaction ID. All transaction IDs greater than or equal to `xmax` had not yet completed as of the time of the snapshot, and thus are invisible.
`xip_list`	Transactions in progress at the time of the snapshot. A transaction ID that is `xmin <= X < xmax` and not in this list was already completed at the time of the snapshot, and thus is either visible or dead according to its commit status. This list does not include the transaction IDs of subtransactions.

In releases of Postgres Pro before 13 there was no `xid8` type, so variants of these functions were provided that used `bigint` to represent a 64-bit XID, with a correspondingly distinct snapshot data type `txid_snapshot`. These older functions have `txid` in their names. They are still supported for backward compatibility, but may be removed from a future release. See Table 9.78.

Table 9.78. Deprecated Transaction ID and Snapshot Information Functions

Function Description
`txid_current () → bigint` See `pg_current_xact_id()`.
`txid_current_if_assigned () → bigint` See `pg_current_xact_id_if_assigned()`.
`txid_current_snapshot () → txid_snapshot` See `pg_current_snapshot()`.
`txid_snapshot_xip ( txid_snapshot ) → setof bigint` See `pg_snapshot_xip()`.
`txid_snapshot_xmax ( txid_snapshot ) → bigint` See `pg_snapshot_xmax()`.
`txid_snapshot_xmin ( txid_snapshot ) → bigint` See `pg_snapshot_xmin()`.
`txid_visible_in_snapshot ( bigint, txid_snapshot ) → boolean` See `pg_visible_in_snapshot()`.
`txid_status ( bigint ) → text` See `pg_xact_status()`.

The functions shown in Table 9.79 provide information about when past transactions were committed. They only provide useful data when the track_commit_timestamp configuration option is enabled, and only for transactions that were committed after it was enabled.

Table 9.79. Committed Transaction Information Functions

Function Description
`pg_xact_commit_timestamp ( xid ) → timestamp with time zone` Returns the commit timestamp of a transaction.
`pg_xact_commit_timestamp_origin ( xid ) → record ( timestamp timestamp with time zone, roident oid )` Returns the commit timestamp and replication origin of a transaction.
`pg_last_committed_xact () → record ( xid xid, timestamp timestamp with time zone, roident oid )` Returns the transaction ID, commit timestamp and replication origin of the latest committed transaction.

The functions shown in Table 9.80 print information initialized during `initdb`, such as the catalog version. They also show information about write-ahead logging and checkpoint processing. This information is cluster-wide, not specific to any one database. These functions provide most of the same information, from the same source, as the pg_controldata application.

Table 9.80. Control Data Functions

Function Description
`pg_control_checkpoint () → record` Returns information about current checkpoint state, as shown in Table 9.81.
`pg_control_system () → record` Returns information about current control file state, as shown in Table 9.82.
`pg_control_init () → record` Returns information about cluster initialization state, as shown in Table 9.83.
`pg_control_recovery () → record` Returns information about recovery state, as shown in Table 9.84.

Table 9.81. `pg_control_checkpoint` Output Columns

Column Name	Data Type
checkpoint_lsn	pg_lsn
redo_lsn	pg_lsn
redo_wal_file	text
timeline_id	integer
prev_timeline_id	integer
full_page_writes	boolean
next_xid	text
next_oid	oid
next_multixact_id	xid
next_multi_offset	xid
oldest_xid	xid
oldest_xid_dbid	oid
oldest_active_xid	xid

Column Name	Data Type
oldest_multi_xid	xid
oldest_multi_dbid	oid
oldest_commit_ts_xid	xid
newest_commit_ts_xid	xid
checkpoint_time	timestamp with time zone

Table 9.82. `pg_control_system` Output Columns

Column Name	Data Type
pg_control_version	integer
catalog_version_no	integer
system_identifier	bigint
pg_control_last_modified	timestamp with time zone
pg_control_edition	text

Table 9.83. `pg_control_init` Output Columns

Column Name	Data Type
max_data_alignment	integer
database_block_size	integer
blocks_per_segment	integer
wal_block_size	integer
bytes_per_wal_segment	integer
max_identifier_length	integer
max_index_columns	integer
max_toast_chunk_size	integer
large_object_chunk_size	integer
float8_pass_by_value	boolean
data_page_checksum_version	integer
icu_version	text

> **Note**
>
> `icu_version` is NULL if Postgres Pro is built without ICU.

Table 9.84. `pg_control_recovery` Output Columns

Column Name	Data Type
min_recovery_end_lsn	pg_lsn
min_recovery_end_timeline	integer
backup_start_lsn	pg_lsn
backup_end_lsn	pg_lsn

Column Name	Data Type
end_of_backup_record_required	boolean

9.27. System Administration Functions

The functions described in this section are used to control and monitor a Postgres Pro installation.

9.27.1. Configuration Settings Functions

Table 9.85 shows the functions available to query and alter run-time configuration parameters.

Table 9.85. Configuration Settings Functions

Function Description Example(s)
current_setting (*setting_name* text [, *missing_ok* boolean]) → text Returns the current value of the setting *setting_name* . If there is no such setting, current_setting throws an error unless *missing_ok* is supplied and is true (in which case NULL is returned). This function corresponds to the SQL command SHOW. current_setting('datestyle') → ISO, MDY
set_config (*setting_name* text, *new_value* text, *is_local* boolean) → text Sets the parameter *setting_name* to *new_value* , and returns that value. If *is_local* is true, the new value will only apply during the current transaction. If you want the new value to apply for the rest of the current session, use false instead. This function corresponds to the SQL command SET. set_config('log_statement_stats', 'off', false) → off
pg_backend_set_config (*pid* int, *config* text, *wait* int default 0) → boolean Sets one or more parameters provided in the *config* string for the backend with the specified PID. Following the postgresql.conf convention, each configuration parameter in the *config* string must be written on a separate line, in the *name*=*value* format. The pg_backend_set_config function only affects run-time parameters. When called, it modifies the main configuration until the end of the session or the next pg_backend_set_config call. The changes take effect starting from the next transaction.
pg_backend_load_library (*pid* int, *name* text, *wait* int default 0) → boolean Loads the library with the provided name for the backend with the specified PID. You can load only one library at a time. When run without superuser privileges, pg_backend_load_library only allows to load libraries located in $libdir/plugins. If you need to load a library from a different location, run this function on behalf of a superuser.

Functions pg_backend_set_config and pg_backend_load_library are designed to set configuration parameters and load shared libraries in other sessions, which may be useful for tracing sessions with unexpected behavior. To avoid potential security issues, these functions can only be called by a superuser.

> **Note**
>
> This functionality cannot be used together with the built-in connection pooler described in Chapter 34.

By default, pg_backend_set_config and pg_backend_load_library return true, without waiting for response from the other backend. You can use the optional wait parameter to specify the time interval, in seconds, for which to wait for the confirmation that the target backend has received the command.

If the confirmation is received, the functions return `true`. Otherwise, `false` is returned. Note that the returned value does not reflect the actual result of the operation. If a configuration update fails, an error occurs on the target backend, and the current command on this backend is aborted.

Consider the following examples:

```
SELECT pg_backend_set_config(pg_backend_pid(), 'statement_timeout=10000');
 pg_backend_set_config
-----------------------
 t
(1 row)

SELECT pg_backend_set_config(pg_backend_pid(),
       'statement_timeout=20000
        lock_timeout=10000');
 pg_backend_set_config
-----------------------
 t
(1 row)

SELECT pg_backend_set_config(pg_backend_pid(), 'fsync=on');
ERROR:  parameter "fsync" cannot be changed now

SELECT pg_backend_set_config(pg_backend_pid(), 'log_min_messages=INFO');
ERROR:  permission denied to set parameter "log_min_messages"

SELECT pg_backend_load_library(pg_backend_pid(), 'pgoutput');
 pg_backend_load_library
-------------------------
 t
(1 row)
```

9.27.2. Server Signaling Functions

The functions shown in Table 9.86 send control signals to other server processes. Use of these functions is restricted to superusers by default but access may be granted to others using `GRANT`, with noted exceptions.

Each of these functions returns `true` if the signal was successfully sent and `false` if sending the signal failed.

Table 9.86. Server Signaling Functions

Function Description
`pg_cancel_backend ( pid integer ) → boolean` Cancels the current query of the session whose backend process has the specified process ID. This is also allowed if the calling role is a member of the role whose backend is being canceled or the calling role has been granted `pg_signal_backend`, however only superusers can cancel superuser backends.
`pg_log_backend_memory_contexts ( pid integer ) → boolean` Requests to log the memory contexts of the backend with the specified process ID. These memory contexts will be logged at `LOG` message level. They will appear in the server log based on the log configuration set (See Section 19.8 for more information), but will not be sent to the client regardless of client_min_messages. Only superusers can request to log the memory contexts.
`pg_reload_conf () → boolean`

Function Description
Causes all processes of the Postgres Pro server to reload their configuration files. (This is initiated by sending a SIGHUP signal to the postmaster process, which in turn sends SIGHUP to each of its children.) You can use the pg_file_settings and pg_hba_file_rules views to check the configuration files for possible errors, before reloading.
pg_rotate_logfile () → boolean Signals the log-file manager to switch to a new output file immediately. This works only when the built-in log collector is running, since otherwise there is no log-file manager subprocess.
pg_terminate_backend (*pid* integer, *timeout* bigint DEFAULT 0) → boolean Terminates the session whose backend process has the specified process ID. This is also allowed if the calling role is a member of the role whose backend is being terminated or the calling role has been granted pg_signal_backend , however only superusers can terminate superuser backends. If *timeout* is not specified or zero, this function returns true whether the process actually terminates or not, indicating only that the sending of the signal was successful. If the *timeout* is specified (in milliseconds) and greater than zero, the function waits until the process is actually terminated or until the given time has passed. If the process is terminated, the function returns true. On timeout, a warning is emitted and false is returned.

pg_cancel_backend and pg_terminate_backend send signals (SIGINT or SIGTERM respectively) to backend processes identified by process ID. The process ID of an active backend can be found from the pid column of the pg_stat_activity view, or by listing the postgres processes on the server (using ps on Unix or the Task Manager on Windows). The role of an active backend can be found from the usename column of the pg_stat_activity view.

pg_log_backend_memory_contexts can be used to log the memory contexts of a backend process. For example:

```
postgres=# SELECT pg_log_backend_memory_contexts(pg_backend_pid());
 pg_log_backend_memory_contexts
--------------------------------
 t
(1 row)
```

One message for each memory context will be logged. For example:

```
LOG:  logging memory contexts of PID 10377
STATEMENT:  SELECT pg_log_backend_memory_contexts(pg_backend_pid());
LOG:  level: 0; TopMemoryContext: 80800 total in 6 blocks; 14432 free (5 chunks); 66368
 used
LOG:  level: 1; pgstat TabStatusArray lookup hash table: 8192 total in 1 blocks; 1408
 free (0 chunks); 6784 used
LOG:  level: 1; TopTransactionContext: 8192 total in 1 blocks; 7720 free (1 chunks);
 472 used
LOG:  level: 1; RowDescriptionContext: 8192 total in 1 blocks; 6880 free (0 chunks);
 1312 used
LOG:  level: 1; MessageContext: 16384 total in 2 blocks; 5152 free (0 chunks); 11232
 used
LOG:  level: 1; Operator class cache: 8192 total in 1 blocks; 512 free (0 chunks); 7680
 used
LOG:  level: 1; smgr relation table: 16384 total in 2 blocks; 4544 free (3 chunks);
 11840 used
LOG:  level: 1; TransactionAbortContext: 32768 total in 1 blocks; 32504 free (0
 chunks); 264 used
...
LOG:  level: 1; ErrorContext: 8192 total in 1 blocks; 7928 free (3 chunks); 264 used
LOG:  Grand total: 1651920 bytes in 201 blocks; 622360 free (88 chunks); 1029560 used
```

If there are more than 100 child contexts under the same parent, the first 100 child contexts are logged, along with a summary of the remaining contexts. Note that frequent calls to this function could incur significant overhead, because it may generate a large number of log messages.

9.27.3. Backup Control Functions

The functions shown in Table 9.87 assist in making on-line backups. These functions cannot be executed during recovery (except non-exclusive `pg_start_backup`, non-exclusive `pg_stop_backup`, `pg_is_in_backup`, `pg_backup_start_time` and `pg_wal_lsn_diff`).

For details about proper usage of these functions, see Section 25.3.

Table 9.87. Backup Control Functions

Function Description
`pg_create_restore_point ( name text ) → pg_lsn` Creates a named marker record in the write-ahead log that can later be used as a recovery target, and returns the corresponding write-ahead log location. The given name can then be used with recovery_target_name to specify the point up to which recovery will proceed. Avoid creating multiple restore points with the same name, since recovery will stop at the first one whose name matches the recovery target. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
`pg_current_wal_flush_lsn () → pg_lsn` Returns the current write-ahead log flush location (see notes below).
`pg_current_wal_insert_lsn () → pg_lsn` Returns the current write-ahead log insert location (see notes below).
`pg_current_wal_lsn () → pg_lsn` Returns the current write-ahead log write location (see notes below).
`pg_start_backup ( label text [, fast boolean [, exclusive boolean ]] ) → pg_lsn` Prepares the server to begin an on-line backup. The only required parameter is an arbitrary user-defined label for the backup. (Typically this would be the name under which the backup dump file will be stored.) If the optional second parameter is given as `true`, it specifies executing `pg_start_backup` as quickly as possible. This forces an immediate checkpoint which will cause a spike in I/O operations, slowing any concurrently executing queries. The optional third parameter specifies whether to perform an exclusive or non-exclusive backup (default is exclusive). When used in exclusive mode, this function writes a backup label file (`backup_label`) and, if there are any links in the `pg_tblspc/` directory, a tablespace map file (`tablespace_map`) into the database cluster's data directory, then performs a checkpoint, and then returns the backup's starting write-ahead log location. (The user can ignore this result value, but it is provided in case it is useful.) When used in non-exclusive mode, the contents of these files are instead returned by the `pg_stop_backup` function, and should be copied to the backup area by the user. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
`pg_stop_backup ( exclusive boolean [, wait_for_archive boolean ] ) → setof record ( lsn pg_lsn , labelfile text, spcmapfile text )` Finishes performing an exclusive or non-exclusive on-line backup. The `exclusive` parameter must match the previous `pg_start_backup` call. In an exclusive backup, `pg_stop_backup` removes the backup label file and, if it exists, the tablespace map file created by `pg_start_backup`. In a non-exclusive backup, the desired contents of these files are returned as part of the result of the function, and should be written to files in the backup area (not in the data directory).

Function Description
There is an optional second parameter of type boolean. If false, the function will return immediately after the backup is completed, without waiting for WAL to be archived. This behavior is only useful with backup software that independently monitors WAL archiving. Otherwise, WAL required to make the backup consistent might be missing and make the backup useless. By default or when this parameter is true, pg_stop_backup will wait for WAL to be archived when archiving is enabled. (On a standby, this means that it will wait only when archive_mode = always. If write activity on the primary is low, it may be useful to run pg_switch_wal on the primary in order to trigger an immediate segment switch.) When executed on a primary, this function also creates a backup history file in the write-ahead log archive area. The history file includes the label given to pg_start_backup, the starting and ending write-ahead log locations for the backup, and the starting and ending times of the backup. After recording the ending location, the current write-ahead log insertion point is automatically advanced to the next write-ahead log file, so that the ending write-ahead log file can be archived immediately to complete the backup. The result of the function is a single record. The *lsn* column holds the backup's ending write-ahead log location (which again can be ignored). The second and third columns are NULL when ending an exclusive backup; after a non-exclusive backup they hold the desired contents of the label and tablespace map files. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_stop_backup () → pg_lsn Finishes performing an exclusive on-line backup. This simplified version is equivalent to pg_stop_backup(true, true), except that it only returns the pg_lsn result. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_is_in_backup () → boolean Returns true if an on-line exclusive backup is in progress.
pg_backup_start_time () → timestamp with time zone Returns the start time of the current on-line exclusive backup if one is in progress, otherwise NULL.
pg_switch_wal () → pg_lsn Forces the server to switch to a new write-ahead log file, which allows the current file to be archived (assuming you are using continuous archiving). The result is the ending write-ahead log location plus 1 within the just-completed write-ahead log file. If there has been no write-ahead log activity since the last write-ahead log switch, pg_switch_wal does nothing and returns the start location of the write-ahead log file currently in use. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_walfile_name (*lsn* pg_lsn) → text Converts a write-ahead log location to the name of the WAL file holding that location.
pg_walfile_name_offset (*lsn* pg_lsn) → record (*file_name* text, *file_offset* integer) Converts a write-ahead log location to a WAL file name and byte offset within that file.
pg_wal_lsn_diff (*lsn1* pg_lsn , *lsn2* pg_lsn) → numeric Calculates the difference in bytes (*lsn1* - *lsn2*) between two write-ahead log locations. This can be used with pg_stat_replication or some of the functions shown in Table 9.87 to get the replication lag.

pg_current_wal_lsn displays the current write-ahead log write location in the same format used by the above functions. Similarly, pg_current_wal_insert_lsn displays the current write-ahead log insertion location and pg_current_wal_flush_lsn displays the current write-ahead log flush location. The insertion location is the “logical” end of the write-ahead log at any instant, while the write location is the end

of what has actually been written out from the server's internal buffers, and the flush location is the last location known to be written to durable storage. The write location is the end of what can be examined from outside the server, and is usually what you want if you are interested in archiving partially-complete write-ahead log files. The insertion and flush locations are made available primarily for server debugging purposes. These are all read-only operations and do not require superuser permissions.

You can use `pg_walfile_name_offset` to extract the corresponding write-ahead log file name and byte offset from a `pg_lsn` value. For example:

```
postgres=# SELECT * FROM pg_walfile_name_offset(pg_stop_backup());
        file_name         | file_offset
--------------------------+-------------
 00000001000000000000000D |     4039624
(1 row)
```

Similarly, `pg_walfile_name` extracts just the write-ahead log file name. When the given write-ahead log location is exactly at a write-ahead log file boundary, both these functions return the name of the preceding write-ahead log file. This is usually the desired behavior for managing write-ahead log archiving behavior, since the preceding file is the last one that currently needs to be archived.

9.27.4. Recovery Control Functions

The functions shown in Table 9.88 provide information about the current status of a standby server. These functions may be executed both during recovery and in normal running.

Table 9.88. Recovery Information Functions

Function Description
`pg_is_in_recovery` () → `boolean` Returns true if recovery is still in progress.
`pg_last_wal_receive_lsn` () → `pg_lsn` Returns the last write-ahead log location that has been received and synced to disk by streaming replication. While streaming replication is in progress this will increase monotonically. If recovery has completed then this will remain static at the location of the last WAL record received and synced to disk during recovery. If streaming replication is disabled, or if it has not yet started, the function returns `NULL`.
`pg_last_wal_replay_lsn` () → `pg_lsn` Returns the last write-ahead log location that has been replayed during recovery. If recovery is still in progress this will increase monotonically. If recovery has completed then this will remain static at the location of the last WAL record applied during recovery. When the server has been started normally without recovery, the function returns `NULL`.
`pg_last_xact_replay_timestamp` () → `timestamp with time zone` Returns the time stamp of the last transaction replayed during recovery. This is the time at which the commit or abort WAL record for that transaction was generated on the primary. If no transactions have been replayed during recovery, the function returns `NULL`. Otherwise, if recovery is still in progress this will increase monotonically. If recovery has completed then this will remain static at the time of the last transaction applied during recovery. When the server has been started normally without recovery, the function returns `NULL`.

The functions shown in Table 9.89 control the progress of recovery. These functions may be executed only during recovery.

Table 9.89. Recovery Control Functions

Function Description
`pg_is_wal_replay_paused` () → `boolean`

Function Description
Returns true if recovery pause is requested.
`pg_get_wal_replay_pause_state` () → `text` Returns recovery pause state. The return values are `not paused` if pause is not requested, `pause requested` if pause is requested but recovery is not yet paused, and `paused` if the recovery is actually paused.
`pg_promote` (*`wait`* `boolean DEFAULT true`, *`wait_seconds`* `integer DEFAULT 60`) → `boolean` Promotes a standby server to primary status. With *`wait`* set to `true` (the default), the function waits until promotion is completed or *`wait_seconds`* seconds have passed, and returns `true` if promotion is successful and `false` otherwise. If *`wait`* is set to `false`, the function returns `true` immediately after sending a `SIGUSR1` signal to the postmaster to trigger promotion. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
`pg_wal_replay_pause` () → `void` Request to pause recovery. A request doesn't mean that recovery stops right away. If you want a guarantee that recovery is actually paused, you need to check for the recovery pause state returned by `pg_get_wal_replay_pause_state()`. Note that `pg_is_wal_replay_paused()` returns whether a request is made. While recovery is paused, no further database changes are applied. If hot standby is active, all new queries will see the same consistent snapshot of the database, and no further query conflicts will be generated until recovery is resumed. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
`pg_wal_replay_resume` () → `void` Restarts recovery if it was paused. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.

`pg_wal_replay_pause` and `pg_wal_replay_resume` cannot be executed while a promotion is ongoing. If a promotion is triggered while recovery is paused, the paused state ends and promotion continues.

If streaming replication is disabled, the paused state may continue indefinitely without a problem. If streaming replication is in progress then WAL records will continue to be received, which will eventually fill available disk space, depending upon the duration of the pause, the rate of WAL generation and available disk space.

9.27.5. Snapshot Synchronization Functions

Postgres Pro allows database sessions to synchronize their snapshots. A *snapshot* determines which data is visible to the transaction that is using the snapshot. Synchronized snapshots are necessary when two or more sessions need to see identical content in the database. If two sessions just start their transactions independently, there is always a possibility that some third transaction commits between the executions of the two `START TRANSACTION` commands, so that one session sees the effects of that transaction and the other does not.

To solve this problem, Postgres Pro allows a transaction to *export* the snapshot it is using. As long as the exporting transaction remains open, other transactions can *import* its snapshot, and thereby be guaranteed that they see exactly the same view of the database that the first transaction sees. But note that any database changes made by any one of these transactions remain invisible to the other transactions, as is usual for changes made by uncommitted transactions. So the transactions are synchronized with respect to pre-existing data, but act normally for changes they make themselves.

Snapshots are exported with the `pg_export_snapshot` function, shown in Table 9.90, and imported with the SET TRANSACTION command.

Table 9.90. Snapshot Synchronization Functions

Function Description
`pg_export_snapshot () → text` Saves the transaction's current snapshot and returns a `text` string identifying the snapshot. This string must be passed (outside the database) to clients that want to import the snapshot. The snapshot is available for import only until the end of the transaction that exported it. A transaction can export more than one snapshot, if needed. Note that doing so is only useful in `READ COMMITTED` transactions, since in `REPEATABLE READ` and higher isolation levels, transactions use the same snapshot throughout their lifetime. Once a transaction has exported any snapshots, it cannot be prepared with PREPARE TRANSACTION.

9.27.6. Replication Management Functions

The functions shown in Table 9.91 are for controlling and interacting with replication features. See Section 26.2.5, Section 26.2.6, and Chapter 52 for information about the underlying features. Use of functions for replication origin is only allowed to the superuser by default, but may be allowed to other users by using the `GRANT` command. Use of functions for replication slots is restricted to superusers and users having `REPLICATION` privilege.

Many of these functions have equivalent commands in the replication protocol; see Section 55.4.

The functions described in Section 9.27.3, Section 9.27.4, and Section 9.27.5 are also relevant for replication.

Table 9.91. Replication Management Functions

Function Description
`pg_create_physical_replication_slot ( slot_name name [, immediately_reserve boolean, temporary boolean ] ) → record ( slot_name name, lsn pg_lsn )` Creates a new physical replication slot named *slot_name*. The optional second parameter, when `true`, specifies that the LSN for this replication slot be reserved immediately; otherwise the LSN is reserved on first connection from a streaming replication client. Streaming changes from a physical slot is only possible with the streaming-replication protocol — see Section 55.4. The optional third parameter, *temporary*, when set to true, specifies that the slot should not be permanently stored to disk and is only meant for use by the current session. Temporary slots are also released upon any error. This function corresponds to the replication protocol command `CREATE_REPLICATION_SLOT ... PHYSICAL`.
`pg_drop_replication_slot ( slot_name name ) → void` Drops the physical or logical replication slot named *slot_name*. Same as replication protocol command `DROP_REPLICATION_SLOT`.
`pg_create_logical_replication_slot ( slot_name name, plugin name [, temporary boolean, twophase boolean ] ) → record ( slot_name name, lsn pg_lsn )` Creates a new logical (decoding) replication slot named *slot_name* using the output plugin *plugin*. The optional third parameter, *temporary*, when set to true, specifies that the slot should not be permanently stored to disk and is only meant for use by the current session. Temporary slots are also released upon any error. The optional fourth parameter, *twophase*, when set to true, specifies that the decoding of prepared transactions is enabled for this slot. A call to this function has the same effect as the replication protocol command `CREATE_REPLICATION_SLOT ... LOGICAL`.
`pg_copy_physical_replication_slot ( src_slot_name name, dst_slot_name name [, temporary boolean ] ) → record ( slot_name name, lsn pg_lsn )` Copies an existing physical replication slot named *src_slot_name* to a physical replication slot named *dst_slot_name*. The copied physical slot starts to reserve WAL from the same

Function **Description**
LSN as the source slot. *temporary* is optional. If *temporary* is omitted, the same value as the source slot is used.
pg_copy_logical_replication_slot (*src_slot_name* name, *dst_slot_name* name [, *temporary* boolean [, *plugin* name]]) → record (*slot_name* name, *lsn* pg_lsn) Copies an existing logical replication slot named *src_slot_name* to a logical replication slot named *dst_slot_name*, optionally changing the output plugin and persistence. The copied logical slot starts from the same LSN as the source logical slot. Both *temporary* and *plugin* are optional; if they are omitted, the values of the source slot are used.
pg_logical_slot_get_changes (*slot_name* name, *upto_lsn* pg_lsn , *upto_nchanges* integer, VARIADIC *options* text[]) → setof record (*lsn* pg_lsn , *xid* xid, *data* text) Returns changes in the slot *slot_name*, starting from the point from which changes have been consumed last. If *upto_lsn* and *upto_nchanges* are NULL, logical decoding will continue until end of WAL. If *upto_lsn* is non-NULL, decoding will include only those transactions which commit prior to the specified LSN. If *upto_nchanges* is non-NULL, decoding will stop when the number of rows produced by decoding exceeds the specified value. Note, however, that the actual number of rows returned may be larger, since this limit is only checked after adding the rows produced when decoding each new transaction commit.
pg_logical_slot_peek_changes (*slot_name* name, *upto_lsn* pg_lsn , *upto_nchanges* integer, VARIADIC *options* text[]) → setof record (*lsn* pg_lsn , *xid* xid, *data* text) Behaves just like the pg_logical_slot_get_changes() function, except that changes are not consumed; that is, they will be returned again on future calls.
pg_logical_slot_get_binary_changes (*slot_name* name, *upto_lsn* pg_lsn , *upto_nchanges* integer, VARIADIC *options* text[]) → setof record (*lsn* pg_lsn , *xid* xid, *data* bytea) Behaves just like the pg_logical_slot_get_changes() function, except that changes are returned as bytea.
pg_logical_slot_peek_binary_changes (*slot_name* name, *upto_lsn* pg_lsn , *upto_nchanges* integer, VARIADIC *options* text[]) → setof record (*lsn* pg_lsn , *xid* xid, *data* bytea) Behaves just like the pg_logical_slot_peek_changes() function, except that changes are returned as bytea.
pg_replication_slot_advance (*slot_name* name, *upto_lsn* pg_lsn) → record (*slot_name* name, *end_lsn* pg_lsn) Advances the current confirmed position of a replication slot named *slot_name*. The slot will not be moved backwards, and it will not be moved beyond the current insert location. Returns the name of the slot and the actual position that it was advanced to. The updated slot position information is written out at the next checkpoint if any advancing is done. So in the event of a crash, the slot may return to an earlier position.
pg_replication_origin_create (*node_name* text) → oid Creates a replication origin with the given external name, and returns the internal ID assigned to it.
pg_replication_origin_drop (*node_name* text) → void Deletes a previously-created replication origin, including any associated replay progress.
pg_replication_origin_oid (*node_name* text) → oid Looks up a replication origin by name and returns the internal ID. If no such replication origin is found, NULL is returned.
pg_replication_origin_session_setup (*node_name* text) → void

Function Description
Marks the current session as replaying from the given origin, allowing replay progress to be tracked. Can only be used if no origin is currently selected. Use `pg_replication_origin_session_reset` to undo.
`pg_replication_origin_session_reset` () → `void` Cancels the effects of `pg_replication_origin_session_setup()`.
`pg_replication_origin_session_is_setup` () → `boolean` Returns true if a replication origin has been selected in the current session.
`pg_replication_origin_session_progress` (*`flush`* `boolean`) → `pg_lsn` Returns the replay location for the replication origin selected in the current session. The parameter *`flush`* determines whether the corresponding local transaction will be guaranteed to have been flushed to disk or not.
`pg_replication_origin_xact_setup` (*`origin_lsn`* `pg_lsn` , *`origin_timestamp`* `timestamp with time zone`) → `void` Marks the current transaction as replaying a transaction that has committed at the given LSN and timestamp. Can only be called when a replication origin has been selected using `pg_replication_origin_session_setup`.
`pg_replication_origin_xact_reset` () → `void` Cancels the effects of `pg_replication_origin_xact_setup()`.
`pg_replication_origin_advance` (*`node_name`* `text`, *`lsn`* `pg_lsn`) → `void` Sets replication progress for the given node to the given location. This is primarily useful for setting up the initial location, or setting a new location after configuration changes and similar. Be aware that careless use of this function can lead to inconsistently replicated data.
`pg_replication_origin_progress` (*`node_name`* `text`, *`flush`* `boolean`) → `pg_lsn` Returns the replay location for the given replication origin. The parameter *`flush`* determines whether the corresponding local transaction will be guaranteed to have been flushed to disk or not.

`pg_logical_emit_message` (*`transactional`* `boolean`, *`prefix`* `text`, *`content`* `text`) → `pg_lsn`
`pg_logical_emit_message` (*`transactional`* `boolean`, *`prefix`* `text`, *`content`* `bytea`) → `pg_lsn`
Emits a logical decoding message. This can be used to pass generic messages to logical decoding plugins through WAL. The *`transactional`* parameter specifies if the message should be part of the current transaction, or if it should be written immediately and decoded as soon as the logical decoder reads the record. The *`prefix`* parameter is a textual prefix that can be used by logical decoding plugins to easily recognize messages that are interesting for them. The *`content`* parameter is the content of the message, given either in text or binary form.

9.27.7. Database Object Management Functions

The functions shown in Table 9.92 calculate the disk space usage of database objects, or assist in presentation or understanding of usage results. `bigint` results are measured in bytes. If an OID that does not represent an existing object is passed to one of these functions, `NULL` is returned.

Table 9.92. Database Object Size Functions

Function Description
`pg_column_size` (`"any"`) → `integer` Shows the number of bytes used to store any individual data value. If applied directly to a table column value, this reflects any compression that was done.
`pg_column_compression` (`"any"`) → `text`

Function Description
Shows the compression algorithm that was used to compress an individual variable-length value. Returns NULL if the value is not compressed.
pg_database_size (name) → bigint pg_database_size (oid) → bigint Computes the total disk space used by the database with the specified name or OID. To use this function, you must have CONNECT privilege on the specified database (which is granted by default) or be a member of the pg_read_all_stats role.
pg_indexes_size (regclass) → bigint Computes the total disk space used by indexes attached to the specified table.
pg_relation_size (*relation* regclass [, *fork* text]) → bigint Computes the disk space used by one "fork" of the specified relation. (Note that for most purposes it is more convenient to use the higher-level functions pg_total_relation_size or pg_table_size, which sum the sizes of all forks.) With one argument, this returns the size of the main data fork of the relation. The second argument can be provided to specify which fork to examine: • main returns the size of the main data fork of the relation. • fsm returns the size of the Free Space Map (see Section 70.3) associated with the relation. • vm returns the size of the Visibility Map (see Section 70.4) associated with the relation. • init returns the size of the initialization fork, if any, associated with the relation.
pg_temp_relation_size (*relation* regclass) → bigint Accepts the OID or name of a temporary table and returns the total size in bytes of main fork of that relation. We extend physical file for temp table when table doesn't fit into temp_ buffers cache anymore. So total and on-disk size of the temporary table can differ. For other kinds of relations it will not throw any error, just return NULL.
pg_size_bytes (text) → bigint Converts a size in human-readable format (as returned by pg_size_pretty) into bytes.
pg_size_pretty (bigint) → text pg_size_pretty (numeric) → text Converts a size in bytes into a more easily human-readable format with size units (bytes, kB, MB, GB or TB as appropriate). Note that the units are powers of 2 rather than powers of 10, so 1kB is 1024 bytes, 1MB is 1024^2 = 1048576 bytes, and so on.
pg_table_size (regclass) → bigint Computes the disk space used by the specified table, excluding indexes (but including its TOAST table if any, free space map, and visibility map).
pg_tablespace_size (name) → bigint pg_tablespace_size (oid) → bigint Computes the total disk space used in the tablespace with the specified name or OID. To use this function, you must have CREATE privilege on the specified tablespace or be a member of the pg_read_all_stats role, unless it is the default tablespace for the current database.
pg_total_relation_size (regclass) → bigint Computes the total disk space used by the specified table, including all indexes and TOAST data. The result is equivalent to pg_table_size + pg_indexes_size.

The functions above that operate on tables or indexes accept a regclass argument, which is simply the OID of the table or index in the pg_class system catalog. You do not have to look up the OID by hand, however, since the regclass data type's input converter will do the work for you. See Section 8.19 for details.

The functions shown in Table 9.93 assist in identifying the specific disk files associated with database objects.

Table 9.93. Database Object Location Functions

Function Description
`pg_relation_filenode ( relation regclass ) → oid` Returns the "filenode" number currently assigned to the specified relation. The filenode is the base component of the file name(s) used for the relation (see Section 70.1 for more information). For most relations the result is the same as `pg_class .relfilenode`, but for certain system catalogs `relfilenode` is zero and this function must be used to get the correct value. The function returns NULL if passed a relation that does not have storage, such as a view.
`pg_relation_filepath ( relation regclass ) → text` Returns the entire file path name (relative to the database cluster's data directory, `PGDATA`) of the relation.
`pg_filenode_relation ( tablespace oid, filenode oid ) → regclass` Returns a relation's OID given the tablespace OID and filenode it is stored under. This is essentially the inverse mapping of `pg_relation_filepath`. For a relation in the database's default tablespace, the tablespace can be specified as zero. Returns `NULL` if no relation in the current database is associated with the given values.

Table 9.94 lists functions used to manage collations.

Table 9.94. Collation Management Functions

Function Description
`pg_collation_actual_version ( oid ) → text` Returns the actual version of the collation object as it is currently installed in the operating system. If this is different from the value in `pg_collation .collversion`, then objects depending on the collation might need to be rebuilt. See also ALTER COLLATION.
`pg_import_system_collations ( schema regnamespace ) → integer` Adds collations to the system catalog `pg_collation` based on all the locales it finds in the operating system. This is what `initdb` uses; see Section 23.2.2 for more details. If additional locales are installed into the operating system later on, this function can be run again to add collations for the new locales. Locales that match existing entries in `pg_collation` will be skipped. (But collation objects based on locales that are no longer present in the operating system are not removed by this function.) The *schema* parameter would typically be `pg_catalog`, but that is not a requirement; the collations could be installed into some other schema as well. The function returns the number of new collation objects it created. Use of this function is restricted to superusers.

Table 9.95 lists functions that provide information about the structure of partitioned tables.

Table 9.95. Partitioning Information Functions

Function Description
`pg_partition_tree ( regclass ) → setof record ( relid regclass, parentrelid regclass, isleaf boolean, level integer )` Lists the tables or indexes in the partition tree of the given partitioned table or partitioned index, with one row for each partition. Information provided includes the OID of the partition, the OID of its immediate parent, a boolean value telling if the partition is a leaf, and an integer telling its level in the hierarchy. The level value is 0 for the input table or index, 1 for its immediate child partitions, 2 for their partitions, and so on. Returns no rows if the relation does not exist or is not a partition or partitioned table.

Function Description
`pg_partition_ancestors` (`regclass`) → `setof regclass` Lists the ancestor relations of the given partition, including the relation itself. Returns no rows if the relation does not exist or is not a partition or partitioned table.
`pg_partition_root` (`regclass`) → `regclass` Returns the top-most parent of the partition tree to which the given relation belongs. Returns `NULL` if the relation does not exist or is not a partition or partitioned table.

For example, to check the total size of the data contained in a partitioned table `measurement`, one could use the following query:

```
SELECT pg_size_pretty(sum(pg_relation_size(relid))) AS total_size
  FROM pg_partition_tree('measurement');
```

9.27.8. Index Maintenance Functions

Table 9.96 shows the functions available for index maintenance tasks. (Note that these maintenance tasks are normally done automatically by autovacuum; use of these functions is only required in special cases.) These functions cannot be executed during recovery. Use of these functions is restricted to superusers and the owner of the given index.

Table 9.96. Index Maintenance Functions

Function Description
`brin_summarize_new_values` (*`index`* `regclass`) → `integer` Scans the specified BRIN index to find page ranges in the base table that are not currently summarized by the index; for any such range it creates a new summary index tuple by scanning those table pages. Returns the number of new page range summaries that were inserted into the index.
`brin_summarize_range` (*`index`* `regclass`, *`blockNumber`* `bigint`) → `integer` Summarizes the page range covering the given block, if not already summarized. This is like `brin_summarize_new_values` except that it only processes the page range that covers the given table block number.
`brin_desummarize_range` (*`index`* `regclass`, *`blockNumber`* `bigint`) → `void` Removes the BRIN index tuple that summarizes the page range covering the given table block, if there is one.
`gin_clean_pending_list` (*`index`* `regclass`) → `bigint` Cleans up the “pending” list of the specified GIN index by moving entries in it, in bulk, to the main GIN data structure. Returns the number of pages removed from the pending list. If the argument is a GIN index built with the `fastupdate` option disabled, no cleanup happens and the result is zero, because the index doesn't have a pending list. See Section 67.4.1 and Section 67.5 for details about the pending list and `fastupdate` option.

9.27.9. Generic File Access Functions

The functions shown in Table 9.97 provide native access to files on the machine hosting the server. Only files within the database cluster directory and the `log_directory` can be accessed, unless the user is a superuser or is granted the role `pg_read_server_files`. Use a relative path for files in the cluster directory, and a path matching the `log_directory` configuration setting for log files.

Note that granting users the EXECUTE privilege on `pg_read_file()`, or related functions, allows them the ability to read any file on the server that the database server process can read; these functions bypass all in-database privilege checks. This means that, for example, a user with such access is able to read the contents of the `pg_authid` table where authentication information is stored, as well as read any table data in the database. Therefore, granting access to these functions should be carefully considered.

Some of these functions take an optional *missing_ok* parameter, which specifies the behavior when the file or directory does not exist. If `true`, the function returns `NULL` or an empty result set, as appropriate. If `false`, an error is raised. The default is `false`.

Table 9.97. Generic File Access Functions

Function Description
`pg_ls_dir ( dirname text [, missing_ok boolean, include_dot_dirs boolean ] ) → setof text` Returns the names of all files (and directories and other special files) in the specified directory. The *include_dot_dirs* parameter indicates whether "." and ".." are to be included in the result set; the default is to exclude them. Including them can be useful when *missing_ok* is `true`, to distinguish an empty directory from a non-existent directory. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
`pg_ls_logdir () → setof record ( name text, size bigint, modification timestamp with time zone )` Returns the name, size, and last modification time (mtime) of each ordinary file in the server's log directory. Filenames beginning with a dot, directories, and other special files are excluded. This function is restricted to superusers and members of the `pg_monitor` role by default, but other users can be granted EXECUTE to run the function.
`pg_ls_waldir () → setof record ( name text, size bigint, modification timestamp with time zone )` Returns the name, size, and last modification time (mtime) of each ordinary file in the server's write-ahead log (WAL) directory. Filenames beginning with a dot, directories, and other special files are excluded. This function is restricted to superusers and members of the `pg_monitor` role by default, but other users can be granted EXECUTE to run the function.
`pg_ls_archive_statusdir () → setof record ( name text, size bigint, modification timestamp with time zone )` Returns the name, size, and last modification time (mtime) of each ordinary file in the server's WAL archive status directory (`pg_wal/archive_status`). Filenames beginning with a dot, directories, and other special files are excluded. This function is restricted to superusers and members of the `pg_monitor` role by default, but other users can be granted EXECUTE to run the function.
`pg_ls_tmpdir ( [ tablespace oid ] ) → setof record ( name text, size bigint, modification timestamp with time zone )` Returns the name, size, and last modification time (mtime) of each ordinary file in the temporary file directory for the specified *tablespace*. If *tablespace* is not provided, the `pg_default` tablespace is examined. Filenames beginning with a dot, directories, and other special files are excluded. This function is restricted to superusers and members of the `pg_monitor` role by default, but other users can be granted EXECUTE to run the function.
`pg_read_file ( filename text [, offset bigint, length bigint [, missing_ok boolean ]] ) → text` Returns all or part of a text file, starting at the given byte *offset*, returning at most *length* bytes (less if the end of file is reached first). If *offset* is negative, it is relative to the end of the file. If *offset* and *length* are omitted, the entire file is returned. The bytes read from the file are interpreted as a string in the database's encoding; an error is thrown if they are not valid in that encoding. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.

Function Description

`pg_read_binary_file` (*filename* `text` [, *offset* `bigint`, *length* `bigint` [, *missing_ok* `boolean`]]) → `bytea`
Returns all or part of a file. This function is identical to `pg_read_file` except that it can read arbitrary binary data, returning the result as `bytea` not `text`; accordingly, no encoding checks are performed.
This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
In combination with the `convert_from` function, this function can be used to read a text file in a specified encoding and convert to the database's encoding:
`SELECT convert_from(pg_read_binary_file('file_in_utf8.txt'), 'UTF8');`

`pg_stat_file` (*filename* `text` [, *missing_ok* `boolean`]) → `record` (*size* `bigint`, *access* `timestamp with time zone`, *modification* `timestamp with time zone`, *change* `timestamp with time zone`, *creation* `timestamp with time zone`, *isdir* `boolean`) Returns a record containing the file's size, last access time stamp, last modification time stamp, last file status change time stamp (Unix platforms only), file creation time stamp (Windows only), and a flag indicating if it is a directory. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.

9.27.10. Advisory Lock Functions

The functions shown in Table 9.98 manage advisory locks. For details about proper use of these functions, see Section 13.3.5.

All these functions are intended to be used to lock application-defined resources, which can be identified either by a single 64-bit key value or two 32-bit key values (note that these two key spaces do not overlap). If another session already holds a conflicting lock on the same resource identifier, the functions will either wait until the resource becomes available, or return a `false` result, as appropriate for the function. Locks can be either shared or exclusive: a shared lock does not conflict with other shared locks on the same resource, only with exclusive locks. Locks can be taken at session level (so that they are held until released or the session ends) or at transaction level (so that they are held until the current transaction ends; there is no provision for manual release). Multiple session-level lock requests stack, so that if the same resource identifier is locked three times there must then be three unlock requests to release the resource in advance of session end.

Table 9.98. Advisory Lock Functions

Function Description

`pg_advisory_lock` (*key* `bigint`) → `void`
`pg_advisory_lock` (*key1* `integer`, *key2* `integer`) → `void`
Obtains an exclusive session-level advisory lock, waiting if necessary.

`pg_advisory_lock_shared` (*key* `bigint`) → `void`
`pg_advisory_lock_shared` (*key1* `integer`, *key2* `integer`) → `void`
Obtains a shared session-level advisory lock, waiting if necessary.

`pg_advisory_unlock` (*key* `bigint`) → `boolean`
`pg_advisory_unlock` (*key1* `integer`, *key2* `integer`) → `boolean`
Releases a previously-acquired exclusive session-level advisory lock. Returns `true` if the lock is successfully released. If the lock was not held, `false` is returned, and in addition, an SQL warning will be reported by the server.

`pg_advisory_unlock_all` () → `void`

Function Description
Releases all session-level advisory locks held by the current session. (This function is implicitly invoked at session end, even if the client disconnects ungracefully.)

`pg_advisory_unlock_shared` (*key* `bigint`) → `boolean`
`pg_advisory_unlock_shared` (*key1* `integer`, *key2* `integer`) → `boolean`
Releases a previously-acquired shared session-level advisory lock. Returns `true` if the lock is successfully released. If the lock was not held, `false` is returned, and in addition, an SQL warning will be reported by the server.

`pg_advisory_xact_lock` (*key* `bigint`) → `void`
`pg_advisory_xact_lock` (*key1* `integer`, *key2* `integer`) → `void`
Obtains an exclusive transaction-level advisory lock, waiting if necessary.

`pg_advisory_xact_lock_shared` (*key* `bigint`) → `void`
`pg_advisory_xact_lock_shared` (*key1* `integer`, *key2* `integer`) → `void`
Obtains a shared transaction-level advisory lock, waiting if necessary.

`pg_try_advisory_lock` (*key* `bigint`) → `boolean`
`pg_try_advisory_lock` (*key1* `integer`, *key2* `integer`) → `boolean`
Obtains an exclusive session-level advisory lock if available. This will either obtain the lock immediately and return `true`, or return `false` without waiting if the lock cannot be acquired immediately.

`pg_try_advisory_lock_shared` (*key* `bigint`) → `boolean`
`pg_try_advisory_lock_shared` (*key1* `integer`, *key2* `integer`) → `boolean`
Obtains a shared session-level advisory lock if available. This will either obtain the lock immediately and return `true`, or return `false` without waiting if the lock cannot be acquired immediately.

`pg_try_advisory_xact_lock` (*key* `bigint`) → `boolean`
`pg_try_advisory_xact_lock` (*key1* `integer`, *key2* `integer`) → `boolean`
Obtains an exclusive transaction-level advisory lock if available. This will either obtain the lock immediately and return `true`, or return `false` without waiting if the lock cannot be acquired immediately.

`pg_try_advisory_xact_lock_shared` (*key* `bigint`) → `boolean`
`pg_try_advisory_xact_lock_shared` (*key1* `integer`, *key2* `integer`) → `boolean`
Obtains a shared transaction-level advisory lock if available. This will either obtain the lock immediately and return `true`, or return `false` without waiting if the lock cannot be acquired immediately.

9.27.11. Compression Control Functions

The functions shown in Table 9.99 provide information about CFS state and activity and control CFS garbage collection.

Table 9.99. Compression Control Functions

Name	Return Type	Description
`cfs_start_gc(n_workers integer)`	`integer`	Starts garbage collection using the specified number of workers. You can only run this function to start the garbage collection manually if background garbage collection is disabled.

Name	Return Type	Description
`cfs_enable_gc(enabled boolean)`	`boolean`	Enables/disables background garbage collection. Alternatively, you can use the cfs_gc configuration variable.
`cfs_gc_relation(rel regclass)`	`integer`	Performs garbage collection for a particular table. This function returns the number of processed segments.
`cfs_version()`	`text`	Displays the CFS version and the specific compression algorithm used.
`cfs_estimate(rel regclass)`	`float8`	Estimates the effect of table compression. Returns the average compression ratio for the first ten blocks of the relation.
`cfs_compression_ratio(rel regclass)`	`float8`	Returns the actual compression ratio for all segments of the compressed relation.
`cfs_fragmentation(rel regclass)`	`float8`	Returns the average fragmentation ratio of the relation files.
`cfs_gc_activity_processed_bytes()`	`int64`	Returns the total size of pages processed by CFS during garbage collection.
`cfs_gc_activity_processed_pages()`	`int64`	Returns the number of pages processed by CFS during garbage collection.
`cfs_gc_activity_processed_files()`	`int64`	Returns the number of files compacted by CFS during garbage collection.
`cfs_gc_activity_scanned_files()`	`int64`	Returns the number of files scanned by CFS during garbage collection.

9.27.12. Operation Log Support Functions

An operation log stores information about system events of critical importance, such as an upgrade, execution of pg_resetwal and so on. This information is not interesting to regular users, but is highly useful for vendor's technical support. Recording to the operation log is only done at the system level (without any actions on the part of the user), and SQL functions are used to read the operation log. The function shown in Table 9.100 reads the operation log.

Table 9.100. Operation Log Support Functions

Function Description
`pg_operation_log` () → `setof record` (*`event`* `text`, *`edition`* `text`, *`version`* `text`, *`lsn`* `pg_lsn`, *`last`* `timestamptz`, *`count`* `int4`) Where: • *`event`* — event (operation) type. Can be `bootstrap`, `startup`, `pg_resetwal`, `pg_rewind`, `pg_upgrade` or `promoted`. • *`edition`* — Postgres Pro edition. Can be `vanilla`, `1c`, `std`, `ent` or `unknown`. • *`version`* — Postgres Pro version.

Function Description

• *lsn* — latest checkpoint location, returned by pg_controldata as of the moment when the event occurs.
• *last* — date/time of the last occurrence of this event type if events are accumulated or date/time of the event occurrence otherwise.
• *count* — number of events of this type if events are accumulated or 1 otherwise.
This system function is created automatically for new databases and needs to be created for existing databases, as follows:
`CREATE OR REPLACE FUNCTION`
`  pg_operation_log(`
`    OUT event text,`
`    OUT edition text,`
`    OUT version text,`
`    OUT lsn pg_lsn,`
`    OUT last timestamptz,`
`    OUT count int4)`
`  RETURNS SETOF record`
`  LANGUAGE INTERNAL`
`  STABLE STRICT PARALLEL SAFE`
`AS 'pg_operation_log';`

This is an example of what the pg_operation_log function returns:

```
select * from pg_operation_log();
   event    | edition | version |    lsn    |          last          | count
------------+---------+---------+-----------+------------------------+-------
 startup    | vanilla | 10.22.0 | 0/8000028 | 2022-10-27 23:06:27+03 |     1
 pg_upgrade | 1c      | 15.0.0  | 0/8000028 | 2022-10-27 23:06:27+03 |     1
 startup    | 1c      | 15.0.0  | 0/80001F8 | 2022-10-27 23:06:53+03 |     2
(3 rows)
```

Note

If an operation log is empty, before a record for pg_upgrade, a record is added for startup with the previous *version* having the following specifics: as there is no information in pg_upgrade on the patch version number of the previous version for each edition (1c, std, ent), the patch version number (third number in the version number) is set to zero. For an upgrade from 1c or vanilla, it cannot be distinguished whether the edition of the database before upgrade is vanilla or 1c, and vanilla edition is used for the startup record.

9.27.13. Debugging Functions

The function shown in Table 9.101 can assist you in low-level activities, such as debugging or exploring corrupted Postgres Pro databases.

Table 9.101. Snapshot Synchronization Functions

Name	Return Type	Description
pg_snapshot_any()	void	Sets the current transaction to ignore MVCC rules and see all versions of data.

Use pg_snapshot_any with care. Run it in a transaction with isolation level REPEATABLE READ or higher, otherwise the specific snapshot will be replaced by a new one by the next query. Only superusers can run this function.

Note

If you created the database cluster using the server version that did not provide this function, execute the command:

```
CREATE FUNCTION pg_snapshot_any() RETURNS void AS 'pg_snapshot_any' LANGUAGE
 internal;
```

9.28. Trigger Functions

While many uses of triggers involve user-written trigger functions, Postgres Pro provides a few built-in trigger functions that can be used directly in user-defined triggers. These are summarized in Table 9.102. (Additional built-in trigger functions exist, which implement foreign key constraints and deferred index constraints. Those are not documented here since users need not use them directly.)

For more information about creating triggers, see CREATE TRIGGER.

Table 9.102. Built-In Trigger Functions

Function **Description** **Example Usage**

`suppress_redundant_updates_trigger ( ) → trigger`
Suppresses do-nothing update operations. See below for details.
`CREATE TRIGGER ... suppress_redundant_updates_trigger()`

`tsvector_update_trigger ( ) → trigger`
Automatically updates a `tsvector` column from associated plain-text document column(s). The text search configuration to use is specified by name as a trigger argument. See Section 12.4.3 for details.
`CREATE TRIGGER ... tsvector_update_trigger(tsvcol, 'pg_catalog.swedish', title, body)`

`tsvector_update_trigger_column ( ) → trigger`
Automatically updates a `tsvector` column from associated plain-text document column(s). The text search configuration to use is taken from a `regconfig` column of the table. See Section 12.4.3 for details.
`CREATE TRIGGER ... tsvector_update_trigger_column(tsvcol, tsconfigcol, title, body)`

The `suppress_redundant_updates_trigger` function, when applied as a row-level `BEFORE UPDATE` trigger, will prevent any update that does not actually change the data in the row from taking place. This overrides the normal behavior which always performs a physical row update regardless of whether or not the data has changed. (This normal behavior makes updates run faster, since no checking is required, and is also useful in certain cases.)

Ideally, you should avoid running updates that don't actually change the data in the record. Redundant updates can cost considerable unnecessary time, especially if there are lots of indexes to alter, and space in dead rows that will eventually have to be vacuumed. However, detecting such situations in client code is not always easy, or even possible, and writing expressions to detect them can be error-prone. An alternative is to use `suppress_redundant_updates_trigger`, which will skip updates that don't change the data. You should use this with care, however. The trigger takes a small but non-trivial time for each record, so if most of the records affected by updates do actually change, use of this trigger will make updates run slower on average.

The `suppress_redundant_updates_trigger` function can be added to a table like this:

```
CREATE TRIGGER z_min_update
BEFORE UPDATE ON tablename
FOR EACH ROW EXECUTE FUNCTION suppress_redundant_updates_trigger();
```

In most cases, you need to fire this trigger last for each row, so that it does not override other triggers that might wish to alter the row. Bearing in mind that triggers fire in name order, you would therefore choose a trigger name that comes after the name of any other trigger you might have on the table. (Hence the “z” prefix in the example.)

9.29. Event Trigger Functions

Postgres Pro provides these helper functions to retrieve information from event triggers.

For more information about event triggers, see Chapter 42.

9.29.1. Capturing Changes at Command End

`pg_event_trigger_ddl_commands () → setof record`

`pg_event_trigger_ddl_commands` returns a list of DDL commands executed by each user action, when invoked in a function attached to a `ddl_command_end` event trigger. If called in any other context, an error is raised. `pg_event_trigger_ddl_commands` returns one row for each base command executed; some commands that are a single SQL sentence may return more than one row. This function returns the following columns:

Name	Type	Description
`classid`	`oid`	OID of catalog the object belongs in
`objid`	`oid`	OID of the object itself
`objsubid`	`integer`	Sub-object ID (e.g., attribute number for a column)
`command_tag`	`text`	Command tag
`object_type`	`text`	Type of the object
`schema_name`	`text`	Name of the schema the object belongs in, if any; otherwise `NULL`. No quoting is applied.
`object_identity`	`text`	Text rendering of the object identity, schema-qualified. Each identifier included in the identity is quoted if necessary.
`in_extension`	`boolean`	True if the command is part of an extension script
`command`	`pg_ddl_command`	A complete representation of the command, in internal format. This cannot be output directly, but it can be passed to other functions to obtain different pieces of information about the command.

9.29.2. Processing Objects Dropped by a DDL Command

`pg_event_trigger_dropped_objects () → setof record`

`pg_event_trigger_dropped_objects` returns a list of all objects dropped by the command in whose `sql_drop` event it is called. If called in any other context, an error is raised. This function returns the following columns:

Name	Type	Description
`classid`	`oid`	OID of catalog the object belonged in

Name	Type	Description
objid	oid	OID of the object itself
objsubid	integer	Sub-object ID (e.g., attribute number for a column)
original	boolean	True if this was one of the root object(s) of the deletion
normal	boolean	True if there was a normal dependency relationship in the dependency graph leading to this object
is_temporary	boolean	True if this was a temporary object
object_type	text	Type of the object
schema_name	text	Name of the schema the object belonged in, if any; otherwise NULL. No quoting is applied.
object_name	text	Name of the object, if the combination of schema and name can be used as a unique identifier for the object; otherwise NULL. No quoting is applied, and name is never schema-qualified.
object_identity	text	Text rendering of the object identity, schema-qualified. Each identifier included in the identity is quoted if necessary.
address_names	text[]	An array that, together with object_type and address_args, can be used by the pg_get_object_address function to recreate the object address in a remote server containing an identically named object of the same kind.
address_args	text[]	Complement for address_names

The pg_event_trigger_dropped_objects function can be used in an event trigger like this:

```
CREATE FUNCTION test_event_trigger_for_drops()
        RETURNS event_trigger LANGUAGE plpgsql AS $$
DECLARE
    obj record;
BEGIN
    FOR obj IN SELECT * FROM pg_event_trigger_dropped_objects()
    LOOP
        RAISE NOTICE '% dropped object: % %.% %',
                     tg_tag,
                     obj.object_type,
                     obj.schema_name,
                     obj.object_name,
                     obj.object_identity;
    END LOOP;
END;
$$;
```

```
CREATE EVENT TRIGGER test_event_trigger_for_drops
   ON sql_drop
   EXECUTE FUNCTION test_event_trigger_for_drops();
```

9.29.3. Handling a Table Rewrite Event

The functions shown in Table 9.103 provide information about a table for which a `table_rewrite` event has just been called. If called in any other context, an error is raised.

Table 9.103. Table Rewrite Information Functions

Function Description
`pg_event_trigger_table_rewrite_oid` () → `oid` Returns the OID of the table about to be rewritten.
`pg_event_trigger_table_rewrite_reason` () → `integer` Returns a code explaining the reason(s) for rewriting. The value is a bitmap built from the following values: `1` (the table has changed its persistence), `2` (default value of a column has changed), `4` (a column has a new data type) and `8` (the table access method has changed).

These functions can be used in an event trigger like this:

```
CREATE FUNCTION test_event_trigger_table_rewrite_oid()
 RETURNS event_trigger
 LANGUAGE plpgsql AS
$$
BEGIN
  RAISE NOTICE 'rewriting table % for reason %',
                pg_event_trigger_table_rewrite_oid()::regclass,
                pg_event_trigger_table_rewrite_reason();
END;
$$;

CREATE EVENT TRIGGER test_table_rewrite_oid
                  ON table_rewrite
   EXECUTE FUNCTION test_event_trigger_table_rewrite_oid();
```

9.30. Statistics Information Functions

Postgres Pro provides a function to inspect complex statistics defined using the `CREATE STATISTICS` command.

9.30.1. Inspecting MCV Lists

`pg_mcv_list_items ( pg_mcv_list ) → setof record`

`pg_mcv_list_items` returns a set of records describing all items stored in a multi-column MCV list. It returns the following columns:

Name	Type	Description
`index`	`integer`	index of the item in the MCV list
`values`	`text[]`	values stored in the MCV item
`nulls`	`boolean[]`	flags identifying `NULL` values
`frequency`	`double precision`	frequency of this MCV item
`base_frequency`	`double precision`	base frequency of this MCV item

The `pg_mcv_list_items` function can be used like this:

```
SELECT m.* FROM pg_statistic_ext join pg_statistic_ext_data on (oid = stxoid),
                pg_mcv_list_items(stxdmcv) m WHERE stxname = 'stts';
```

Values of the `pg_mcv_list` type can be obtained only from the `pg_statistic_ext_data.stxdmcv` column.

Chapter 10. Type Conversion

SQL statements can, intentionally or not, require the mixing of different data types in the same expression. Postgres Pro has extensive facilities for evaluating mixed-type expressions.

In many cases a user does not need to understand the details of the type conversion mechanism. However, implicit conversions done by Postgres Pro can affect the results of a query. When necessary, these results can be tailored by using *explicit* type conversion.

This chapter introduces the Postgres Pro type conversion mechanisms and conventions. Refer to the relevant sections in Chapter 8 and Chapter 9 for more information on specific data types and allowed functions and operators.

10.1. Overview

SQL is a strongly typed language. That is, every data item has an associated data type which determines its behavior and allowed usage. Postgres Pro has an extensible type system that is more general and flexible than other SQL implementations. Hence, most type conversion behavior in Postgres Pro is governed by general rules rather than by ad hoc heuristics. This allows the use of mixed-type expressions even with user-defined types.

The Postgres Pro scanner/parser divides lexical elements into five fundamental categories: integers, non-integer numbers, strings, identifiers, and key words. Constants of most non-numeric types are first classified as strings. The SQL language definition allows specifying type names with strings, and this mechanism can be used in Postgres Pro to start the parser down the correct path. For example, the query:

```
SELECT text 'Origin' AS "label", point '(0,0)' AS "value";

 label  | value
--------+-------
 Origin | (0,0)
(1 row)
```

has two literal constants, of type `text` and `point`. If a type is not specified for a string literal, then the placeholder type `unknown` is assigned initially, to be resolved in later stages as described below.

There are four fundamental SQL constructs requiring distinct type conversion rules in the Postgres Pro parser:

Function calls

Much of the Postgres Pro type system is built around a rich set of functions. Functions can have one or more arguments. Since Postgres Pro permits function overloading, the function name alone does not uniquely identify the function to be called; the parser must select the right function based on the data types of the supplied arguments.

Operators

Postgres Pro allows expressions with prefix (one-argument) operators, as well as infix (two-argument) operators. Like functions, operators can be overloaded, so the same problem of selecting the right operator exists.

Value Storage

SQL `INSERT` and `UPDATE` statements place the results of expressions into a table. The expressions in the statement must be matched up with, and perhaps converted to, the types of the target columns.

`UNION`, `CASE`, and related constructs

Since all query results from a unionized `SELECT` statement must appear in a single set of columns, the types of the results of each `SELECT` clause must be matched up and converted to a uniform set. Similarly, the result expressions of a `CASE` construct must be converted to a common type so that the `CASE` expression as a whole has a known output type. Some other constructs, such as `ARRAY[]`

and the GREATEST and LEAST functions, likewise require determination of a common type for several subexpressions.

The system catalogs store information about which conversions, or *casts*, exist between which data types, and how to perform those conversions. Additional casts can be added by the user with the CREATE CAST command. (This is usually done in conjunction with defining new data types. The set of casts between built-in types has been carefully crafted and is best not altered.)

An additional heuristic provided by the parser allows improved determination of the proper casting behavior among groups of types that have implicit casts. Data types are divided into several basic *type categories*, including boolean, numeric, string, bitstring, datetime, timespan, geometric, network, and user-defined. (For a list see Table 54.65; but note it is also possible to create custom type categories.) Within each category there can be one or more *preferred types*, which are preferred when there is a choice of possible types. With careful selection of preferred types and available implicit casts, it is possible to ensure that ambiguous expressions (those with multiple candidate parsing solutions) can be resolved in a useful way.

All type conversion rules are designed with several principles in mind:

- Implicit conversions should never have surprising or unpredictable outcomes.
- There should be no extra overhead in the parser or executor if a query does not need implicit type conversion. That is, if a query is well-formed and the types already match, then the query should execute without spending extra time in the parser and without introducing unnecessary implicit conversion calls in the query.
- Additionally, if a query usually requires an implicit conversion for a function, and if then the user defines a new function with the correct argument types, the parser should use this new function and no longer do implicit conversion to use the old function.

10.2. Operators

The specific operator that is referenced by an operator expression is determined using the following procedure. Note that this procedure is indirectly affected by the precedence of the operators involved, since that will determine which sub-expressions are taken to be the inputs of which operators. See Section 4.1.6 for more information.

Operator Type Resolution

1. Select the operators to be considered from the pg_operator system catalog. If a non-schema-qualified operator name was used (the usual case), the operators considered are those with the matching name and argument count that are visible in the current search path (see Section 5.9.3). If a qualified operator name was given, only operators in the specified schema are considered.

   - (Optional) If the search path finds multiple operators with identical argument types, only the one appearing earliest in the path is considered. Operators with different argument types are considered on an equal footing regardless of search path position.

2. Check for an operator accepting exactly the input argument types. If one exists (there can be only one exact match in the set of operators considered), use it. Lack of an exact match creates a security hazard when calling, via qualified name [1] (not typical), any operator found in a schema that permits untrusted users to create objects. In such situations, cast arguments to force an exact match.

   a. (Optional) If one argument of a binary operator invocation is of the unknown type, then assume it is the same type as the other argument for this check. Invocations involving two unknown inputs, or a prefix operator with an unknown input, will never find a match at this step.

   b. (Optional) If one argument of a binary operator invocation is of the unknown type and the other is of a domain type, next check to see if there is an operator accepting exactly the domain's base type on both sides; if so, use it.

[1] The hazard does not arise with a non-schema-qualified name, because a search path containing schemas that permit untrusted users to create objects is not a secure schema usage pattern.

3. Look for the best match.

   a. Discard candidate operators for which the input types do not match and cannot be converted (using an implicit conversion) to match. `unknown` literals are assumed to be convertible to anything for this purpose. If only one candidate remains, use it; else continue to the next step.

   b. If any input argument is of a domain type, treat it as being of the domain's base type for all subsequent steps. This ensures that domains act like their base types for purposes of ambiguous-operator resolution.

   c. Run through all candidates and keep those with the most exact matches on input types. Keep all candidates if none have exact matches. If only one candidate remains, use it; else continue to the next step.

   d. Run through all candidates and keep those that accept preferred types (of the input data type's type category) at the most positions where type conversion will be required. Keep all candidates if none accept preferred types. If only one candidate remains, use it; else continue to the next step.

   e. If any input arguments are `unknown`, check the type categories accepted at those argument positions by the remaining candidates. At each position, select the `string` category if any candidate accepts that category. (This bias towards string is appropriate since an unknown-type literal looks like a string.) Otherwise, if all the remaining candidates accept the same type category, select that category; otherwise fail because the correct choice cannot be deduced without more clues. Now discard candidates that do not accept the selected type category. Furthermore, if any candidate accepts a preferred type in that category, discard candidates that accept non-preferred types for that argument. Keep all candidates if none survive these tests. If only one candidate remains, use it; else continue to the next step.

   f. If there are both `unknown` and known-type arguments, and all the known-type arguments have the same type, assume that the `unknown` arguments are also of that type, and check which candidates can accept that type at the `unknown`-argument positions. If exactly one candidate passes this test, use it. Otherwise, fail.

Some examples follow.

Example 10.1. Square Root Operator Type Resolution

There is only one square root operator (prefix `|/`) defined in the standard catalog, and it takes an argument of type `double precision`. The scanner assigns an initial type of `integer` to the argument in this query expression:

```
SELECT |/ 40 AS "square root of 40";
 square root of 40
-------------------
 6.324555320336759
(1 row)
```

So the parser does a type conversion on the operand and the query is equivalent to:

```
SELECT |/ CAST(40 AS double precision) AS "square root of 40";
```

Example 10.2. String Concatenation Operator Type Resolution

A string-like syntax is used for working with string types and for working with complex extension types. Strings with unspecified type are matched with likely operator candidates.

An example with one unspecified argument:

```
SELECT text 'abc' || 'def' AS "text and unknown";

 text and unknown
------------------
 abcdef
```

```
(1 row)
```

In this case the parser looks to see if there is an operator taking `text` for both arguments. Since there is, it assumes that the second argument should be interpreted as type `text`.

Here is a concatenation of two values of unspecified types:

```
SELECT 'abc' || 'def' AS "unspecified";

 unspecified
-------------
 abcdef
(1 row)
```

In this case there is no initial hint for which type to use, since no types are specified in the query. So, the parser looks for all candidate operators and finds that there are candidates accepting both string-category and bit-string-category inputs. Since string category is preferred when available, that category is selected, and then the preferred type for strings, `text`, is used as the specific type to resolve the unknown-type literals as.

Example 10.3. Absolute-Value and Negation Operator Type Resolution

The Postgres Pro operator catalog has several entries for the prefix operator `@`, all of which implement absolute-value operations for various numeric data types. One of these entries is for type `float8`, which is the preferred type in the numeric category. Therefore, Postgres Pro will use that entry when faced with an `unknown` input:

```
SELECT @ '-4.5' AS "abs";
 abs
-----
 4.5
(1 row)
```

Here the system has implicitly resolved the unknown-type literal as type `float8` before applying the chosen operator. We can verify that `float8` and not some other type was used:

```
SELECT @ '-4.5e500' AS "abs";

ERROR:  "-4.5e500" is out of range for type double precision
```

On the other hand, the prefix operator `~` (bitwise negation) is defined only for integer data types, not for `float8`. So, if we try a similar case with `~`, we get:

```
SELECT ~ '20' AS "negation";

ERROR:  operator is not unique: ~ "unknown"
HINT:  Could not choose a best candidate operator. You might need to add
explicit type casts.
```

This happens because the system cannot decide which of the several possible `~` operators should be preferred. We can help it out with an explicit cast:

```
SELECT ~ CAST('20' AS int8) AS "negation";

 negation
----------
      -21
(1 row)
```

Example 10.4. Array Inclusion Operator Type Resolution

Here is another example of resolving an operator with one known and one unknown input:

```
SELECT array[1,2] <@ '{1,2,3}' as "is subset";
```

```
 is subset
-----------
 t
(1 row)
```

The Postgres Pro operator catalog has several entries for the infix operator `<@`, but the only two that could possibly accept an integer array on the left-hand side are array inclusion (`anyarray <@ anyarray`) and range inclusion (`anyelement <@ anyrange`). Since none of these polymorphic pseudo-types (see Section 8.21) are considered preferred, the parser cannot resolve the ambiguity on that basis. However, Step 3.f tells it to assume that the unknown-type literal is of the same type as the other input, that is, integer array. Now only one of the two operators can match, so array inclusion is selected. (Had range inclusion been selected, we would have gotten an error, because the string does not have the right format to be a range literal.)

Example 10.5. Custom Operator on a Domain Type

Users sometimes try to declare operators applying just to a domain type. This is possible but is not nearly as useful as it might seem, because the operator resolution rules are designed to select operators applying to the domain's base type. As an example consider

```
CREATE DOMAIN mytext AS text CHECK(...);
CREATE FUNCTION mytext_eq_text (mytext, text) RETURNS boolean AS ...;
CREATE OPERATOR = (procedure=mytext_eq_text, leftarg=mytext, rightarg=text);
CREATE TABLE mytable (val mytext);

SELECT * FROM mytable WHERE val = 'foo';
```

This query will not use the custom operator. The parser will first see if there is a `mytext = mytext` operator (Step 2.a), which there is not; then it will consider the domain's base type `text`, and see if there is a `text = text` operator (Step 2.b), which there is; so it resolves the `unknown`-type literal as `text` and uses the `text = text` operator. The only way to get the custom operator to be used is to explicitly cast the literal:

```
SELECT * FROM mytable WHERE val = text 'foo';
```

so that the `mytext = text` operator is found immediately according to the exact-match rule. If the best-match rules are reached, they actively discriminate against operators on domain types. If they did not, such an operator would create too many ambiguous-operator failures, because the casting rules always consider a domain as castable to or from its base type, and so the domain operator would be considered usable in all the same cases as a similarly-named operator on the base type.

10.3. Functions

The specific function that is referenced by a function call is determined using the following procedure.

Function Type Resolution

1. Select the functions to be considered from the `pg_proc` system catalog. If a non-schema-qualified function name was used, the functions considered are those with the matching name and argument count that are visible in the current search path (see Section 5.9.3). If a qualified function name was given, only functions in the specified schema are considered.

   a. (Optional) If the search path finds multiple functions of identical argument types, only the one appearing earliest in the path is considered. Functions of different argument types are considered on an equal footing regardless of search path position.

   b. (Optional) If a function is declared with a `VARIADIC` array parameter, and the call does not use the `VARIADIC` keyword, then the function is treated as if the array parameter were replaced by one or more occurrences of its element type, as needed to match the call. After such expansion the function might have effective argument types identical to some non-variadic function. In that case the function appearing earlier in the search path is used, or if the two functions are in the same schema, the non-variadic one is preferred.

This creates a security hazard when calling, via qualified name [2], a variadic function found in a schema that permits untrusted users to create objects. A malicious user can take control and execute arbitrary SQL functions as though you executed them. Substitute a call bearing the `VARIADIC` keyword, which bypasses this hazard. Calls populating `VARIADIC "any"` parameters often have no equivalent formulation containing the `VARIADIC` keyword. To issue those calls safely, the function's schema must permit only trusted users to create objects.

c. (Optional) Functions that have default values for parameters are considered to match any call that omits zero or more of the defaultable parameter positions. If more than one such function matches a call, the one appearing earliest in the search path is used. If there are two or more such functions in the same schema with identical parameter types in the non-defaulted positions (which is possible if they have different sets of defaultable parameters), the system will not be able to determine which to prefer, and so an “ambiguous function call” error will result if no better match to the call can be found.

This creates an availability hazard when calling, via qualified name[2], any function found in a schema that permits untrusted users to create objects. A malicious user can create a function with the name of an existing function, replicating that function's parameters and appending novel parameters having default values. This precludes new calls to the original function. To forestall this hazard, place functions in schemas that permit only trusted users to create objects.

2. Check for a function accepting exactly the input argument types. If one exists (there can be only one exact match in the set of functions considered), use it. Lack of an exact match creates a security hazard when calling, via qualified name[2], a function found in a schema that permits untrusted users to create objects. In such situations, cast arguments to force an exact match. (Cases involving `unknown` will never find a match at this step.)

3. If no exact match is found, see if the function call appears to be a special type conversion request. This happens if the function call has just one argument and the function name is the same as the (internal) name of some data type. Furthermore, the function argument must be either an unknown-type literal, or a type that is binary-coercible to the named data type, or a type that could be converted to the named data type by applying that type's I/O functions (that is, the conversion is either to or from one of the standard string types). When these conditions are met, the function call is treated as a form of `CAST` specification. [3]

4. Look for the best match.

   a. Discard candidate functions for which the input types do not match and cannot be converted (using an implicit conversion) to match. `unknown` literals are assumed to be convertible to anything for this purpose. If only one candidate remains, use it; else continue to the next step.

   b. If any input argument is of a domain type, treat it as being of the domain's base type for all subsequent steps. This ensures that domains act like their base types for purposes of ambiguous-function resolution.

   c. Run through all candidates and keep those with the most exact matches on input types. Keep all candidates if none have exact matches. If only one candidate remains, use it; else continue to the next step.

   d. Run through all candidates and keep those that accept preferred types (of the input data type's type category) at the most positions where type conversion will be required. Keep all candidates if none accept preferred types. If only one candidate remains, use it; else continue to the next step.

   e. If any input arguments are `unknown`, check the type categories accepted at those argument positions by the remaining candidates. At each position, select the `string` category if any candidate accepts that category. (This bias towards string is appropriate since an unknown-type literal looks like a string.) Otherwise, if all the remaining candidates accept the same type category,

[2] The hazard does not arise with a non-schema-qualified name, because a search path containing schemas that permit untrusted users to create objects is not a secure schema usage pattern.
[3] The reason for this step is to support function-style cast specifications in cases where there is not an actual cast function. If there is a cast function, it is conventionally named after its output type, and so there is no need to have a special case. See CREATE CAST for additional commentary.

select that category; otherwise fail because the correct choice cannot be deduced without more clues. Now discard candidates that do not accept the selected type category. Furthermore, if any candidate accepts a preferred type in that category, discard candidates that accept non-preferred types for that argument. Keep all candidates if none survive these tests. If only one candidate remains, use it; else continue to the next step.

f. If there are both `unknown` and known-type arguments, and all the known-type arguments have the same type, assume that the `unknown` arguments are also of that type, and check which candidates can accept that type at the `unknown`-argument positions. If exactly one candidate passes this test, use it. Otherwise, fail.

Note that the “best match” rules are identical for operator and function type resolution. Some examples follow.

Example 10.6. Rounding Function Argument Type Resolution

There is only one `round` function that takes two arguments; it takes a first argument of type `numeric` and a second argument of type `integer`. So the following query automatically converts the first argument of type `integer` to `numeric`:

```
SELECT round(4, 4);

 round
--------
 4.0000
(1 row)
```

That query is actually transformed by the parser to:

```
SELECT round(CAST (4 AS numeric), 4);
```

Since numeric constants with decimal points are initially assigned the type `numeric`, the following query will require no type conversion and therefore might be slightly more efficient:

```
SELECT round(4.0, 4);
```

Example 10.7. Variadic Function Resolution

```
CREATE FUNCTION public.variadic_example(VARIADIC numeric[]) RETURNS int
  LANGUAGE sql AS 'SELECT 1';
CREATE FUNCTION
```

This function accepts, but does not require, the VARIADIC keyword. It tolerates both integer and numeric arguments:

```
SELECT public.variadic_example(0),
       public.variadic_example(0.0),
       public.variadic_example(VARIADIC array[0.0]);
 variadic_example | variadic_example | variadic_example
------------------+------------------+------------------
                1 |                1 |                1
(1 row)
```

However, the first and second calls will prefer more-specific functions, if available:

```
CREATE FUNCTION public.variadic_example(numeric) RETURNS int
  LANGUAGE sql AS 'SELECT 2';
CREATE FUNCTION

CREATE FUNCTION public.variadic_example(int) RETURNS int
  LANGUAGE sql AS 'SELECT 3';
CREATE FUNCTION

SELECT public.variadic_example(0),
```

```
       public.variadic_example(0.0),
       public.variadic_example(VARIADIC array[0.0]);
 variadic_example | variadic_example | variadic_example
------------------+------------------+------------------
                3 |                2 |                1
(1 row)
```

Given the default configuration and only the first function existing, the first and second calls are insecure. Any user could intercept them by creating the second or third function. By matching the argument type exactly and using the `VARIADIC` keyword, the third call is secure.

Example 10.8. Substring Function Type Resolution

There are several `substr` functions, one of which takes types `text` and `integer`. If called with a string constant of unspecified type, the system chooses the candidate function that accepts an argument of the preferred category `string` (namely of type `text`).

```
SELECT substr('1234', 3);

 substr
--------
     34
(1 row)
```

If the string is declared to be of type `varchar`, as might be the case if it comes from a table, then the parser will try to convert it to become `text`:

```
SELECT substr(varchar '1234', 3);

 substr
--------
     34
(1 row)
```

This is transformed by the parser to effectively become:

```
SELECT substr(CAST (varchar '1234' AS text), 3);
```

> **Note**
>
> The parser learns from the `pg_cast` catalog that `text` and `varchar` are binary-compatible, meaning that one can be passed to a function that accepts the other without doing any physical conversion. Therefore, no type conversion call is really inserted in this case.

And, if the function is called with an argument of type `integer`, the parser will try to convert that to `text`:

```
SELECT substr(1234, 3);
ERROR:  function substr(integer, integer) does not exist
HINT:  No function matches the given name and argument types. You might need
to add explicit type casts.
```

This does not work because `integer` does not have an implicit cast to `text`. An explicit cast will work, however:

```
SELECT substr(CAST (1234 AS text), 3);

 substr
--------
     34
(1 row)
```

10.4. Value Storage

Values to be inserted into a table are converted to the destination column's data type according to the following steps.

Value Storage Type Conversion

1. Check for an exact match with the target.
2. Otherwise, try to convert the expression to the target type. This is possible if an *assignment cast* between the two types is registered in the `pg_cast` catalog (see CREATE CAST). Alternatively, if the expression is an unknown-type literal, the contents of the literal string will be fed to the input conversion routine for the target type.
3. Check to see if there is a sizing cast for the target type. A sizing cast is a cast from that type to itself. If one is found in the `pg_cast` catalog, apply it to the expression before storing into the destination column. The implementation function for such a cast always takes an extra parameter of type `integer`, which receives the destination column's `atttypmod` value (typically its declared length, although the interpretation of `atttypmod` varies for different data types), and it may take a third `boolean` parameter that says whether the cast is explicit or implicit. The cast function is responsible for applying any length-dependent semantics such as size checking or truncation.

Example 10.9. `character` Storage Type Conversion

For a target column declared as `character(20)` the following statement shows that the stored value is sized correctly:

```
CREATE TABLE vv (v character(20));
INSERT INTO vv SELECT 'abc' || 'def';
SELECT v, octet_length(v) FROM vv;

          v           | octet_length
----------------------+--------------
 abcdef               |           20
(1 row)
```

What has really happened here is that the two unknown literals are resolved to `text` by default, allowing the `||` operator to be resolved as `text` concatenation. Then the `text` result of the operator is converted to `bpchar` ("blank-padded char", the internal name of the `character` data type) to match the target column type. (Since the conversion from `text` to `bpchar` is binary-coercible, this conversion does not insert any real function call.) Finally, the sizing function `bpchar(bpchar, integer, boolean)` is found in the system catalog and applied to the operator's result and the stored column length. This type-specific function performs the required length check and addition of padding spaces.

10.5. `UNION`, `CASE`, and Related Constructs

SQL `UNION` constructs must match up possibly dissimilar types to become a single result set. The resolution algorithm is applied separately to each output column of a union query. The `INTERSECT` and `EXCEPT` constructs resolve dissimilar types in the same way as `UNION`. Some other constructs, including `CASE`, `ARRAY`, `VALUES`, and the `GREATEST` and `LEAST` functions, use the identical algorithm to match up their component expressions and select a result data type.

Type Resolution for `UNION`, `CASE`, and Related Constructs

1. If all inputs are of the same type, and it is not `unknown`, resolve as that type.
2. If any input is of a domain type, treat it as being of the domain's base type for all subsequent steps. [4]
3. If all inputs are of type `unknown`, resolve as type `text` (the preferred type of the string category). Otherwise, `unknown` inputs are ignored for the purposes of the remaining rules.

[4] Somewhat like the treatment of domain inputs for operators and functions, this behavior allows a domain type to be preserved through a `UNION` or similar construct, so long as the user is careful to ensure that all inputs are implicitly or explicitly of that exact type. Otherwise the domain's base type will be used.

4. If the non-unknown inputs are not all of the same type category, fail.
5. Select the first non-unknown input type as the candidate type, then consider each other non-unknown input type, left to right. [5] If the candidate type can be implicitly converted to the other type, but not vice-versa, select the other type as the new candidate type. Then continue considering the remaining inputs. If, at any stage of this process, a preferred type is selected, stop considering additional inputs.
6. Convert all inputs to the final candidate type. Fail if there is not an implicit conversion from a given input type to the candidate type.

Some examples follow.

Example 10.10. Type Resolution with Underspecified Types in a Union

```
SELECT text 'a' AS "text" UNION SELECT 'b';

 text
------
 a
 b
(2 rows)
```

Here, the unknown-type literal `'b'` will be resolved to type `text`.

Example 10.11. Type Resolution in a Simple Union

```
SELECT 1.2 AS "numeric" UNION SELECT 1;

 numeric
---------
       1
     1.2
(2 rows)
```

The literal `1.2` is of type `numeric`, and the `integer` value `1` can be cast implicitly to `numeric`, so that type is used.

Example 10.12. Type Resolution in a Transposed Union

```
SELECT 1 AS "real" UNION SELECT CAST('2.2' AS REAL);

 real
------
    1
  2.2
(2 rows)
```

Here, since type `real` cannot be implicitly cast to `integer`, but `integer` can be implicitly cast to `real`, the union result type is resolved as `real`.

Example 10.13. Type Resolution in a Nested Union

```
SELECT NULL UNION SELECT NULL UNION SELECT 1;

ERROR:  UNION types text and integer cannot be matched
```

This failure occurs because Postgres Pro treats multiple `UNION`s as a nest of pairwise operations; that is, this input is the same as

```
(SELECT NULL UNION SELECT NULL) UNION SELECT 1;
```

The inner `UNION` is resolved as emitting type `text`, according to the rules given above. Then the outer `UNION` has inputs of types `text` and `integer`, leading to the observed error. The problem can be fixed by ensuring that the leftmost `UNION` has at least one input of the desired result type.

[5] For historical reasons, `CASE` treats its `ELSE` clause (if any) as the "first" input, with the `THEN` clauses(s) considered after that. In all other cases, "left to right" means the order in which the expressions appear in the query text.

INTERSECT and EXCEPT operations are likewise resolved pairwise. However, the other constructs described in this section consider all of their inputs in one resolution step.

10.6. SELECT Output Columns

The rules given in the preceding sections will result in assignment of non-unknown data types to all expressions in an SQL query, except for unspecified-type literals that appear as simple output columns of a SELECT command. For example, in

```
SELECT 'Hello World';
```

there is nothing to identify what type the string literal should be taken as. In this situation Postgres Pro will fall back to resolving the literal's type as text.

When the SELECT is one arm of a UNION (or INTERSECT or EXCEPT) construct, or when it appears within INSERT ... SELECT, this rule is not applied since rules given in preceding sections take precedence. The type of an unspecified-type literal can be taken from the other UNION arm in the first case, or from the destination column in the second case.

RETURNING lists are treated the same as SELECT output lists for this purpose.

> **Note**
>
> Prior to Postgres Pro 10, this rule did not exist, and unspecified-type literals in a SELECT output list were left as type unknown. That had assorted bad consequences, so it's been changed.

Chapter 11. Indexes

Indexes are a common way to enhance database performance. An index allows the database server to find and retrieve specific rows much faster than it could do without an index. But indexes also add overhead to the database system as a whole, so they should be used sensibly.

11.1. Introduction

Suppose we have a table similar to this:

```
CREATE TABLE test1 (
    id integer,
    content varchar
);
```

and the application issues many queries of the form:

```
SELECT content FROM test1 WHERE id = constant;
```

With no advance preparation, the system would have to scan the entire `test1` table, row by row, to find all matching entries. If there are many rows in `test1` and only a few rows (perhaps zero or one) that would be returned by such a query, this is clearly an inefficient method. But if the system has been instructed to maintain an index on the `id` column, it can use a more efficient method for locating matching rows. For instance, it might only have to walk a few levels deep into a search tree.

A similar approach is used in most non-fiction books: terms and concepts that are frequently looked up by readers are collected in an alphabetic index at the end of the book. The interested reader can scan the index relatively quickly and flip to the appropriate page(s), rather than having to read the entire book to find the material of interest. Just as it is the task of the author to anticipate the items that readers are likely to look up, it is the task of the database programmer to foresee which indexes will be useful.

The following command can be used to create an index on the `id` column, as discussed:

```
CREATE INDEX test1_id_index ON test1 (id);
```

The name `test1_id_index` can be chosen freely, but you should pick something that enables you to remember later what the index was for.

To remove an index, use the `DROP INDEX` command. Indexes can be added to and removed from tables at any time.

Once an index is created, no further intervention is required: the system will update the index when the table is modified, and it will use the index in queries when it thinks doing so would be more efficient than a sequential table scan. But you might have to run the `ANALYZE` command regularly to update statistics to allow the query planner to make educated decisions. See Chapter 14 for information about how to find out whether an index is used and when and why the planner might choose *not* to use an index.

Indexes can also benefit `UPDATE` and `DELETE` commands with search conditions. Indexes can moreover be used in join searches. Thus, an index defined on a column that is part of a join condition can also significantly speed up queries with joins.

In general, PostgreSQL indexes can be used to optimize queries that contain one or more `WHERE` or `JOIN` clauses of the form

indexed-column indexable-operator comparison-value

Here, the *indexed-column* is whatever column or expression the index has been defined on. The *indexable-operator* is an operator that is a member of the index's *operator class* for the indexed column. (More details about that appear below.) And the *comparison-value* can be any expression that is not volatile and does not reference the index's table.

In some cases the query planner can extract an indexable clause of this form from another SQL construct. A simple example is that if the original clause was

comparison-value operator indexed-column

then it can be flipped around into indexable form if the original *operator* has a commutator operator that is a member of the index's operator class.

Creating an index on a large table can take a long time. By default, Postgres Pro allows reads (SELECT statements) to occur on the table in parallel with index creation, but writes (INSERT, UPDATE, DELETE) are blocked until the index build is finished. In production environments this is often unacceptable. It is possible to allow writes to occur in parallel with index creation, but there are several caveats to be aware of — for more information see Building Indexes Concurrently.

After an index is created, the system has to keep it synchronized with the table. This adds overhead to data manipulation operations. Indexes can also prevent the creation of heap-only tuples. Therefore indexes that are seldom or never used in queries should be removed.

11.2. Index Types

Postgres Pro provides several index types: B-tree, Hash, GiST, SP-GiST, GIN, BRIN, and the extension bloom. Each index type uses a different algorithm that is best suited to different types of indexable clauses. By default, the CREATE INDEX command creates B-tree indexes, which fit the most common situations. The other index types are selected by writing the keyword USING followed by the index type name. For example, to create a Hash index:

```
CREATE INDEX name ON table USING HASH (column);
```

11.2.1. B-Tree

B-trees can handle equality and range queries on data that can be sorted into some ordering. In particular, the Postgres Pro query planner will consider using a B-tree index whenever an indexed column is involved in a comparison using one of these operators:

```
<    <=    =    >=    >
```

Constructs equivalent to combinations of these operators, such as BETWEEN and IN, can also be implemented with a B-tree index search. Also, an IS NULL or IS NOT NULL condition on an index column can be used with a B-tree index.

The optimizer can also use a B-tree index for queries involving the pattern matching operators LIKE and ~ *if* the pattern is a constant and is anchored to the beginning of the string — for example, col LIKE 'foo%' or col ~ '^foo', but not col LIKE '%bar'. However, if your database does not use the C locale you will need to create the index with a special operator class to support indexing of pattern-matching queries; see Section 11.10 below. It is also possible to use B-tree indexes for ILIKE and ~*, but only if the pattern starts with non-alphabetic characters, i.e., characters that are not affected by upper/lower case conversion.

B-tree indexes can also be used to retrieve data in sorted order. This is not always faster than a simple scan and sort, but it is often helpful.

B-tree indexes are also capable of optimizing “nearest-neighbor” searches, such as

```
SELECT * FROM events ORDER BY event_date <-> date '2017-05-05' LIMIT 10;
```

which finds the ten events closest to a given target date. The ability to do this is again dependent on the particular operator class being used.

11.2.2. Hash

Hash indexes store a 32-bit hash code derived from the value of the indexed column. Hence, such indexes can only handle simple equality comparisons. The query planner will consider using a hash index whenever an indexed column is involved in a comparison using the equal operator:

=

11.2.3. GiST

GiST indexes are not a single kind of index, but rather an infrastructure within which many different indexing strategies can be implemented. Accordingly, the particular operators with which a GiST index can be used vary depending on the indexing strategy (the *operator class*). As an example, the standard distribution of Postgres Pro includes GiST operator classes for several two-dimensional geometric data types, which support indexed queries using these operators:

```
<<   &<   &>   >>   <<|   &<|   |&>   |>>   @>   <@   ~=   &&
```

(See Section 9.11 for the meaning of these operators.) The GiST operator classes included in the standard distribution are documented in Table 65.1. Many other GiST operator classes are available in the `contrib` collection or as separate projects. For more information see Chapter 65.

GiST indexes are also capable of optimizing "nearest-neighbor" searches, such as

```
SELECT * FROM places ORDER BY location <-> point '(101,456)' LIMIT 10;
```

which finds the ten places closest to a given target point. The ability to do this is again dependent on the particular operator class being used. In Table 65.1, operators that can be used in this way are listed in the column "Ordering Operators".

11.2.4. SP-GiST

SP-GiST indexes, like GiST indexes, offer an infrastructure that supports various kinds of searches. SP-GiST permits implementation of a wide range of different non-balanced disk-based data structures, such as quadtrees, k-d trees, and radix trees (tries). As an example, the standard distribution of Postgres Pro includes SP-GiST operator classes for two-dimensional points, which support indexed queries using these operators:

```
<<   >>   ~=   <@   <<|   |>>
```

(See Section 9.11 for the meaning of these operators.) The SP-GiST operator classes included in the standard distribution are documented in Table 66.1. For more information see Chapter 66.

Like GiST, SP-GiST supports "nearest-neighbor" searches. For SP-GiST operator classes that support distance ordering, the corresponding operator is listed in the "Ordering Operators" column in Table 66.1.

11.2.5. GIN

GIN indexes are "inverted indexes" which are appropriate for data values that contain multiple component values, such as arrays. An inverted index contains a separate entry for each component value, and can efficiently handle queries that test for the presence of specific component values.

Like GiST and SP-GiST, GIN can support many different user-defined indexing strategies, and the particular operators with which a GIN index can be used vary depending on the indexing strategy. As an example, the standard distribution of Postgres Pro includes a GIN operator class for arrays, which supports indexed queries using these operators:

```
<@   @>   =   &&
```

(See Section 9.19 for the meaning of these operators.) The GIN operator classes included in the standard distribution are documented in Table 67.1. Many other GIN operator classes are available in the `contrib` collection or as separate projects. For more information see Chapter 67.

11.2.6. BRIN

BRIN indexes (a shorthand for Block Range INdexes) store summaries about the values stored in consecutive physical block ranges of a table. Thus, they are most effective for columns whose values are well-correlated with the physical order of the table rows. Like GiST, SP-GiST and GIN, BRIN can support many different indexing strategies, and the particular operators with which a BRIN index can be used

vary depending on the indexing strategy. For data types that have a linear sort order, the indexed data corresponds to the minimum and maximum values of the values in the column for each block range. This supports indexed queries using these operators:

```
<    <=    =    >=    >
```

The BRIN operator classes included in the standard distribution are documented in Table 68.1. For more information see Chapter 68.

11.3. Multicolumn Indexes

An index can be defined on more than one column of a table. For example, if you have a table of this form:

```
CREATE TABLE test2 (
  major int,
  minor int,
  name varchar
);
```

(say, you keep your `/dev` directory in a database...) and you frequently issue queries like:

```
SELECT name FROM test2 WHERE major = constant AND minor = constant;
```

then it might be appropriate to define an index on the columns `major` and `minor` together, e.g.:

```
CREATE INDEX test2_mm_idx ON test2 (major, minor);
```

Currently, only the B-tree, GiST, GIN, and BRIN index types support multiple-key-column indexes. Whether there can be multiple key columns is independent of whether `INCLUDE` columns can be added to the index. Indexes can have up to 32 columns, including `INCLUDE` columns. (This limit can be altered when building Postgres Pro.)

A multicolumn B-tree index can be used with query conditions that involve any subset of the index's columns, but the index is most efficient when there are constraints on the leading (leftmost) columns. The exact rule is that equality constraints on leading columns, plus any inequality constraints on the first column that does not have an equality constraint, will be used to limit the portion of the index that is scanned. Constraints on columns to the right of these columns are checked in the index, so they save visits to the table proper, but they do not reduce the portion of the index that has to be scanned. For example, given an index on `(a, b, c)` and a query condition `WHERE a = 5 AND b >= 42 AND c < 77`, the index would have to be scanned from the first entry with `a` = 5 and `b` = 42 up through the last entry with `a` = 5. Index entries with `c` >= 77 would be skipped, but they'd still have to be scanned through. This index could in principle be used for queries that have constraints on `b` and/or `c` with no constraint on `a` — but the entire index would have to be scanned, so in most cases the planner would prefer a sequential table scan over using the index.

A multicolumn GiST index can be used with query conditions that involve any subset of the index's columns. Conditions on additional columns restrict the entries returned by the index, but the condition on the first column is the most important one for determining how much of the index needs to be scanned. A GiST index will be relatively ineffective if its first column has only a few distinct values, even if there are many distinct values in additional columns.

A multicolumn GIN index can be used with query conditions that involve any subset of the index's columns. Unlike B-tree or GiST, index search effectiveness is the same regardless of which index column(s) the query conditions use.

A multicolumn BRIN index can be used with query conditions that involve any subset of the index's columns. Like GIN and unlike B-tree or GiST, index search effectiveness is the same regardless of which index column(s) the query conditions use. The only reason to have multiple BRIN indexes instead of one multicolumn BRIN index on a single table is to have a different `pages_per_range` storage parameter.

Of course, each column must be used with operators appropriate to the index type; clauses that involve other operators will not be considered.

Multicolumn indexes should be used sparingly. In most situations, an index on a single column is sufficient and saves space and time. Indexes with more than three columns are unlikely to be helpful unless the usage of the table is extremely stylized. See also Section 11.5 and Section 11.9 for some discussion of the merits of different index configurations.

11.4. Indexes and ORDER BY

In addition to simply finding the rows to be returned by a query, an index may be able to deliver them in a specific sorted order. This allows a query's ORDER BY specification to be honored without a separate sorting step. Of the index types currently supported by Postgres Pro, only B-tree can produce sorted output — the other index types return matching rows in an unspecified, implementation-dependent order.

The planner will consider satisfying an ORDER BY specification either by scanning an available index that matches the specification, or by scanning the table in physical order and doing an explicit sort. For a query that requires scanning a large fraction of the table, an explicit sort is likely to be faster than using an index because it requires less disk I/O due to following a sequential access pattern. Indexes are more useful when only a few rows need be fetched. An important special case is ORDER BY in combination with LIMIT *n*: an explicit sort will have to process all the data to identify the first *n* rows, but if there is an index matching the ORDER BY, the first *n* rows can be retrieved directly, without scanning the remainder at all.

By default, B-tree indexes store their entries in ascending order with nulls last (table TID is treated as a tiebreaker column among otherwise equal entries). This means that a forward scan of an index on column x produces output satisfying ORDER BY x (or more verbosely, ORDER BY x ASC NULLS LAST). The index can also be scanned backward, producing output satisfying ORDER BY x DESC (or more verbosely, ORDER BY x DESC NULLS FIRST, since NULLS FIRST is the default for ORDER BY DESC).

You can adjust the ordering of a B-tree index by including the options ASC, DESC, NULLS FIRST, and/or NULLS LAST when creating the index; for example:

```
CREATE INDEX test2_info_nulls_low ON test2 (info NULLS FIRST);
CREATE INDEX test3_desc_index ON test3 (id DESC NULLS LAST);
```

An index stored in ascending order with nulls first can satisfy either ORDER BY x ASC NULLS FIRST or ORDER BY x DESC NULLS LAST depending on which direction it is scanned in.

You might wonder why bother providing all four options, when two options together with the possibility of backward scan would cover all the variants of ORDER BY. In single-column indexes the options are indeed redundant, but in multicolumn indexes they can be useful. Consider a two-column index on (x, y): this can satisfy ORDER BY x, y if we scan forward, or ORDER BY x DESC, y DESC if we scan backward. But it might be that the application frequently needs to use ORDER BY x ASC, y DESC. There is no way to get that ordering from a plain index, but it is possible if the index is defined as (x ASC, y DESC) or (x DESC, y ASC).

Obviously, indexes with non-default sort orderings are a fairly specialized feature, but sometimes they can produce tremendous speedups for certain queries. Whether it's worth maintaining such an index depends on how often you use queries that require a special sort ordering.

11.5. Combining Multiple Indexes

A single index scan can only use query clauses that use the index's columns with operators of its operator class and are joined with AND. For example, given an index on (a, b) a query condition like WHERE a = 5 AND b = 6 could use the index, but a query like WHERE a = 5 OR b = 6 could not directly use the index.

Fortunately, Postgres Pro has the ability to combine multiple indexes (including multiple uses of the same index) to handle cases that cannot be implemented by single index scans. The system can form AND and OR conditions across several index scans. For example, a query like WHERE x = 42 OR x = 47 OR x = 53 OR x = 99 could be broken down into four separate scans of an index on x, each scan using one of the query clauses. The results of these scans are then ORed together to produce the result. Another example is that if we have separate indexes on x and y, one possible implementation of a query

like `WHERE x = 5 AND y = 6` is to use each index with the appropriate query clause and then AND together the index results to identify the result rows.

To combine multiple indexes, the system scans each needed index and prepares a *bitmap* in memory giving the locations of table rows that are reported as matching that index's conditions. The bitmaps are then ANDed and ORed together as needed by the query. Finally, the actual table rows are visited and returned. The table rows are visited in physical order, because that is how the bitmap is laid out; this means that any ordering of the original indexes is lost, and so a separate sort step will be needed if the query has an `ORDER BY` clause. For this reason, and because each additional index scan adds extra time, the planner will sometimes choose to use a simple index scan even though additional indexes are available that could have been used as well.

In all but the simplest applications, there are various combinations of indexes that might be useful, and the database developer must make trade-offs to decide which indexes to provide. Sometimes multicolumn indexes are best, but sometimes it's better to create separate indexes and rely on the index-combination feature. For example, if your workload includes a mix of queries that sometimes involve only column `x`, sometimes only column `y`, and sometimes both columns, you might choose to create two separate indexes on `x` and `y`, relying on index combination to process the queries that use both columns. You could also create a multicolumn index on `(x, y)`. This index would typically be more efficient than index combination for queries involving both columns, but as discussed in Section 11.3, it would be almost useless for queries involving only `y`, so it should not be the only index. A combination of the multicolumn index and a separate index on `y` would serve reasonably well. For queries involving only `x`, the multicolumn index could be used, though it would be larger and hence slower than an index on `x` alone. The last alternative is to create all three indexes, but this is probably only reasonable if the table is searched much more often than it is updated and all three types of query are common. If one of the types of query is much less common than the others, you'd probably settle for creating just the two indexes that best match the common types.

11.6. Unique Indexes

Indexes can also be used to enforce uniqueness of a column's value, or the uniqueness of the combined values of more than one column.

```
CREATE UNIQUE INDEX name ON table (column [, ...]);
```

Currently, only B-tree indexes can be declared unique.

When an index is declared unique, multiple table rows with equal indexed values are not allowed. Null values are not considered equal. A multicolumn unique index will only reject cases where all indexed columns are equal in multiple rows.

Postgres Pro automatically creates a unique index when a unique constraint or primary key is defined for a table. The index covers the columns that make up the primary key or unique constraint (a multicolumn index, if appropriate), and is the mechanism that enforces the constraint.

> **Note**
>
> There's no need to manually create indexes on unique columns; doing so would just duplicate the automatically-created index.

11.7. Indexes on Expressions

An index column need not be just a column of the underlying table, but can be a function or scalar expression computed from one or more columns of the table. This feature is useful to obtain fast access to tables based on the results of computations.

For example, a common way to do case-insensitive comparisons is to use the `lower` function:

```
SELECT * FROM test1 WHERE lower(col1) = 'value';
```

This query can use an index if one has been defined on the result of the `lower(col1)` function:

```
CREATE INDEX test1_lower_col1_idx ON test1 (lower(col1));
```

If we were to declare this index `UNIQUE`, it would prevent creation of rows whose `col1` values differ only in case, as well as rows whose `col1` values are actually identical. Thus, indexes on expressions can be used to enforce constraints that are not definable as simple unique constraints.

As another example, if one often does queries like:

```
SELECT * FROM people WHERE (first_name || ' ' || last_name) = 'John Smith';
```

then it might be worth creating an index like this:

```
CREATE INDEX people_names ON people ((first_name || ' ' || last_name));
```

The syntax of the `CREATE INDEX` command normally requires writing parentheses around index expressions, as shown in the second example. The parentheses can be omitted when the expression is just a function call, as in the first example.

Index expressions are relatively expensive to maintain, because the derived expression(s) must be computed for each row insertion and non-HOT update. However, the index expressions are *not* recomputed during an indexed search, since they are already stored in the index. In both examples above, the system sees the query as just `WHERE indexedcolumn = 'constant'` and so the speed of the search is equivalent to any other simple index query. Thus, indexes on expressions are useful when retrieval speed is more important than insertion and update speed.

11.8. Partial Indexes

A *partial index* is an index built over a subset of a table; the subset is defined by a conditional expression (called the *predicate* of the partial index). The index contains entries only for those table rows that satisfy the predicate. Partial indexes are a specialized feature, but there are several situations in which they are useful.

One major reason for using a partial index is to avoid indexing common values. Since a query searching for a common value (one that accounts for more than a few percent of all the table rows) will not use the index anyway, there is no point in keeping those rows in the index at all. This reduces the size of the index, which will speed up those queries that do use the index. It will also speed up many table update operations because the index does not need to be updated in all cases. Example 11.1 shows a possible application of this idea.

Example 11.1. Setting up a Partial Index to Exclude Common Values

Suppose you are storing web server access logs in a database. Most accesses originate from the IP address range of your organization but some are from elsewhere (say, employees on dial-up connections). If your searches by IP are primarily for outside accesses, you probably do not need to index the IP range that corresponds to your organization's subnet.

Assume a table like this:

```
CREATE TABLE access_log (
    url varchar,
    client_ip inet,
    ...
);
```

To create a partial index that suits our example, use a command such as this:

```
CREATE INDEX access_log_client_ip_ix ON access_log (client_ip)
WHERE NOT (client_ip > inet '192.168.100.0' AND
           client_ip < inet '192.168.100.255');
```

A typical query that can use this index would be:

```
SELECT *
FROM access_log
WHERE url = '/index.html' AND client_ip = inet '212.78.10.32';
```

Here the query's IP address is covered by the partial index. The following query cannot use the partial index, as it uses an IP address that is excluded from the index:

```
SELECT *
FROM access_log
WHERE url = '/index.html' AND client_ip = inet '192.168.100.23';
```

Observe that this kind of partial index requires that the common values be predetermined, so such partial indexes are best used for data distributions that do not change. Such indexes can be recreated occasionally to adjust for new data distributions, but this adds maintenance effort.

Another possible use for a partial index is to exclude values from the index that the typical query workload is not interested in; this is shown in Example 11.2. This results in the same advantages as listed above, but it prevents the “uninteresting” values from being accessed via that index, even if an index scan might be profitable in that case. Obviously, setting up partial indexes for this kind of scenario will require a lot of care and experimentation.

Example 11.2. Setting up a Partial Index to Exclude Uninteresting Values

If you have a table that contains both billed and unbilled orders, where the unbilled orders take up a small fraction of the total table and yet those are the most-accessed rows, you can improve performance by creating an index on just the unbilled rows. The command to create the index would look like this:

```
CREATE INDEX orders_unbilled_index ON orders (order_nr)
    WHERE billed is not true;
```

A possible query to use this index would be:

```
SELECT * FROM orders WHERE billed is not true AND order_nr < 10000;
```

However, the index can also be used in queries that do not involve `order_nr` at all, e.g.:

```
SELECT * FROM orders WHERE billed is not true AND amount > 5000.00;
```

This is not as efficient as a partial index on the `amount` column would be, since the system has to scan the entire index. Yet, if there are relatively few unbilled orders, using this partial index just to find the unbilled orders could be a win.

Note that this query cannot use this index:

```
SELECT * FROM orders WHERE order_nr = 3501;
```

The order 3501 might be among the billed or unbilled orders.

Example 11.2 also illustrates that the indexed column and the column used in the predicate do not need to match. Postgres Pro supports partial indexes with arbitrary predicates, so long as only columns of the table being indexed are involved. However, keep in mind that the predicate must match the conditions used in the queries that are supposed to benefit from the index. To be precise, a partial index can be used in a query only if the system can recognize that the `WHERE` condition of the query mathematically implies the predicate of the index. Postgres Pro does not have a sophisticated theorem prover that can recognize mathematically equivalent expressions that are written in different forms. (Not only is such a general theorem prover extremely difficult to create, it would probably be too slow to be of any real use.) The system can recognize simple inequality implications, for example “x < 1” implies “x < 2”; otherwise the predicate condition must exactly match part of the query's `WHERE` condition or the index will not be recognized as usable. Matching takes place at query planning time, not at run time. As a result, parameterized query clauses do not work with a partial index. For example a prepared query with a parameter might specify “x < ?” which will never imply “x < 2” for all possible values of the parameter.

A third possible use for partial indexes does not require the index to be used in queries at all. The idea here is to create a unique index over a subset of a table, as in Example 11.3. This enforces uniqueness among the rows that satisfy the index predicate, without constraining those that do not.

Example 11.3. Setting up a Partial Unique Index

Suppose that we have a table describing test outcomes. We wish to ensure that there is only one “successful” entry for a given subject and target combination, but there might be any number of “unsuccessful” entries. Here is one way to do it:

```
CREATE TABLE tests (
    subject text,
    target text,
    success boolean,
    ...
);

CREATE UNIQUE INDEX tests_success_constraint ON tests (subject, target)
    WHERE success;
```

This is a particularly efficient approach when there are few successful tests and many unsuccessful ones. It is also possible to allow only one null in a column by creating a unique partial index with an `IS NULL` restriction.

Finally, a partial index can also be used to override the system's query plan choices. Also, data sets with peculiar distributions might cause the system to use an index when it really should not. In that case the index can be set up so that it is not available for the offending query. Normally, Postgres Pro makes reasonable choices about index usage (e.g., it avoids them when retrieving common values, so the earlier example really only saves index size, it is not required to avoid index usage), and grossly incorrect plan choices are cause for a bug report.

Keep in mind that setting up a partial index indicates that you know at least as much as the query planner knows, in particular you know when an index might be profitable. Forming this knowledge requires experience and understanding of how indexes in Postgres Pro work. In most cases, the advantage of a partial index over a regular index will be minimal. There are cases where they are quite counterproductive, as in Example 11.4.

Example 11.4. Do Not Use Partial Indexes as a Substitute for Partitioning

You might be tempted to create a large set of non-overlapping partial indexes, for example

```
CREATE INDEX mytable_cat_1 ON mytable (data) WHERE category = 1;
CREATE INDEX mytable_cat_2 ON mytable (data) WHERE category = 2;
CREATE INDEX mytable_cat_3 ON mytable (data) WHERE category = 3;
...
CREATE INDEX mytable_cat_N ON mytable (data) WHERE category = N;
```

This is a bad idea! Almost certainly, you'll be better off with a single non-partial index, declared like

```
CREATE INDEX mytable_cat_data ON mytable (category, data);
```

(Put the category column first, for the reasons described in Section 11.3.) While a search in this larger index might have to descend through a couple more tree levels than a search in a smaller index, that's almost certainly going to be cheaper than the planner effort needed to select the appropriate one of the partial indexes. The core of the problem is that the system does not understand the relationship among the partial indexes, and will laboriously test each one to see if it's applicable to the current query.

If your table is large enough that a single index really is a bad idea, you should look into using partitioning instead (see Section 5.11). With that mechanism, the system does understand that the tables and indexes are non-overlapping, so far better performance is possible.

More information about partial indexes can be found in ston89b, olson93, and seshadri95.

11.9. Index-Only Scans and Covering Indexes

All indexes in Postgres Pro are *secondary* indexes, meaning that each index is stored separately from the table's main data area (which is called the table's *heap* in Postgres Pro terminology). This means

that in an ordinary index scan, each row retrieval requires fetching data from both the index and the heap. Furthermore, while the index entries that match a given indexable `WHERE` condition are usually close together in the index, the table rows they reference might be anywhere in the heap. The heap-access portion of an index scan thus involves a lot of random access into the heap, which can be slow, particularly on traditional rotating media. (As described in Section 11.5, bitmap scans try to alleviate this cost by doing the heap accesses in sorted order, but that only goes so far.)

To solve this performance problem, Postgres Pro supports *index-only scans*, which can answer queries from an index alone without any heap access. The basic idea is to return values directly out of each index entry instead of consulting the associated heap entry. There are two fundamental restrictions on when this method can be used:

1. The index type must support index-only scans. B-tree indexes always do. GiST and SP-GiST indexes support index-only scans for some operator classes but not others. Other index types have no support. The underlying requirement is that the index must physically store, or else be able to reconstruct, the original data value for each index entry. As a counterexample, GIN indexes cannot support index-only scans because each index entry typically holds only part of the original data value.
2. The query must reference only columns stored in the index. For example, given an index on columns `x` and `y` of a table that also has a column `z`, these queries could use index-only scans:

   ```
   SELECT x, y FROM tab WHERE x = 'key';
   SELECT x FROM tab WHERE x = 'key' AND y < 42;
   ```

   but these queries could not:

   ```
   SELECT x, z FROM tab WHERE x = 'key';
   SELECT x FROM tab WHERE x = 'key' AND z < 42;
   ```

   (Expression indexes and partial indexes complicate this rule, as discussed below.)

If these two fundamental requirements are met, then all the data values required by the query are available from the index, so an index-only scan is physically possible. But there is an additional requirement for any table scan in Postgres Pro: it must verify that each retrieved row be “visible” to the query's MVCC snapshot, as discussed in Chapter 13. Visibility information is not stored in index entries, only in heap entries; so at first glance it would seem that every row retrieval would require a heap access anyway. And this is indeed the case, if the table row has been modified recently. However, for seldom-changing data there is a way around this problem. Postgres Pro tracks, for each page in a table's heap, whether all rows stored in that page are old enough to be visible to all current and future transactions. This information is stored in a bit in the table's *visibility map*. An index-only scan, after finding a candidate index entry, checks the visibility map bit for the corresponding heap page. If it's set, the row is known visible and so the data can be returned with no further work. If it's not set, the heap entry must be visited to find out whether it's visible, so no performance advantage is gained over a standard index scan. Even in the successful case, this approach trades visibility map accesses for heap accesses; but since the visibility map is four orders of magnitude smaller than the heap it describes, far less physical I/O is needed to access it. In most situations the visibility map remains cached in memory all the time.

In short, while an index-only scan is possible given the two fundamental requirements, it will be a win only if a significant fraction of the table's heap pages have their all-visible map bits set. But tables in which a large fraction of the rows are unchanging are common enough to make this type of scan very useful in practice.

To make effective use of the index-only scan feature, you might choose to create a *covering index*, which is an index specifically designed to include the columns needed by a particular type of query that you run frequently. Since queries typically need to retrieve more columns than just the ones they search on, Postgres Pro allows you to create an index in which some columns are just “payload” and are not part of the search key. This is done by adding an `INCLUDE` clause listing the extra columns. For example, if you commonly run queries like

```
SELECT y FROM tab WHERE x = 'key';
```

the traditional approach to speeding up such queries would be to create an index on `x` only. However, an index defined as

```
CREATE INDEX tab_x_y ON tab(x) INCLUDE (y);
```

could handle these queries as index-only scans, because `y` can be obtained from the index without visiting the heap.

Because column `y` is not part of the index's search key, it does not have to be of a data type that the index can handle; it's merely stored in the index and is not interpreted by the index machinery. Also, if the index is a unique index, that is

```
CREATE UNIQUE INDEX tab_x_y ON tab(x) INCLUDE (y);
```

the uniqueness condition applies to just column `x`, not to the combination of `x` and `y`. (An `INCLUDE` clause can also be written in `UNIQUE` and `PRIMARY KEY` constraints, providing alternative syntax for setting up an index like this.)

It's wise to be conservative about adding non-key payload columns to an index, especially wide columns. If an index tuple exceeds the maximum size allowed for the index type, data insertion will fail. In any case, non-key columns duplicate data from the index's table and bloat the size of the index, thus potentially slowing searches. And remember that there is little point in including payload columns in an index unless the table changes slowly enough that an index-only scan is likely to not need to access the heap. If the heap tuple must be visited anyway, it costs nothing more to get the column's value from there. Other restrictions are that expressions are not currently supported as included columns, and that only B-tree, GiST and SP-GiST indexes currently support included columns.

Before Postgres Pro had the `INCLUDE` feature, people sometimes made covering indexes by writing the payload columns as ordinary index columns, that is writing

```
CREATE INDEX tab_x_y ON tab(x, y);
```

even though they had no intention of ever using `y` as part of a `WHERE` clause. This works fine as long as the extra columns are trailing columns; making them be leading columns is unwise for the reasons explained in Section 11.3. However, this method doesn't support the case where you want the index to enforce uniqueness on the key column(s).

Suffix truncation always removes non-key columns from upper B-Tree levels. As payload columns, they are never used to guide index scans. The truncation process also removes one or more trailing key column(s) when the remaining prefix of key column(s) happens to be sufficient to describe tuples on the lowest B-Tree level. In practice, covering indexes without an `INCLUDE` clause often avoid storing columns that are effectively payload in the upper levels. However, explicitly defining payload columns as non-key columns *reliably* keeps the tuples in upper levels small.

In principle, index-only scans can be used with expression indexes. For example, given an index on `f(x)` where `x` is a table column, it should be possible to execute

```
SELECT f(x) FROM tab WHERE f(x) < 1;
```

as an index-only scan; and this is very attractive if `f()` is an expensive-to-compute function. However, Postgres Pro's planner is currently not very smart about such cases. It considers a query to be potentially executable by index-only scan only when all *columns* needed by the query are available from the index. In this example, `x` is not needed except in the context `f(x)`, but the planner does not notice that and concludes that an index-only scan is not possible. If an index-only scan seems sufficiently worthwhile, this can be worked around by adding `x` as an included column, for example

```
CREATE INDEX tab_f_x ON tab (f(x)) INCLUDE (x);
```

An additional caveat, if the goal is to avoid recalculating `f(x)`, is that the planner won't necessarily match uses of `f(x)` that aren't in indexable `WHERE` clauses to the index column. It will usually get this right in simple queries such as shown above, but not in queries that involve joins. These deficiencies may be remedied in future versions of Postgres Pro.

Partial indexes also have interesting interactions with index-only scans. Consider the partial index shown in Example 11.3:

```
CREATE UNIQUE INDEX tests_success_constraint ON tests (subject, target)
    WHERE success;
```

In principle, we could do an index-only scan on this index to satisfy a query like

```
SELECT target FROM tests WHERE subject = 'some-subject' AND success;
```

But there's a problem: the `WHERE` clause refers to `success` which is not available as a result column of the index. Nonetheless, an index-only scan is possible because the plan does not need to recheck that part of the `WHERE` clause at run time: all entries found in the index necessarily have `success = true` so this need not be explicitly checked in the plan. Postgres Pro versions 9.6 and later will recognize such cases and allow index-only scans to be generated, but older versions will not.

11.10. Operator Classes and Operator Families

An index definition can specify an *operator class* for each column of an index.

```
CREATE INDEX name ON table (column opclass [ ( opclass_options ) ] [sort options]
 [, ...]);
```

The operator class identifies the operators to be used by the index for that column. For example, a B-tree index on the type `int4` would use the `int4_ops` class; this operator class includes comparison functions for values of type `int4`. In practice the default operator class for the column's data type is usually sufficient. The main reason for having operator classes is that for some data types, there could be more than one meaningful index behavior. For example, we might want to sort a complex-number data type either by absolute value or by real part. We could do this by defining two operator classes for the data type and then selecting the proper class when making an index. The operator class determines the basic sort ordering (which can then be modified by adding sort options `COLLATE`, `ASC`/`DESC` and/or `NULLS FIRST`/`NULLS LAST`).

There are also some built-in operator classes besides the default ones:

- The operator classes `text_pattern_ops`, `varchar_pattern_ops`, and `bpchar_pattern_ops` support B-tree indexes on the types `text`, `varchar`, and `char` respectively. The difference from the default operator classes is that the values are compared strictly character by character rather than according to the locale-specific collation rules. This makes these operator classes suitable for use by queries involving pattern matching expressions (`LIKE` or POSIX regular expressions) when the database does not use the standard “C” locale. As an example, you might index a `varchar` column like this:

  ```
  CREATE INDEX test_index ON test_table (col varchar_pattern_ops);
  ```

  Note that you should also create an index with the default operator class if you want queries involving ordinary `<`, `<=`, `>`, or `>=` comparisons to use an index. Such queries cannot use the *xxx*`_pattern_ops` operator classes. (Ordinary equality comparisons can use these operator classes, however.) It is possible to create multiple indexes on the same column with different operator classes. If you do use the C locale, you do not need the *xxx*`_pattern_ops` operator classes, because an index with the default operator class is usable for pattern-matching queries in the C locale.

The following query shows all defined operator classes:

```
SELECT am.amname AS index_method,
       opc.opcname AS opclass_name,
       opc.opcintype::regtype AS indexed_type,
       opc.opcdefault AS is_default
    FROM pg_am am, pg_opclass opc
    WHERE opc.opcmethod = am.oid
    ORDER BY index_method, opclass_name;
```

An operator class is actually just a subset of a larger structure called an *operator family*. In cases where several data types have similar behaviors, it is frequently useful to define cross-data-type operators and allow these to work with indexes. To do this, the operator classes for each of the types must be grouped

into the same operator family. The cross-type operators are members of the family, but are not associated with any single class within the family.

This expanded version of the previous query shows the operator family each operator class belongs to:

```
SELECT am.amname AS index_method,
       opc.opcname AS opclass_name,
       opf.opfname AS opfamily_name,
       opc.opcintype::regtype AS indexed_type,
       opc.opcdefault AS is_default
    FROM pg_am am, pg_opclass opc, pg_opfamily opf
    WHERE opc.opcmethod = am.oid AND
          opc.opcfamily = opf.oid
    ORDER BY index_method, opclass_name;
```

This query shows all defined operator families and all the operators included in each family:

```
SELECT am.amname AS index_method,
       opf.opfname AS opfamily_name,
       amop.amopopr::regoperator AS opfamily_operator
    FROM pg_am am, pg_opfamily opf, pg_amop amop
    WHERE opf.opfmethod = am.oid AND
          amop.amopfamily = opf.oid
    ORDER BY index_method, opfamily_name, opfamily_operator;
```

Tip

psql has commands `\dAc`, `\dAf`, and `\dAo`, which provide slightly more sophisticated versions of these queries.

11.11. Indexes and Collations

An index can support only one collation per index column. If multiple collations are of interest, multiple indexes may be needed.

Consider these statements:

```
CREATE TABLE test1c (
    id integer,
    content varchar COLLATE "x"
);

CREATE INDEX test1c_content_index ON test1c (content);
```

The index automatically uses the collation of the underlying column. So a query of the form

```
SELECT * FROM test1c WHERE content > constant;
```

could use the index, because the comparison will by default use the collation of the column. However, this index cannot accelerate queries that involve some other collation. So if queries of the form, say,

```
SELECT * FROM test1c WHERE content > constant COLLATE "y";
```

are also of interest, an additional index could be created that supports the `"y"` collation, like this:

```
CREATE INDEX test1c_content_y_index ON test1c (content COLLATE "y");
```

11.12. Examining Index Usage

Although indexes in Postgres Pro do not need maintenance or tuning, it is still important to check which indexes are actually used by the real-life query workload. Examining index usage for an individual query

is done with the EXPLAIN command; its application for this purpose is illustrated in Section 14.1. It is also possible to gather overall statistics about index usage in a running server, as described in Section 27.2.

It is difficult to formulate a general procedure for determining which indexes to create. There are a number of typical cases that have been shown in the examples throughout the previous sections. A good deal of experimentation is often necessary. The rest of this section gives some tips for that:

- Always run ANALYZE first. This command collects statistics about the distribution of the values in the table. This information is required to estimate the number of rows returned by a query, which is needed by the planner to assign realistic costs to each possible query plan. In absence of any real statistics, some default values are assumed, which are almost certain to be inaccurate. Examining an application's index usage without having run `ANALYZE` is therefore a lost cause. See Section 24.1.3 and Section 24.1.6 for more information.
- Use real data for experimentation. Using test data for setting up indexes will tell you what indexes you need for the test data, but that is all.

  It is especially fatal to use very small test data sets. While selecting 1000 out of 100000 rows could be a candidate for an index, selecting 1 out of 100 rows will hardly be, because the 100 rows probably fit within a single disk page, and there is no plan that can beat sequentially fetching 1 disk page.

  Also be careful when making up test data, which is often unavoidable when the application is not yet in production. Values that are very similar, completely random, or inserted in sorted order will skew the statistics away from the distribution that real data would have.
- When indexes are not used, it can be useful for testing to force their use. There are run-time parameters that can turn off various plan types (see Section 19.7.1). For instance, turning off sequential scans (`enable_seqscan`) and nested-loop joins (`enable_nestloop`), which are the most basic plans, will force the system to use a different plan. If the system still chooses a sequential scan or nested-loop join then there is probably a more fundamental reason why the index is not being used; for example, the query condition does not match the index. (What kind of query can use what kind of index is explained in the previous sections.)
- If forcing index usage does use the index, then there are two possibilities: Either the system is right and using the index is indeed not appropriate, or the cost estimates of the query plans are not reflecting reality. So you should time your query with and without indexes. The `EXPLAIN ANALYZE` command can be useful here.
- If it turns out that the cost estimates are wrong, there are, again, two possibilities. The total cost is computed from the per-row costs of each plan node times the selectivity estimate of the plan node. The costs estimated for the plan nodes can be adjusted via run-time parameters (described in Section 19.7.2). An inaccurate selectivity estimate is due to insufficient statistics. It might be possible to improve this by tuning the statistics-gathering parameters (see ALTER TABLE).

  If you do not succeed in adjusting the costs to be more appropriate, then you might have to resort to forcing index usage explicitly. You might also want to contact the Postgres Pro developers to examine the issue.

11.13. Using k-NN Algorithm for Optimizing Queries

Postgres Pro Enterprise can optimize k-nearest neighbors (k-NN) search for B-tree, GiST, and SP-GiST index types. With these index types, you can use ordering operators that return the rows in the order defined by the `ORDER BY` clause of the following type:

```
ORDER BY index_column operator constant
```

where *operator* is the supported ordering operator, such as `<->`. In this case, Postgres Pro Enterprise uses a special scan strategy for k-NN search.

For B-tree indexes, you can use only one ordering operator on the first index column. GiST and SP-GiST do not limit the number of ordering operators you can use for k-NN search. For multicolumn GiST

indexes, you can also use multiple ordering operators for each column included into the multicolumn index. For example:

```
SELECT * FROM points ORDER BY column1 <-> '(0, 0)', column2 <-> '(1, 1)'
```

where *column1* and *column2* are index columns of the multicolumn GiST index.

You can run k-NN search for all built-in and custom data types that support the concept of distance. In database queries, k-NN search can provide performance benefits for various use cases: geographic information systems (GIS), classification problems (majority voting), clusterization, looking for similar objects or nearest events, detecting duplicates and typos, trigram matching, multimedia search, and more.

To natively implement k-NN search, Postgres Pro Enterprise uses distance-based priority queue for index traversal. Depending on the index type, the search algorithm will differ:

- For GiST and SP-GiST index types, the priority queue is based on the pairing heap that can be effectively balanced. Inner nodes of the tree represent the minimum bounding rectangle (MBR) for their children. Leaf nodes store actual tuple entries. Postgres Pro Enterprise uses a heuristic to maintain the order by distance between the queue entries and the target point defined by the search argument. For inner nodes, the minimal distance for the child node is calculated. For leaf nodes, the distance to the tuple entry is used. In the tree nodes, leaf nodes are stored before the inner nodes in the list, so tuple entries are processed first. Each time a result is returned from the queue, it is guaranteed to be the closest one to the target point among the remaining entries. Thus, there is no need to scan all nodes. Once the required k entries are extracted from the queue, search can stop.
- B-tree indexes use a simpler algorithm. If the target point falls into the scan range, Postgres Pro Enterprise performs bidirectional scan starting from this point, advancing at each step in the direction that includes the nearest point. Otherwise, a simple unidirectional scan in the right direction is used.

k-NN search performance has logarithmic dependence on the data size and linear dependence on k. As k tends to the number of rows in the table, the k-NN search time gradually tends to a naive algorithm that consecutively reads the whole table, sorts the data, and returns the first k entries. Since k-NN approach reduces the number of rows that need to be sorted, you can get significant performance benefits if the total number of rows returned by a query is big, or the rows are long. In the worst-case scenario, when all points are equally far from the target point, you have to traverse the whole index, but performance gain can still be achieved because only k entries need to be read from the table, at random.

Another benefit of using k-NN algorithm is simpler logic: you do not need to know the search “radius” in advance, and can resume the search if required.

11.13.1. Examples

Suppose you have the `spots` table containing coordinates of multiple points. To find ten closest points to the given target point, you can run the following query:

```
SELECT coordinates, (coordinates <-> '5.0,5.0'::point) AS dist
FROM spots ORDER BY dist ASC LIMIT 10;

              coordinates              |       dist
---------------------------------------+------------------
 (3.57192993164062,6.51727240153665) | 2.08362656457647
 (3.49502563476562,6.49134782128243) | 2.11874164636854
 (3.4393,6.4473)                     | 2.12848814420001
 (3.31787109375,6.50089913799597)    | 2.25438592075067
 (2.6323,6.4779)                     | 2.79109148900569
 (2.66349792480469,6.53159856871478) | 2.79374947392946
 (1.84102535247803,6.27874198581057) |  3.4079762161672
 (1.2255,6.1228)                     | 3.93796014327215
 (1.22772216796875,6.15693947094637) | 3.94570513108469
```

```
 (9.6977,4.044503)                  | 4.79388775494473
(10 rows)
```

If you need to find ten closest points that contain the word "mars" in their names, you can use a multi-column index:

```
CREATE INDEX pt_fts_idx ON spots USING gist(point, to_tsvector('english',asciiname));

SELECT asciiname,point, (point <->'5.0,5.0'::point) AS dist
FROM spots WHERE to_tsvector('english', asciiname)
@@ to_tsquery('english','mars') ORDER BY dist ASC LIMIT 10;
```

Suppose you have the `events` table that describes arbitrary historical events. To select five events that happened close to the launch of the first satellite Sputnik-1 on October 4, 1957, run:

```
SELECT date, event,  ('1957-10-04'::date <-> date) AS dist
FROM events ORDER BY dist ASC LIMIT 5;

    date    |                 event                      | dist
------------+--------------------------------------------+------
 1957-10-04 | Gregory T Linteris, astronaut, is born     |    0
            | in New Jersey                              |
 1957-10-04 | USSR launches the first artificial         |    0
            | Earth satellite Sputnik-1                  |
 1957-10-04 | "Leave It to Beaver" sitcom                |    0
            | debuts on CBS                              |
 1957-10-03 | Lorinc Szabo, Hungarian poet,              |    1
            | dies aged 57                               |
 1957-10-05 | All-Stars beat Montreal in 11th            |    1
            | NHL All-Star Game                          |
(5 rows)
```

Consider an example of fuzzy search on trigrams. Let's create a trigram index on the `events` table, as follows:

```
CREATE INDEX events_trgm ON events USING gist(event gist_trgm_ops);
```

Now let's find three events that best match the following search query:

```
SELECT date, event, ('jeorge ewashington' <-> event ) AS dist
FROM events ORDER BY dist ASC LIMIT 3;

    date    |                 event                      |  dist
------------+--------------------------------------------+---------
 1732-02-11 | George Washington                          | 0.458333
 1792-12-05 | George Washington is re-elected U.S.       | 0.674419
            | President                                  |
 1945-05-12 | Jayotis Washington is born                 | 0.714286
(3 rows)
```

11.13.2. See Also

Index Types
Ordering Operators

Chapter 12. Full Text Search

12.1. Introduction

Full Text Searching (or just *text search*) provides the capability to identify natural-language *documents* that satisfy a *query*, and optionally to sort them by relevance to the query. The most common type of search is to find all documents containing given *query terms* and return them in order of their *similarity* to the query. Notions of `query` and `similarity` are very flexible and depend on the specific application. The simplest search considers `query` as a set of words and `similarity` as the frequency of query words in the document.

Textual search operators have existed in databases for years. Postgres Pro has `~`, `~*`, `LIKE`, and `ILIKE` operators for textual data types, but they lack many essential properties required by modern information systems:

- There is no linguistic support, even for English. Regular expressions are not sufficient because they cannot easily handle derived words, e.g., `satisfies` and `satisfy`. You might miss documents that contain `satisfies`, although you probably would like to find them when searching for `satisfy`. It is possible to use `OR` to search for multiple derived forms, but this is tedious and error-prone (some words can have several thousand derivatives).
- They provide no ordering (ranking) of search results, which makes them ineffective when thousands of matching documents are found.
- They tend to be slow because there is no index support, so they must process all documents for every search.

Full text indexing allows documents to be *preprocessed* and an index saved for later rapid searching. Preprocessing includes:

Parsing documents into tokens. It is useful to identify various classes of tokens, e.g., numbers, words, complex words, email addresses, so that they can be processed differently. In principle token classes depend on the specific application, but for most purposes it is adequate to use a predefined set of classes. Postgres Pro uses a *parser* to perform this step. A standard parser is provided, and custom parsers can be created for specific needs.

Converting tokens into lexemes. A lexeme is a string, just like a token, but it has been *normalized* so that different forms of the same word are made alike. For example, normalization almost always includes folding upper-case letters to lower-case, and often involves removal of suffixes (such as `s` or `es` in English). This allows searches to find variant forms of the same word, without tediously entering all the possible variants. Also, this step typically eliminates *stop words*, which are words that are so common that they are useless for searching. (In short, then, tokens are raw fragments of the document text, while lexemes are words that are believed useful for indexing and searching.) Postgres Pro uses *dictionaries* to perform this step. Various standard dictionaries are provided, and custom ones can be created for specific needs.

Storing preprocessed documents optimized for searching. For example, each document can be represented as a sorted array of normalized lexemes. Along with the lexemes it is often desirable to store positional information to use for *proximity ranking*, so that a document that contains a more "dense" region of query words is assigned a higher rank than one with scattered query words.

Dictionaries allow fine-grained control over how tokens are normalized. With appropriate dictionaries, you can:

- Define stop words that should not be indexed.
- Map synonyms to a single word using Ispell.
- Map phrases to a single word using a thesaurus.
- Map different variations of a word to a canonical form using an Ispell dictionary.
- Map different variations of a word to a canonical form using Snowball stemmer rules.

A data type `tsvector` is provided for storing preprocessed documents, along with a type `tsquery` for representing processed queries (Section 8.11). There are many functions and operators available for

these data types (Section 9.13), the most important of which is the match operator `@@`, which we introduce in Section 12.1.2. Full text searches can be accelerated using indexes (Section 12.9).

12.1.1. What Is a Document?

A *document* is the unit of searching in a full text search system; for example, a magazine article or email message. The text search engine must be able to parse documents and store associations of lexemes (key words) with their parent document. Later, these associations are used to search for documents that contain query words.

For searches within Postgres Pro, a document is normally a textual field within a row of a database table, or possibly a combination (concatenation) of such fields, perhaps stored in several tables or obtained dynamically. In other words, a document can be constructed from different parts for indexing and it might not be stored anywhere as a whole. For example:

```
SELECT title || ' ' ||  author || ' ' ||  abstract || ' ' || body AS document
FROM messages
WHERE mid = 12;

SELECT m.title || ' ' || m.author || ' ' || m.abstract || ' ' || d.body AS document
FROM messages m, docs d
WHERE m.mid = d.did AND m.mid = 12;
```

> **Note**
>
> Actually, in these example queries, `coalesce` should be used to prevent a single `NULL` attribute from causing a `NULL` result for the whole document.

Another possibility is to store the documents as simple text files in the file system. In this case, the database can be used to store the full text index and to execute searches, and some unique identifier can be used to retrieve the document from the file system. However, retrieving files from outside the database requires superuser permissions or special function support, so this is usually less convenient than keeping all the data inside Postgres Pro. Also, keeping everything inside the database allows easy access to document metadata to assist in indexing and display.

For text search purposes, each document must be reduced to the preprocessed `tsvector` format. Searching and ranking are performed entirely on the `tsvector` representation of a document — the original text need only be retrieved when the document has been selected for display to a user. We therefore often speak of the `tsvector` as being the document, but of course it is only a compact representation of the full document.

12.1.2. Basic Text Matching

Full text searching in Postgres Pro is based on the match operator `@@`, which returns `true` if a `tsvector` (document) matches a `tsquery` (query). It doesn't matter which data type is written first:

```
SELECT 'a fat cat sat on a mat and ate a fat rat'::tsvector @@ 'cat & rat'::tsquery;
 ?column?
----------
 t

SELECT 'fat & cow'::tsquery @@ 'a fat cat sat on a mat and ate a fat rat'::tsvector;
 ?column?
----------
 f
```

As the above example suggests, a `tsquery` is not just raw text, any more than a `tsvector` is. A `tsquery` contains search terms, which must be already-normalized lexemes, and may combine multiple terms using AND, OR, NOT, and FOLLOWED BY operators. (For syntax details see Section 8.11.2.) There are functions `to_tsquery`, `plainto_tsquery`, and `phraseto_tsquery` that are helpful in converting user-

written text into a proper `tsquery`, primarily by normalizing words appearing in the text. Similarly, `to_tsvector` is used to parse and normalize a document string. So in practice a text search match would look more like this:

```
SELECT to_tsvector('fat cats ate fat rats') @@ to_tsquery('fat & rat');
 ?column?
----------
 t
```

Observe that this match would not succeed if written as

```
SELECT 'fat cats ate fat rats'::tsvector @@ to_tsquery('fat & rat');
 ?column?
----------
 f
```

since here no normalization of the word `rats` will occur. The elements of a `tsvector` are lexemes, which are assumed already normalized, so `rats` does not match `rat`.

The `@@` operator also supports `text` input, allowing explicit conversion of a text string to `tsvector` or `tsquery` to be skipped in simple cases. The variants available are:

```
tsvector @@ tsquery
tsquery  @@ tsvector
text @@ tsquery
text @@ text
```

The first two of these we saw already. The form `text @@ tsquery` is equivalent to `to_tsvector(x) @@ y`. The form `text @@ text` is equivalent to `to_tsvector(x) @@ plainto_tsquery(y)`.

Within a `tsquery`, the `&` (AND) operator specifies that both its arguments must appear in the document to have a match. Similarly, the `|` (OR) operator specifies that at least one of its arguments must appear, while the `!` (NOT) operator specifies that its argument must *not* appear in order to have a match. For example, the query `fat & ! rat` matches documents that contain `fat` but not `rat`.

Searching for phrases is possible with the help of the `<->` (FOLLOWED BY) `tsquery` operator, which matches only if its arguments have matches that are adjacent and in the given order. For example:

```
SELECT to_tsvector('fatal error') @@ to_tsquery('fatal <-> error');
 ?column?
----------
 t

SELECT to_tsvector('error is not fatal') @@ to_tsquery('fatal <-> error');
 ?column?
----------
 f
```

There is a more general version of the FOLLOWED BY operator having the form `<N>`, where *N* is an integer standing for the difference between the positions of the matching lexemes. `<1>` is the same as `<->`, while `<2>` allows exactly one other lexeme to appear between the matches, and so on. The `phraseto_tsquery` function makes use of this operator to construct a `tsquery` that can match a multi-word phrase when some of the words are stop words. For example:

```
SELECT phraseto_tsquery('cats ate rats');
       phraseto_tsquery
-------------------------------
 'cat' <-> 'ate' <-> 'rat'

SELECT phraseto_tsquery('the cats ate the rats');
       phraseto_tsquery
-------------------------------
 'cat' <-> 'ate' <2> 'rat'
```

A special case that's sometimes useful is that `<0>` can be used to require that two patterns match the same word.

Parentheses can be used to control nesting of the `tsquery` operators. Without parentheses, `|` binds least tightly, then `&`, then `<->`, and `!` most tightly.

It's worth noticing that the AND/OR/NOT operators mean something subtly different when they are within the arguments of a FOLLOWED BY operator than when they are not, because within FOLLOWED BY the exact position of the match is significant. For example, normally `!x` matches only documents that do not contain `x` anywhere. But `!x <-> y` matches `y` if it is not immediately after an `x`; an occurrence of `x` elsewhere in the document does not prevent a match. Another example is that `x & y` normally only requires that `x` and `y` both appear somewhere in the document, but `(x & y) <-> z` requires `x` and `y` to match at the same place, immediately before a `z`. Thus this query behaves differently from `x <-> z & y <-> z`, which will match a document containing two separate sequences `x z` and `y z`. (This specific query is useless as written, since `x` and `y` could not match at the same place; but with more complex situations such as prefix-match patterns, a query of this form could be useful.)

12.1.3. Configurations

The above are all simple text search examples. As mentioned before, full text search functionality includes the ability to do many more things: skip indexing certain words (stop words), process synonyms, and use sophisticated parsing, e.g., parse based on more than just white space. This functionality is controlled by *text search configurations*. Postgres Pro comes with predefined configurations for many languages, and you can easily create your own configurations. (psql's `\dF` command shows all available configurations.)

During installation an appropriate configuration is selected and default_text_search_config is set accordingly in `postgresql.conf`. If you are using the same text search configuration for the entire cluster you can use the value in `postgresql.conf`. To use different configurations throughout the cluster but the same configuration within any one database, use `ALTER DATABASE ... SET`. Otherwise, you can set `default_text_search_config` in each session.

Each text search function that depends on a configuration has an optional `regconfig` argument, so that the configuration to use can be specified explicitly. `default_text_search_config` is used only when this argument is omitted.

To make it easier to build custom text search configurations, a configuration is built up from simpler database objects. Postgres Pro's text search facility provides four types of configuration-related database objects:

- *Text search parsers* break documents into tokens and classify each token (for example, as words or numbers).
- *Text search dictionaries* convert tokens to normalized form and reject stop words.
- *Text search templates* provide the functions underlying dictionaries. (A dictionary simply specifies a template and a set of parameters for the template.)
- *Text search configurations* select a parser and a set of dictionaries to use to normalize the tokens produced by the parser.

Text search parsers and templates are built from low-level C functions; therefore it requires C programming ability to develop new ones, and superuser privileges to install one into a database. (There are examples of add-on parsers and templates in the `contrib/` area of the Postgres Pro distribution.) Since dictionaries and configurations just parameterize and connect together some underlying parsers and templates, no special privilege is needed to create a new dictionary or configuration. Examples of creating custom dictionaries and configurations appear later in this chapter.

12.2. Tables and Indexes

The examples in the previous section illustrated full text matching using simple constant strings. This section shows how to search table data, optionally using indexes.

12.2.1. Searching a Table

It is possible to do a full text search without an index. A simple query to print the `title` of each row that contains the word `friend` in its `body` field is:

```
SELECT title
FROM pgweb
WHERE to_tsvector('english', body) @@ to_tsquery('english', 'friend');
```

This will also find related words such as `friends` and `friendly`, since all these are reduced to the same normalized lexeme.

The query above specifies that the `english` configuration is to be used to parse and normalize the strings. Alternatively we could omit the configuration parameters:

```
SELECT title
FROM pgweb
WHERE to_tsvector(body) @@ to_tsquery('friend');
```

This query will use the configuration set by default_text_search_config.

A more complex example is to select the ten most recent documents that contain `create` and `table` in the `title` or `body`:

```
SELECT title
FROM pgweb
WHERE to_tsvector(title || ' ' || body) @@ to_tsquery('create & table')
ORDER BY last_mod_date DESC
LIMIT 10;
```

For clarity we omitted the `coalesce` function calls which would be needed to find rows that contain `NULL` in one of the two fields.

Although these queries will work without an index, most applications will find this approach too slow, except perhaps for occasional ad-hoc searches. Practical use of text searching usually requires creating an index.

12.2.2. Creating Indexes

We can create a GIN index (Section 12.9) to speed up text searches:

```
CREATE INDEX pgweb_idx ON pgweb USING GIN (to_tsvector('english', body));
```

Notice that the 2-argument version of `to_tsvector` is used. Only text search functions that specify a configuration name can be used in expression indexes (Section 11.7). This is because the index contents must be unaffected by default_text_search_config. If they were affected, the index contents might be inconsistent because different entries could contain `tsvector`s that were created with different text search configurations, and there would be no way to guess which was which. It would be impossible to dump and restore such an index correctly.

Because the two-argument version of `to_tsvector` was used in the index above, only a query reference that uses the 2-argument version of `to_tsvector` with the same configuration name will use that index. That is, `WHERE to_tsvector('english', body) @@ 'a & b'` can use the index, but `WHERE to_tsvector(body) @@ 'a & b'` cannot. This ensures that an index will be used only with the same configuration used to create the index entries.

It is possible to set up more complex expression indexes wherein the configuration name is specified by another column, e.g.:

```
CREATE INDEX pgweb_idx ON pgweb USING GIN (to_tsvector(config_name, body));
```

where `config_name` is a column in the `pgweb` table. This allows mixed configurations in the same index while recording which configuration was used for each index entry. This would be useful, for example, if

the document collection contained documents in different languages. Again, queries that are meant to use the index must be phrased to match, e.g., `WHERE to_tsvector(config_name, body) @@ 'a & b'`.

Indexes can even concatenate columns:

```
CREATE INDEX pgweb_idx ON pgweb USING GIN (to_tsvector('english', title || ' ' ||
 body));
```

Another approach is to create a separate `tsvector` column to hold the output of `to_tsvector`. To keep this column automatically up to date with its source data, use a stored generated column. This example is a concatenation of `title` and `body`, using `coalesce` to ensure that one field will still be indexed when the other is `NULL`:

```
ALTER TABLE pgweb
    ADD COLUMN textsearchable_index_col tsvector
                GENERATED ALWAYS AS (to_tsvector('english', coalesce(title, '') || ' '
 || coalesce(body, ''))) STORED;
```

Then we create a GIN index to speed up the search:

```
CREATE INDEX textsearch_idx ON pgweb USING GIN (textsearchable_index_col);
```

Now we are ready to perform a fast full text search:

```
SELECT title
FROM pgweb
WHERE textsearchable_index_col @@ to_tsquery('create & table')
ORDER BY last_mod_date DESC
LIMIT 10;
```

One advantage of the separate-column approach over an expression index is that it is not necessary to explicitly specify the text search configuration in queries in order to make use of the index. As shown in the example above, the query can depend on `default_text_search_config`. Another advantage is that searches will be faster, since it will not be necessary to redo the `to_tsvector` calls to verify index matches. (This is more important when using a GiST index than a GIN index; see Section 12.9.) The expression-index approach is simpler to set up, however, and it requires less disk space since the `tsvector` representation is not stored explicitly.

12.3. Controlling Text Search

To implement full text searching there must be a function to create a `tsvector` from a document and a `tsquery` from a user query. Also, we need to return results in a useful order, so we need a function that compares documents with respect to their relevance to the query. It's also important to be able to display the results nicely. Postgres Pro provides support for all of these functions.

12.3.1. Parsing Documents

Postgres Pro provides the function `to_tsvector` for converting a document to the `tsvector` data type.

```
to_tsvector([ config regconfig, ] document text) returns tsvector
```

`to_tsvector` parses a textual document into tokens, reduces the tokens to lexemes, and returns a `tsvector` which lists the lexemes together with their positions in the document. The document is processed according to the specified or default text search configuration. Here is a simple example:

```
SELECT to_tsvector('english', 'a fat  cat sat on a mat - it ate a fat rats');
                  to_tsvector
-----------------------------------------------------
 'ate':9 'cat':3 'fat':2,11 'mat':7 'rat':12 'sat':4
```

In the example above we see that the resulting `tsvector` does not contain the words `a`, `on`, or `it`, the word `rats` became `rat`, and the punctuation sign `-` was ignored.

The to_tsvector function internally calls a parser which breaks the document text into tokens and assigns a type to each token. For each token, a list of dictionaries (Section 12.6) is consulted, where the list can vary depending on the token type. The first dictionary that *recognizes* the token emits one or more normalized *lexemes* to represent the token. For example, rats became rat because one of the dictionaries recognized that the word rats is a plural form of rat. Some words are recognized as *stop words* (Section 12.6.1), which causes them to be ignored since they occur too frequently to be useful in searching. In our example these are a, on, and it. If no dictionary in the list recognizes the token then it is also ignored. In this example that happened to the punctuation sign – because there are in fact no dictionaries assigned for its token type (Space symbols), meaning space tokens will never be indexed. The choices of parser, dictionaries and which types of tokens to index are determined by the selected text search configuration (Section 12.7). It is possible to have many different configurations in the same database, and predefined configurations are available for various languages. In our example we used the default configuration english for the English language.

The function setweight can be used to label the entries of a tsvector with a given *weight*, where a weight is one of the letters A, B, C, or D. This is typically used to mark entries coming from different parts of a document, such as title versus body. Later, this information can be used for ranking of search results.

Because to_tsvector(NULL) will return NULL, it is recommended to use coalesce whenever a field might be null. Here is the recommended method for creating a tsvector from a structured document:

```
UPDATE tt SET ti =
    setweight(to_tsvector(coalesce(title,'')), 'A')    ||
    setweight(to_tsvector(coalesce(keyword,'')), 'B')  ||
    setweight(to_tsvector(coalesce(abstract,'')), 'C') ||
    setweight(to_tsvector(coalesce(body,'')), 'D');
```

Here we have used setweight to label the source of each lexeme in the finished tsvector, and then merged the labeled tsvector values using the tsvector concatenation operator ||. (Section 12.4.1 gives details about these operations.)

12.3.2. Parsing Queries

Postgres Pro provides the functions to_tsquery, plainto_tsquery, phraseto_tsquery and websearch_to_tsquery for converting a query to the tsquery data type. to_tsquery offers access to more features than either plainto_tsquery or phraseto_tsquery, but it is less forgiving about its input. websearch_to_tsquery is a simplified version of to_tsquery with an alternative syntax, similar to the one used by web search engines.

```
to_tsquery([ config regconfig, ] querytext text) returns tsquery
```

to_tsquery creates a tsquery value from *querytext*, which must consist of single tokens separated by the tsquery operators & (AND), | (OR), ! (NOT), and <-> (FOLLOWED BY), possibly grouped using parentheses. In other words, the input to to_tsquery must already follow the general rules for tsquery input, as described in Section 8.11.2. The difference is that while basic tsquery input takes the tokens at face value, to_tsquery normalizes each token into a lexeme using the specified or default configuration, and discards any tokens that are stop words according to the configuration. For example:

```
SELECT to_tsquery('english', 'The & Fat & Rats');
  to_tsquery
---------------
 'fat' & 'rat'
```

As in basic tsquery input, weight(s) can be attached to each lexeme to restrict it to match only tsvector lexemes of those weight(s). For example:

```
SELECT to_tsquery('english', 'Fat | Rats:AB');
    to_tsquery
------------------
 'fat' | 'rat':AB
```

Also, * can be attached to a lexeme to specify prefix matching:

```
SELECT to_tsquery('supern:*A & star:A*B');
        to_tsquery
--------------------------
 'supern':*A & 'star':*AB
```

Such a lexeme will match any word in a tsvector that begins with the given string.

to_tsquery can also accept single-quoted phrases. This is primarily useful when the configuration includes a thesaurus dictionary that may trigger on such phrases. In the example below, a thesaurus contains the rule supernovae stars : sn:

```
SELECT to_tsquery('''supernovae stars'' & !crab');
  to_tsquery
---------------
 'sn' & !'crab'
```

Without quotes, to_tsquery will generate a syntax error for tokens that are not separated by an AND, OR, or FOLLOWED BY operator.

```
plainto_tsquery([ config regconfig, ] querytext text) returns tsquery
```

plainto_tsquery transforms the unformatted text *querytext* to a tsquery value. The text is parsed and normalized much as for to_tsvector, then the & (AND) tsquery operator is inserted between surviving words.

Example:

```
SELECT plainto_tsquery('english', 'The Fat Rats');
 plainto_tsquery
-----------------
 'fat' & 'rat'
```

Note that plainto_tsquery will not recognize tsquery operators, weight labels, or prefix-match labels in its input:

```
SELECT plainto_tsquery('english', 'The Fat & Rats:C');
   plainto_tsquery
---------------------
 'fat' & 'rat' & 'c'
```

Here, all the input punctuation was discarded.

```
phraseto_tsquery([ config regconfig, ] querytext text) returns tsquery
```

phraseto_tsquery behaves much like plainto_tsquery, except that it inserts the <-> (FOLLOWED BY) operator between surviving words instead of the & (AND) operator. Also, stop words are not simply discarded, but are accounted for by inserting <*N*> operators rather than <-> operators. This function is useful when searching for exact lexeme sequences, since the FOLLOWED BY operators check lexeme order not just the presence of all the lexemes.

Example:

```
SELECT phraseto_tsquery('english', 'The Fat Rats');
 phraseto_tsquery
------------------
 'fat' <-> 'rat'
```

Like plainto_tsquery, the phraseto_tsquery function will not recognize tsquery operators, weight labels, or prefix-match labels in its input:

```
SELECT phraseto_tsquery('english', 'The Fat & Rats:C');
      phraseto_tsquery
-----------------------------
```

```
 'fat' <-> 'rat' <-> 'c'
```

`websearch_to_tsquery([ config regconfig, ] querytext text) returns tsquery`

`websearch_to_tsquery` creates a `tsquery` value from *querytext* using an alternative syntax in which simple unformatted text is a valid query. Unlike `plainto_tsquery` and `phraseto_tsquery`, it also recognizes certain operators. Moreover, this function will never raise syntax errors, which makes it possible to use raw user-supplied input for search. The following syntax is supported:

- `unquoted text`: text not inside quote marks will be converted to terms separated by `&` operators, as if processed by `plainto_tsquery`.
- `"quoted text"`: text inside quote marks will be converted to terms separated by `<->` operators, as if processed by `phraseto_tsquery`.
- `OR`: the word “or” will be converted to the `|` operator.
- `-`: a dash will be converted to the `!` operator.

Other punctuation is ignored. So like `plainto_tsquery` and `phraseto_tsquery`, the `websearch_to_tsquery` function will not recognize `tsquery` operators, weight labels, or prefix-match labels in its input.

Examples:

```
SELECT websearch_to_tsquery('english', 'The fat rats');
 websearch_to_tsquery
----------------------
 'fat' & 'rat'
(1 row)

SELECT websearch_to_tsquery('english', '"supernovae stars" -crab');
       websearch_to_tsquery
---------------------------------
 'supernova' <-> 'star' & !'crab'
(1 row)

SELECT websearch_to_tsquery('english', '"sad cat" or "fat rat"');
       websearch_to_tsquery
----------------------------------
 'sad' <-> 'cat' | 'fat' <-> 'rat'
(1 row)

SELECT websearch_to_tsquery('english', 'signal -"segmentation fault"');
         websearch_to_tsquery
---------------------------------------
 'signal' & !( 'segment' <-> 'fault' )
(1 row)

SELECT websearch_to_tsquery('english', '""" )( dummy \\ query <->');
 websearch_to_tsquery
----------------------
 'dummi' & 'queri'
(1 row)
```

12.3.3. Ranking Search Results

Ranking attempts to measure how relevant documents are to a particular query, so that when there are many matches the most relevant ones can be shown first. Postgres Pro provides two predefined ranking functions, which take into account lexical, proximity, and structural information; that is, they consider how often the query terms appear in the document, how close together the terms are in the document, and how important is the part of the document where they occur. However, the concept of relevancy is vague and very application-specific. Different applications might require additional information for ranking, e.g., document modification time. The built-in ranking functions are only examples. You can

write your own ranking functions and/or combine their results with additional factors to fit your specific needs.

The two ranking functions currently available are:

`ts_rank([ weights float4[], ] vector tsvector, query tsquery [, normalization integer ]) returns float4`

Ranks vectors based on the frequency of their matching lexemes.

`ts_rank_cd([ weights float4[], ] vector tsvector, query tsquery [, normalization integer ]) returns float4`

This function computes the *cover density* ranking for the given document vector and query, as described in Clarke, Cormack, and Tudhope's "Relevance Ranking for One to Three Term Queries" in the journal "Information Processing and Management", 1999. Cover density is similar to `ts_rank` ranking except that the proximity of matching lexemes to each other is taken into consideration.

This function requires lexeme positional information to perform its calculation. Therefore, it ignores any "stripped" lexemes in the `tsvector`. If there are no unstripped lexemes in the input, the result will be zero. (See Section 12.4.1 for more information about the `strip` function and positional information in `tsvector`s.)

For both these functions, the optional *`weights`* argument offers the ability to weigh word instances more or less heavily depending on how they are labeled. The weight arrays specify how heavily to weigh each category of word, in the order:

```
{D-weight, C-weight, B-weight, A-weight}
```

If no *`weights`* are provided, then these defaults are used:

```
{0.1, 0.2, 0.4, 1.0}
```

Typically weights are used to mark words from special areas of the document, like the title or an initial abstract, so they can be treated with more or less importance than words in the document body.

Since a longer document has a greater chance of containing a query term it is reasonable to take into account document size, e.g., a hundred-word document with five instances of a search word is probably more relevant than a thousand-word document with five instances. Both ranking functions take an integer *`normalization`* option that specifies whether and how a document's length should impact its rank. The integer option controls several behaviors, so it is a bit mask: you can specify one or more behaviors using `|` (for example, `2|4`).

- 0 (the default) ignores the document length
- 1 divides the rank by 1 + the logarithm of the document length
- 2 divides the rank by the document length
- 4 divides the rank by the mean harmonic distance between extents (this is implemented only by `ts_rank_cd`)
- 8 divides the rank by the number of unique words in document
- 16 divides the rank by 1 + the logarithm of the number of unique words in document
- 32 divides the rank by itself + 1

If more than one flag bit is specified, the transformations are applied in the order listed.

It is important to note that the ranking functions do not use any global information, so it is impossible to produce a fair normalization to 1% or 100% as sometimes desired. Normalization option 32 (`rank/(rank+1)`) can be applied to scale all ranks into the range zero to one, but of course this is just a cosmetic change; it will not affect the ordering of the search results.

Here is an example that selects only the ten highest-ranked matches:

```
SELECT title, ts_rank_cd(textsearch, query) AS rank
FROM apod, to_tsquery('neutrino|(dark & matter)') query
WHERE query @@ textsearch
ORDER BY rank DESC
```

```
LIMIT 10;
                     title                     |   rank
-----------------------------------------------+----------
 Neutrinos in the Sun                          |      3.1
 The Sudbury Neutrino Detector                 |      2.4
 A MACHO View of Galactic Dark Matter          |  2.01317
 Hot Gas and Dark Matter                       |  1.91171
 The Virgo Cluster: Hot Plasma and Dark Matter |  1.90953
 Rafting for Solar Neutrinos                   |      1.9
 NGC 4650A: Strange Galaxy and Dark Matter     |  1.85774
 Hot Gas and Dark Matter                       |   1.6123
 Ice Fishing for Cosmic Neutrinos              |      1.6
 Weak Lensing Distorts the Universe            | 0.818218
```

This is the same example using normalized ranking:

```
SELECT title, ts_rank_cd(textsearch, query, 32 /* rank/(rank+1) */ ) AS rank
FROM apod, to_tsquery('neutrino|(dark & matter)') query
WHERE  query @@ textsearch
ORDER BY rank DESC
LIMIT 10;
                     title                     |        rank
-----------------------------------------------+--------------------
 Neutrinos in the Sun                          | 0.756097569485493
 The Sudbury Neutrino Detector                 | 0.705882361190954
 A MACHO View of Galactic Dark Matter          | 0.668123210574724
 Hot Gas and Dark Matter                       |  0.65655958650282
 The Virgo Cluster: Hot Plasma and Dark Matter | 0.656301290640973
 Rafting for Solar Neutrinos                   | 0.655172410958162
 NGC 4650A: Strange Galaxy and Dark Matter     | 0.650072921219637
 Hot Gas and Dark Matter                       | 0.617195790024749
 Ice Fishing for Cosmic Neutrinos              | 0.615384618911517
 Weak Lensing Distorts the Universe            | 0.450010798361481
```

Ranking can be expensive since it requires consulting the `tsvector` of each matching document, which can be I/O bound and therefore slow. Unfortunately, it is almost impossible to avoid since practical queries often result in large numbers of matches.

12.3.4. Highlighting Results

To present search results it is ideal to show a part of each document and how it is related to the query. Usually, search engines show fragments of the document with marked search terms. Postgres Pro provides a function `ts_headline` that implements this functionality.

```
ts_headline([ config regconfig, ] document text, query tsquery [, options text ])
 returns text
```

`ts_headline` accepts a document along with a query, and returns an excerpt from the document in which terms from the query are highlighted. The configuration to be used to parse the document can be specified by *config*; if *config* is omitted, the `default_text_search_config` configuration is used.

If an *options* string is specified it must consist of a comma-separated list of one or more *option=value* pairs. The available options are:

- `MaxWords`, `MinWords` (integers): these numbers determine the longest and shortest headlines to output. The default values are 35 and 15.
- `ShortWord` (integer): words of this length or less will be dropped at the start and end of a headline, unless they are query terms. The default value of three eliminates common English articles.
- `HighlightAll` (boolean): if `true` the whole document will be used as the headline, ignoring the preceding three parameters. The default is `false`.

- `MaxFragments` (integer): maximum number of text fragments to display. The default value of zero selects a non-fragment-based headline generation method. A value greater than zero selects fragment-based headline generation (see below).
- `StartSel`, `StopSel` (strings): the strings with which to delimit query words appearing in the document, to distinguish them from other excerpted words. The default values are "`<b>`" and "`</b>`", which can be suitable for HTML output (but see the warning below).
- `FragmentDelimiter` (string): When more than one fragment is displayed, the fragments will be separated by this string. The default is "` ... `".

> **Warning: Cross-site scripting (XSS) safety**
>
> The output from `ts_headline` is not guaranteed to be safe for direct inclusion in web pages. When `HighlightAll` is `false` (the default), some simple XML tags are removed from the document, but this is not guaranteed to remove all HTML markup. Therefore, this does not provide an effective defense against attacks such as cross-site scripting (XSS) attacks, when working with untrusted input. To guard against such attacks, all HTML markup should be removed from the input document, or an HTML sanitizer should be used on the output.

These option names are recognized case-insensitively. You must double-quote string values if they contain spaces or commas.

In non-fragment-based headline generation, `ts_headline` locates matches for the given *`query`* and chooses a single one to display, preferring matches that have more query words within the allowed headline length. In fragment-based headline generation, `ts_headline` locates the query matches and splits each match into "fragments" of no more than `MaxWords` words each, preferring fragments with more query words, and when possible "stretching" fragments to include surrounding words. The fragment-based mode is thus more useful when the query matches span large sections of the document, or when it's desirable to display multiple matches. In either mode, if no query matches can be identified, then a single fragment of the first `MinWords` words in the document will be displayed.

For example:

```
SELECT ts_headline('english',
  'The most common type of search
is to find all documents containing given query terms
and return them in order of their similarity to the
query.',
  to_tsquery('english', 'query & similarity'));
                        ts_headline
------------------------------------------------------------
 containing given <b>query</b> terms                       +
 and return them in order of their <b>similarity</b> to the+
 <b>query</b>.

SELECT ts_headline('english',
  'Search terms may occur
many times in a document,
requiring ranking of the search matches to decide which
occurrences to display in the result.',
  to_tsquery('english', 'search & term'),
  'MaxFragments=10, MaxWords=7, MinWords=3, StartSel=<<, StopSel=>>');
                        ts_headline
------------------------------------------------------------
 <<Search>> <<terms>> may occur                            +
 many times ... ranking of the <<search>> matches to decide
```

`ts_headline` uses the original document, not a `tsvector` summary, so it can be slow and should be used with care.

12.4. Additional Features

This section describes additional functions and operators that are useful in connection with text search.

12.4.1. Manipulating Documents

Section 12.3.1 showed how raw textual documents can be converted into `tsvector` values. Postgres Pro also provides functions and operators that can be used to manipulate documents that are already in `tsvector` form.

`tsvector || tsvector`

The `tsvector` concatenation operator returns a vector which combines the lexemes and positional information of the two vectors given as arguments. Positions and weight labels are retained during the concatenation. Positions appearing in the right-hand vector are offset by the largest position mentioned in the left-hand vector, so that the result is nearly equivalent to the result of performing `to_tsvector` on the concatenation of the two original document strings. (The equivalence is not exact, because any stop-words removed from the end of the left-hand argument will not affect the result, whereas they would have affected the positions of the lexemes in the right-hand argument if textual concatenation were used.)

One advantage of using concatenation in the vector form, rather than concatenating text before applying `to_tsvector`, is that you can use different configurations to parse different sections of the document. Also, because the `setweight` function marks all lexemes of the given vector the same way, it is necessary to parse the text and do `setweight` before concatenating if you want to label different parts of the document with different weights.

`setweight(`*`vector`* `tsvector, `*`weight`* `"char") returns tsvector`

`setweight` returns a copy of the input vector in which every position has been labeled with the given *`weight`*, either `A`, `B`, `C`, or `D`. (`D` is the default for new vectors and as such is not displayed on output.) These labels are retained when vectors are concatenated, allowing words from different parts of a document to be weighted differently by ranking functions.

Note that weight labels apply to *positions*, not *lexemes*. If the input vector has been stripped of positions then `setweight` does nothing.

`length(`*`vector`* `tsvector) returns integer`

Returns the number of lexemes stored in the vector.

`strip(`*`vector`* `tsvector) returns tsvector`

Returns a vector that lists the same lexemes as the given vector, but lacks any position or weight information. The result is usually much smaller than an unstripped vector, but it is also less useful. Relevance ranking does not work as well on stripped vectors as unstripped ones. Also, the `<->` (FOLLOWED BY) `tsquery` operator will never match stripped input, since it cannot determine the distance between lexeme occurrences.

A full list of `tsvector`-related functions is available in Table 9.42.

12.4.2. Manipulating Queries

Section 12.3.2 showed how raw textual queries can be converted into `tsquery` values. Postgres Pro also provides functions and operators that can be used to manipulate queries that are already in `tsquery` form.

`tsquery && tsquery`

Returns the AND-combination of the two given queries.

`tsquery || tsquery`

Returns the OR-combination of the two given queries.

`!! tsquery`

Returns the negation (NOT) of the given query.

`tsquery <-> tsquery`

Returns a query that searches for a match to the first given query immediately followed by a match to the second given query, using the `<->` (FOLLOWED BY) `tsquery` operator. For example:

```
SELECT to_tsquery('fat') <-> to_tsquery('cat | rat');
          ?column?
----------------------------
 'fat' <-> ( 'cat' | 'rat' )
```

`tsquery_phrase(`*`query1`* `tsquery,` *`query2`* `tsquery [,` *`distance`* `integer ]) returns tsquery`

Returns a query that searches for a match to the first given query followed by a match to the second given query at a distance of exactly *`distance`* lexemes, using the `<`*`N`*`>` `tsquery` operator. For example:

```
SELECT tsquery_phrase(to_tsquery('fat'), to_tsquery('cat'), 10);
  tsquery_phrase
------------------
 'fat' <10> 'cat'
```

`numnode(`*`query`* `tsquery) returns integer`

Returns the number of nodes (lexemes plus operators) in a `tsquery`. This function is useful to determine if the *`query`* is meaningful (returns > 0), or contains only stop words (returns 0). Examples:

```
SELECT numnode(plainto_tsquery('the any'));
NOTICE:  query contains only stopword(s) or doesn't contain lexeme(s), ignored
 numnode
---------
       0

SELECT numnode('foo & bar'::tsquery);
 numnode
---------
       3
```

`querytree(`*`query`* `tsquery) returns text`

Returns the portion of a `tsquery` that can be used for searching an index. This function is useful for detecting unindexable queries, for example those containing only stop words or only negated terms. For example:

```
SELECT querytree(to_tsquery('defined'));
 querytree
-----------
 'defin'

SELECT querytree(to_tsquery('!defined'));
 querytree
-----------
 T
```

12.4.2.1. Query Rewriting

The `ts_rewrite` family of functions search a given `tsquery` for occurrences of a target subquery, and replace each occurrence with a substitute subquery. In essence this operation is a `tsquery`-specific version of substring replacement. A target and substitute combination can be thought of as a *query rewrite rule*. A collection of such rewrite rules can be a powerful search aid. For example, you can expand the search using synonyms (e.g., `new york`, `big apple`, `nyc`, `gotham`) or narrow the search

to direct the user to some hot topic. There is some overlap in functionality between this feature and thesaurus dictionaries (Section 12.6.4). However, you can modify a set of rewrite rules on-the-fly without reindexing, whereas updating a thesaurus requires reindexing to be effective.

`ts_rewrite (query tsquery, target tsquery, substitute tsquery) returns tsquery`

This form of `ts_rewrite` simply applies a single rewrite rule: *`target`* is replaced by *`substitute`* wherever it appears in *`query`*. For example:

```
SELECT ts_rewrite('a & b'::tsquery, 'a'::tsquery, 'c'::tsquery);
 ts_rewrite
------------
 'b' & 'c'
```

`ts_rewrite (query tsquery, select text) returns tsquery`

This form of `ts_rewrite` accepts a starting *`query`* and an SQL *`select`* command, which is given as a text string. The *`select`* must yield two columns of `tsquery` type. For each row of the *`select`* result, occurrences of the first column value (the target) are replaced by the second column value (the substitute) within the current *`query`* value. For example:

```
CREATE TABLE aliases (t tsquery PRIMARY KEY, s tsquery);
INSERT INTO aliases VALUES('a', 'c');

SELECT ts_rewrite('a & b'::tsquery, 'SELECT t,s FROM aliases');
 ts_rewrite
------------
 'b' & 'c'
```

Note that when multiple rewrite rules are applied in this way, the order of application can be important; so in practice you will want the source query to `ORDER BY` some ordering key.

Let's consider a real-life astronomical example. We'll expand query `supernovae` using table-driven rewriting rules:

```
CREATE TABLE aliases (t tsquery primary key, s tsquery);
INSERT INTO aliases VALUES(to_tsquery('supernovae'), to_tsquery('supernovae|sn'));

SELECT ts_rewrite(to_tsquery('supernovae & crab'), 'SELECT * FROM aliases');
           ts_rewrite
---------------------------------
 'crab' & ( 'supernova' | 'sn' )
```

We can change the rewriting rules just by updating the table:

```
UPDATE aliases
SET s = to_tsquery('supernovae|sn & !nebulae')
WHERE t = to_tsquery('supernovae');

SELECT ts_rewrite(to_tsquery('supernovae & crab'), 'SELECT * FROM aliases');
                 ts_rewrite
--------------------------------------------
 'crab' & ( 'supernova' | 'sn' & !'nebula' )
```

Rewriting can be slow when there are many rewriting rules, since it checks every rule for a possible match. To filter out obvious non-candidate rules we can use the containment operators for the `tsquery` type. In the example below, we select only those rules which might match the original query:

```
SELECT ts_rewrite('a & b'::tsquery,
                  'SELECT t,s FROM aliases WHERE ''a & b''::tsquery @> t');
 ts_rewrite
------------
 'b' & 'c'
```

12.4.3. Triggers for Automatic Updates

> **Note**
>
> The method described in this section has been obsoleted by the use of stored generated columns, as described in Section 12.2.2.

When using a separate column to store the `tsvector` representation of your documents, it is necessary to create a trigger to update the `tsvector` column when the document content columns change. Two built-in trigger functions are available for this, or you can write your own.

```
tsvector_update_trigger(tsvector_column_name,  config_name, text_column_name [, ... ])
tsvector_update_trigger_column(tsvector_column_name,
  config_column_name, text_column_name [, ... ])
```

These trigger functions automatically compute a `tsvector` column from one or more textual columns, under the control of parameters specified in the `CREATE TRIGGER` command. An example of their use is:

```
CREATE TABLE messages (
    title       text,
    body        text,
    tsv         tsvector
);

CREATE TRIGGER tsvectorupdate BEFORE INSERT OR UPDATE
ON messages FOR EACH ROW EXECUTE FUNCTION
tsvector_update_trigger(tsv, 'pg_catalog.english', title, body);

INSERT INTO messages VALUES('title here', 'the body text is here');

SELECT * FROM messages;
   title    |         body          |            tsv
------------+-----------------------+----------------------------
 title here | the body text is here | 'bodi':4 'text':5 'titl':1

SELECT title, body FROM messages WHERE tsv @@ to_tsquery('title & body');
   title    |         body
------------+-----------------------
 title here | the body text is here
```

Having created this trigger, any change in `title` or `body` will automatically be reflected into `tsv`, without the application having to worry about it.

The first trigger argument must be the name of the `tsvector` column to be updated. The second argument specifies the text search configuration to be used to perform the conversion. For `tsvector_update_trigger`, the configuration name is simply given as the second trigger argument. It must be schema-qualified as shown above, so that the trigger behavior will not change with changes in `search_path`. For `tsvector_update_trigger_column`, the second trigger argument is the name of another table column, which must be of type `regconfig`. This allows a per-row selection of configuration to be made. The remaining argument(s) are the names of textual columns (of type `text`, `varchar`, or `char`). These will be included in the document in the order given. NULL values will be skipped (but the other columns will still be indexed).

A limitation of these built-in triggers is that they treat all the input columns alike. To process columns differently — for example, to weight title differently from body — it is necessary to write a custom trigger. Here is an example using PL/pgSQL as the trigger language:

```
CREATE FUNCTION messages_trigger() RETURNS trigger AS $$
begin
```

```
  new.tsv :=
     setweight(to_tsvector('pg_catalog.english', coalesce(new.title,'')), 'A') ||
     setweight(to_tsvector('pg_catalog.english', coalesce(new.body,'')), 'D');
  return new;
end
$$ LANGUAGE plpgsql;

CREATE TRIGGER tsvectorupdate BEFORE INSERT OR UPDATE
    ON messages FOR EACH ROW EXECUTE FUNCTION messages_trigger();
```

Keep in mind that it is important to specify the configuration name explicitly when creating `tsvector` values inside triggers, so that the column's contents will not be affected by changes to `default_text_search_config`. Failure to do this is likely to lead to problems such as search results changing after a dump and restore.

12.4.4. Gathering Document Statistics

The function `ts_stat` is useful for checking your configuration and for finding stop-word candidates.

```
ts_stat(sqlquery text, [ weights text, ]
        OUT word text, OUT ndoc integer,
        OUT nentry integer) returns setof record
```

sqlquery is a text value containing an SQL query which must return a single `tsvector` column. `ts_stat` executes the query and returns statistics about each distinct lexeme (word) contained in the `tsvector` data. The columns returned are

- *word* `text` — the value of a lexeme
- *ndoc* `integer` — number of documents (`tsvector`s) the word occurred in
- *nentry* `integer` — total number of occurrences of the word

If *weights* is supplied, only occurrences having one of those weights are counted.

For example, to find the ten most frequent words in a document collection:

```
SELECT * FROM ts_stat('SELECT vector FROM apod')
ORDER BY nentry DESC, ndoc DESC, word
LIMIT 10;
```

The same, but counting only word occurrences with weight `A` or `B`:

```
SELECT * FROM ts_stat('SELECT vector FROM apod', 'ab')
ORDER BY nentry DESC, ndoc DESC, word
LIMIT 10;
```

12.5. Parsers

Text search parsers are responsible for splitting raw document text into *tokens* and identifying each token's type, where the set of possible types is defined by the parser itself. Note that a parser does not modify the text at all — it simply identifies plausible word boundaries. Because of this limited scope, there is less need for application-specific custom parsers than there is for custom dictionaries. At present Postgres Pro provides just one built-in parser, which has been found to be useful for a wide range of applications.

The built-in parser is named `pg_catalog.default`. It recognizes 23 token types, shown in Table 12.1.

Table 12.1. Default Parser's Token Types

Alias	Description	Example
`asciiword`	Word, all ASCII letters	`elephant`
`word`	Word, all letters	`mañana`
`numword`	Word, letters and digits	`beta1`

Alias	Description	Example
asciihword	Hyphenated word, all ASCII	up-to-date
hword	Hyphenated word, all letters	lógico-matemática
numhword	Hyphenated word, letters and digits	postgresql-beta1
hword_asciipart	Hyphenated word part, all ASCII	postgresql in the context post-gresql-beta1
hword_part	Hyphenated word part, all letters	lógico or matemática in the context lógi-co-matemática
hword_numpart	Hyphenated word part, letters and digits	beta1 in the context postgresql-beta1
email	Email address	foo@example.com
protocol	Protocol head	http://
url	URL	example.com/stuff/index.html
host	Host	example.com
url_path	URL path	/stuff/index.html, in the context of a URL
file	File or path name	/usr/local/foo.txt, if not within a URL
sfloat	Scientific notation	-1.234e56
float	Decimal notation	-1.234
int	Signed integer	-1234
uint	Unsigned integer	1234
version	Version number	8.3.0
tag	XML tag	<a href="dictionaries.html">
entity	XML entity	&
blank	Space symbols	(any whitespace or punctuation not otherwise recognized)

Note

The parser's notion of a "letter" is determined by the database's locale setting, specifically lc_ctype. Words containing only the basic ASCII letters are reported as a separate token type, since it is sometimes useful to distinguish them. In most European languages, token types word and asciiword should be treated alike.

email does not support all valid email characters as defined by *RFC 5322*. Specifically, the only non-alphanumeric characters supported for email user names are period, dash, and underscore.

tag does not support all valid tag names as defined by *W3C Recommendation, XML*. Specifically, the only tag names supported are those starting with an ASCII letter, underscore, or colon, and containing only letters, digits, hyphens, underscores, periods, and colons. tag also includes XML comments starting with <!-- and ending with -->, and XML declarations (but note that this includes anything starting with <?x and ending with >).

It is possible for the parser to produce overlapping tokens from the same piece of text. As an example, a hyphenated word will be reported both as the entire word and as each component:

```
SELECT alias, description, token FROM ts_debug('foo-bar-beta1');
```

```
      alias      |               description                |     token
-----------------+------------------------------------------+---------------
 numhword        | Hyphenated word, letters and digits      | foo-bar-beta1
 hword_asciipart | Hyphenated word part, all ASCII          | foo
 blank           | Space symbols                            | -
 hword_asciipart | Hyphenated word part, all ASCII          | bar
 blank           | Space symbols                            | -
 hword_numpart   | Hyphenated word part, letters and digits | beta1
```

This behavior is desirable since it allows searches to work for both the whole compound word and for components. Here is another instructive example:

```
SELECT alias, description, token FROM ts_debug('http://example.com/stuff/index.html');
  alias   |  description  |            token
----------+---------------+------------------------------
 protocol | Protocol head | http://
 url      | URL           | example.com/stuff/index.html
 host     | Host          | example.com
 url_path | URL path      | /stuff/index.html
```

12.6. Dictionaries

Dictionaries are used to eliminate words that should not be considered in a search (*stop words*), and to *normalize* words so that different derived forms of the same word will match. A successfully normalized word is called a *lexeme*. Aside from improving search quality, normalization and removal of stop words reduce the size of the `tsvector` representation of a document, thereby improving performance. Normalization does not always have linguistic meaning and usually depends on application semantics.

Some examples of normalization:

- Linguistic — Ispell dictionaries try to reduce input words to a normalized form; stemmer dictionaries remove word endings
- URL locations can be canonicalized to make equivalent URLs match:
  - http://www.pgsql.ru/db/mw/index.html
  - http://www.pgsql.ru/db/mw/
  - http://www.pgsql.ru/db/../db/mw/index.html
- Color names can be replaced by their hexadecimal values, e.g., `red, green, blue, magenta -> FF0000, 00FF00, 0000FF, FF00FF`
- If indexing numbers, we can remove some fractional digits to reduce the range of possible numbers, so for example *3.14*159265359, *3.14*15926, *3.14* will be the same after normalization if only two digits are kept after the decimal point.

A dictionary is a program that accepts a token as input and returns:

- an array of lexemes if the input token is known to the dictionary (notice that one token can produce more than one lexeme)
- a single lexeme with the `TSL_FILTER` flag set, to replace the original token with a new token to be passed to subsequent dictionaries (a dictionary that does this is called a *filtering dictionary*)
- an empty array if the dictionary knows the token, but it is a stop word
- `NULL` if the dictionary does not recognize the input token

Postgres Pro provides predefined dictionaries for many languages. There are also several predefined templates that can be used to create new dictionaries with custom parameters. Each predefined dictionary template is described below. If no existing template is suitable, it is possible to create new ones; see the `contrib/` area of the Postgres Pro distribution for examples.

A text search configuration binds a parser together with a set of dictionaries to process the parser's output tokens. For each token type that the parser can return, a separate list of dictionaries is specified by the configuration. When a token of that type is found by the parser, each dictionary in the list is consulted in turn, until some dictionary recognizes it as a known word. If it is identified as a stop word, or if no dictionary recognizes the token, it will be discarded and not indexed or searched for. Normally,

the first dictionary that returns a non-NULL output determines the result, and any remaining dictionaries are not consulted; but a filtering dictionary can replace the given word with a modified word, which is then passed to subsequent dictionaries.

The general rule for configuring a list of dictionaries is to place first the most narrow, most specific dictionary, then the more general dictionaries, finishing with a very general dictionary, like a Snowball stemmer or simple, which recognizes everything. For example, for an astronomy-specific search (astro_en configuration) one could bind token type asciiword (ASCII word) to a synonym dictionary of astronomical terms, a general English dictionary and a Snowball English stemmer:

```
ALTER TEXT SEARCH CONFIGURATION astro_en
    ADD MAPPING FOR asciiword WITH astrosyn, english_ispell, english_stem;
```

A filtering dictionary can be placed anywhere in the list, except at the end where it'd be useless. Filtering dictionaries are useful to partially normalize words to simplify the task of later dictionaries. For example, a filtering dictionary could be used to remove accents from accented letters, as is done by the unaccent module.

12.6.1. Stop Words

Stop words are words that are very common, appear in almost every document, and have no discrimination value. Therefore, they can be ignored in the context of full text searching. For example, every English text contains words like a and the, so it is useless to store them in an index. However, stop words do affect the positions in tsvector, which in turn affect ranking:

```
SELECT to_tsvector('english', 'in the list of stop words');
        to_tsvector
----------------------------
 'list':3 'stop':5 'word':6
```

The missing positions 1,2,4 are because of stop words. Ranks calculated for documents with and without stop words are quite different:

```
SELECT ts_rank_cd (to_tsvector('english', 'in the list of stop words'),
 to_tsquery('list & stop'));
 ts_rank_cd
------------
       0.05

SELECT ts_rank_cd (to_tsvector('english', 'list stop words'), to_tsquery('list &
 stop'));
 ts_rank_cd
------------
        0.1
```

It is up to the specific dictionary how it treats stop words. For example, ispell dictionaries first normalize words and then look at the list of stop words, while Snowball stemmers first check the list of stop words. The reason for the different behavior is an attempt to decrease noise.

12.6.2. Simple Dictionary

The simple dictionary template operates by converting the input token to lower case and checking it against a file of stop words. If it is found in the file then an empty array is returned, causing the token to be discarded. If not, the lower-cased form of the word is returned as the normalized lexeme. Alternatively, the dictionary can be configured to report non-stop-words as unrecognized, allowing them to be passed on to the next dictionary in the list.

Here is an example of a dictionary definition using the simple template:

```
CREATE TEXT SEARCH DICTIONARY public.simple_dict (
    TEMPLATE = pg_catalog.simple,
    STOPWORDS = english
```

```
);
```

Here, `english` is the base name of a file of stop words. The file's full name will be `$SHAREDIR/tsearch_data/english.stop`, where `$SHAREDIR` means the Postgres Pro installation's shared-data directory, often `/usr/local/share/postgresql` (use `pg_config --sharedir` to determine it if you're not sure). The file format is simply a list of words, one per line. Blank lines and trailing spaces are ignored, and upper case is folded to lower case, but no other processing is done on the file contents.

Now we can test our dictionary:

```
SELECT ts_lexize('public.simple_dict', 'YeS');
 ts_lexize
-----------
 {yes}

SELECT ts_lexize('public.simple_dict', 'The');
 ts_lexize
-----------
 {}
```

We can also choose to return `NULL`, instead of the lower-cased word, if it is not found in the stop words file. This behavior is selected by setting the dictionary's `Accept` parameter to `false`. Continuing the example:

```
ALTER TEXT SEARCH DICTIONARY public.simple_dict ( Accept = false );

SELECT ts_lexize('public.simple_dict', 'YeS');
 ts_lexize
-----------


SELECT ts_lexize('public.simple_dict', 'The');
 ts_lexize
-----------
 {}
```

With the default setting of `Accept = true`, it is only useful to place a `simple` dictionary at the end of a list of dictionaries, since it will never pass on any token to a following dictionary. Conversely, `Accept = false` is only useful when there is at least one following dictionary.

> **Caution**
>
> Most types of dictionaries rely on configuration files, such as files of stop words. These files *must* be stored in UTF-8 encoding. They will be translated to the actual database encoding, if that is different, when they are read into the server.

> **Caution**
>
> Normally, a database session will read a dictionary configuration file only once, when it is first used within the session. If you modify a configuration file and want to force existing sessions to pick up the new contents, issue an `ALTER TEXT SEARCH DICTIONARY` command on the dictionary. This can be a “dummy” update that doesn't actually change any parameter values.

12.6.3. Synonym Dictionary

This dictionary template is used to create dictionaries that replace a word with a synonym. Phrases are not supported (use the thesaurus template (Section 12.6.4) for that). A synonym dictionary can be used to overcome linguistic problems, for example, to prevent an English stemmer dictionary from reducing

the word “Paris” to “pari”. It is enough to have a `Paris paris` line in the synonym dictionary and put it before the `english_stem` dictionary. For example:

```
SELECT * FROM ts_debug('english', 'Paris');
   alias   |   description   | token |  dictionaries  |  dictionary  | lexemes
-----------+-----------------+-------+----------------+--------------+---------
 asciiword | Word, all ASCII | Paris | {english_stem} | english_stem | {pari}

CREATE TEXT SEARCH DICTIONARY my_synonym (
    TEMPLATE = synonym,
    SYNONYMS = my_synonyms
);

ALTER TEXT SEARCH CONFIGURATION english
    ALTER MAPPING FOR asciiword
    WITH my_synonym, english_stem;

SELECT * FROM ts_debug('english', 'Paris');
   alias   |   description   | token |       dictionaries        | dictionary |
 lexemes
-----------+-----------------+-------+---------------------------+------------
+---------
 asciiword | Word, all ASCII | Paris | {my_synonym,english_stem} | my_synonym | {paris}
```

The only parameter required by the `synonym` template is `SYNONYMS`, which is the base name of its configuration file — `my_synonyms` in the above example. The file's full name will be `$SHAREDIR/tsearch_data/my_synonyms.syn` (where `$SHAREDIR` means the Postgres Pro installation's shared-data directory). The file format is just one line per word to be substituted, with the word followed by its synonym, separated by white space. Blank lines and trailing spaces are ignored.

The `synonym` template also has an optional parameter `CaseSensitive`, which defaults to `false`. When `CaseSensitive` is `false`, words in the synonym file are folded to lower case, as are input tokens. When it is `true`, words and tokens are not folded to lower case, but are compared as-is.

An asterisk (`*`) can be placed at the end of a synonym in the configuration file. This indicates that the synonym is a prefix. The asterisk is ignored when the entry is used in `to_tsvector()`, but when it is used in `to_tsquery()`, the result will be a query item with the prefix match marker (see Section 12.3.2). For example, suppose we have these entries in `$SHAREDIR/tsearch_data/synonym_sample.syn`:

```
postgres        pgsql
postgresql      pgsql
postgre pgsql
gogle   googl
indices index*
```

Then we will get these results:

```
mydb=# CREATE TEXT SEARCH DICTIONARY syn (template=synonym, synonyms='synonym_sample');
mydb=# SELECT ts_lexize('syn', 'indices');
 ts_lexize
-----------
 {index}
(1 row)

mydb=# CREATE TEXT SEARCH CONFIGURATION tst (copy=simple);
mydb=# ALTER TEXT SEARCH CONFIGURATION tst ALTER MAPPING FOR asciiword WITH syn;
mydb=# SELECT to_tsvector('tst', 'indices');
 to_tsvector
-------------
 'index':1
```

```
(1 row)

mydb=# SELECT to_tsquery('tst', 'indices');
 to_tsquery
------------
 'index':*
(1 row)

mydb=# SELECT 'indexes are very useful'::tsvector;
            tsvector
--------------------------------
 'are' 'indexes' 'useful' 'very'
(1 row)

mydb=# SELECT 'indexes are very useful'::tsvector @@ to_tsquery('tst', 'indices');
 ?column?
----------
 t
(1 row)
```

12.6.4. Thesaurus Dictionary

A thesaurus dictionary (sometimes abbreviated as TZ) is a collection of words that includes information about the relationships of words and phrases, i.e., broader terms (BT), narrower terms (NT), preferred terms, non-preferred terms, related terms, etc.

Basically a thesaurus dictionary replaces all non-preferred terms by one preferred term and, optionally, preserves the original terms for indexing as well. Postgres Pro's current implementation of the thesaurus dictionary is an extension of the synonym dictionary with added *phrase* support. A thesaurus dictionary requires a configuration file of the following format:

```
# this is a comment
sample word(s) : indexed word(s)
more sample word(s) : more indexed word(s)
...
```

where the colon (`:`) symbol acts as a delimiter between a phrase and its replacement.

A thesaurus dictionary uses a *subdictionary* (which is specified in the dictionary's configuration) to normalize the input text before checking for phrase matches. It is only possible to select one subdictionary. An error is reported if the subdictionary fails to recognize a word. In that case, you should remove the use of the word or teach the subdictionary about it. You can place an asterisk (`*`) at the beginning of an indexed word to skip applying the subdictionary to it, but all sample words *must* be known to the subdictionary.

The thesaurus dictionary chooses the longest match if there are multiple phrases matching the input, and ties are broken by using the last definition.

Specific stop words recognized by the subdictionary cannot be specified; instead use `?` to mark the location where any stop word can appear. For example, assuming that `a` and `the` are stop words according to the subdictionary:

```
? one ? two : swsw
```

matches `a one the two` and `the one a two`; both would be replaced by `swsw`.

Since a thesaurus dictionary has the capability to recognize phrases it must remember its state and interact with the parser. A thesaurus dictionary uses these assignments to check if it should handle the next word or stop accumulation. The thesaurus dictionary must be configured carefully. For example, if the thesaurus dictionary is assigned to handle only the `asciiword` token, then a thesaurus dictionary definition like `one 7` will not work since token type `uint` is not assigned to the thesaurus dictionary.

> **Caution**
>
> Thesauruses are used during indexing so any change in the thesaurus dictionary's parameters *requires* reindexing. For most other dictionary types, small changes such as adding or removing stopwords does not force reindexing.

12.6.4.1. Thesaurus Configuration

To define a new thesaurus dictionary, use the `thesaurus` template. For example:

```
CREATE TEXT SEARCH DICTIONARY thesaurus_simple (
    TEMPLATE = thesaurus,
    DictFile = mythesaurus,
    Dictionary = pg_catalog.english_stem
);
```

Here:

- `thesaurus_simple` is the new dictionary's name
- `mythesaurus` is the base name of the thesaurus configuration file. (Its full name will be `$SHAREDIR/tsearch_data/mythesaurus.ths`, where `$SHAREDIR` means the installation shared-data directory.)
- `pg_catalog.english_stem` is the subdictionary (here, a Snowball English stemmer) to use for thesaurus normalization. Notice that the subdictionary will have its own configuration (for example, stop words), which is not shown here.

Now it is possible to bind the thesaurus dictionary `thesaurus_simple` to the desired token types in a configuration, for example:

```
ALTER TEXT SEARCH CONFIGURATION russian
    ALTER MAPPING FOR asciiword, asciihword, hword_asciipart
    WITH thesaurus_simple;
```

12.6.4.2. Thesaurus Example

Consider a simple astronomical thesaurus `thesaurus_astro`, which contains some astronomical word combinations:

```
supernovae stars : sn
crab nebulae : crab
```

Below we create a dictionary and bind some token types to an astronomical thesaurus and English stemmer:

```
CREATE TEXT SEARCH DICTIONARY thesaurus_astro (
    TEMPLATE = thesaurus,
    DictFile = thesaurus_astro,
    Dictionary = english_stem
);

ALTER TEXT SEARCH CONFIGURATION russian
    ALTER MAPPING FOR asciiword, asciihword, hword_asciipart
    WITH thesaurus_astro, english_stem;
```

Now we can see how it works. `ts_lexize` is not very useful for testing a thesaurus, because it treats its input as a single token. Instead we can use `plainto_tsquery` and `to_tsvector` which will break their input strings into multiple tokens:

```
SELECT plainto_tsquery('supernova star');
 plainto_tsquery
-----------------
 'sn'
```

```
SELECT to_tsvector('supernova star');
 to_tsvector
-------------
 'sn':1
```

In principle, one can use `to_tsquery` if you quote the argument:

```
SELECT to_tsquery('''supernova star''');
 to_tsquery
------------
 'sn'
```

Notice that `supernova star` matches `supernovae stars` in `thesaurus_astro` because we specified the `english_stem` stemmer in the thesaurus definition. The stemmer removed the `e` and `s`.

To index the original phrase as well as the substitute, just include it in the right-hand part of the definition:

```
supernovae stars : sn supernovae stars

SELECT plainto_tsquery('supernova star');
       plainto_tsquery
-----------------------------
 'sn' & 'supernova' & 'star'
```

12.6.5. Ispell Dictionary

The Ispell dictionary template supports *morphological dictionaries*, which can normalize many different linguistic forms of a word into the same lexeme. For example, an English Ispell dictionary can match all declensions and conjugations of the search term `bank`, e.g., `banking`, `banked`, `banks`, `banks'`, and `bank's`.

The standard Postgres Pro distribution does not include any Ispell configuration files. Dictionaries for a large number of languages are available from *Ispell*. Also, some more modern dictionary file formats are supported — *MySpell* (OO < 2.0.1) and *Hunspell* (OO >= 2.0.2). A large list of dictionaries is available on the *OpenOffice Wiki*.

To create an Ispell dictionary perform these steps:

- download dictionary configuration files. OpenOffice extension files have the `.oxt` extension. It is necessary to extract `.aff` and `.dic` files, change extensions to `.affix` and `.dict`. For some dictionary files it is also needed to convert characters to the UTF-8 encoding with commands (for example, for a Norwegian language dictionary):

  ```
  iconv -f ISO_8859-1 -t UTF-8 -o nn_no.affix nn_NO.aff
  iconv -f ISO_8859-1 -t UTF-8 -o nn_no.dict nn_NO.dic
  ```
- copy files to the `$SHAREDIR/tsearch_data` directory
- load files into Postgres Pro with the following command:

  ```
  CREATE TEXT SEARCH DICTIONARY english_hunspell (
      TEMPLATE = ispell,
      DictFile = en_us,
      AffFile = en_us,
      Stopwords = english);
  ```

Here, `DictFile`, `AffFile`, and `StopWords` specify the base names of the dictionary, affixes, and stop-words files. The stop-words file has the same format explained above for the `simple` dictionary type. The format of the other files is not specified here but is available from the above-mentioned web sites.

Ispell dictionaries usually recognize a limited set of words, so they should be followed by another broader dictionary; for example, a Snowball dictionary, which recognizes everything.

The `.affix` file of Ispell has the following structure:

```
prefixes
flag *A:
    .           >   RE      # As in enter > reenter
suffixes
flag T:
    E           >   ST      # As in late > latest
    [^AEIOU]Y   >   -Y,IEST # As in dirty > dirtiest
    [AEIOU]Y    >   EST     # As in gray > grayest
    [^EY]       >   EST     # As in small > smallest
```

And the `.dict` file has the following structure:

```
lapse/ADGRS
lard/DGRS
large/PRTY
lark/MRS
```

Format of the `.dict` file is:

```
basic_form/affix_class_name
```

In the `.affix` file every affix flag is described in the following format:

```
condition > [-stripping_letters,] adding_affix
```

Here, condition has a format similar to the format of regular expressions. It can use groupings `[...]` and `[^...]`. For example, `[AEIOU]Y` means that the last letter of the word is "`y`" and the penultimate letter is "`a`", "`e`", "`i`", "`o`" or "`u`". `[^EY]` means that the last letter is neither "`e`" nor "`y`".

Ispell dictionaries support splitting compound words; a useful feature. Notice that the affix file should specify a special flag using the `compoundwords controlled` statement that marks dictionary words that can participate in compound formation:

```
compoundwords  controlled z
```

Here are some examples for the Norwegian language:

```
SELECT ts_lexize('norwegian_ispell', 'overbuljongterningpakkmesterassistent');
   {over,buljong,terning,pakk,mester,assistent}
SELECT ts_lexize('norwegian_ispell', 'sjokoladefabrikk');
   {sjokoladefabrikk,sjokolade,fabrikk}
```

MySpell format is a subset of Hunspell. The `.affix` file of Hunspell has the following structure:

```
PFX A Y 1
PFX A   0     re         .
SFX T N 4
SFX T   0     st         e
SFX T   y     iest       [^aeiou]y
SFX T   0     est        [aeiou]y
SFX T   0     est        [^ey]
```

The first line of an affix class is the header. Fields of an affix rules are listed after the header:

- parameter name (PFX or SFX)
- flag (name of the affix class)
- stripping characters from beginning (at prefix) or end (at suffix) of the word
- adding affix
- condition that has a format similar to the format of regular expressions.

The `.dict` file looks like the `.dict` file of Ispell:

```
larder/M
```

```
lardy/RT
large/RSPMYT
largehearted
```

> **Note**
>
> MySpell does not support compound words. Hunspell has sophisticated support for compound words. At present, Postgres Pro implements only the basic compound word operations of Hunspell.

12.6.6. Snowball Dictionary

The Snowball dictionary template is based on a project by Martin Porter, inventor of the popular Porter's stemming algorithm for the English language. Snowball now provides stemming algorithms for many languages (see the *Snowball site* for more information). Each algorithm understands how to reduce common variant forms of words to a base, or stem, spelling within its language. A Snowball dictionary requires a `language` parameter to identify which stemmer to use, and optionally can specify a `stopword` file name that gives a list of words to eliminate. (Postgres Pro's standard stopword lists are also provided by the Snowball project.) For example, there is a built-in definition equivalent to

```
CREATE TEXT SEARCH DICTIONARY english_stem (
    TEMPLATE = snowball,
    Language = english,
    StopWords = english
);
```

The stopword file format is the same as already explained.

A Snowball dictionary recognizes everything, whether or not it is able to simplify the word, so it should be placed at the end of the dictionary list. It is useless to have it before any other dictionary because a token will never pass through it to the next dictionary.

12.7. Configuration Example

A text search configuration specifies all options necessary to transform a document into a `tsvector`: the parser to use to break text into tokens, and the dictionaries to use to transform each token into a lexeme. Every call of `to_tsvector` or `to_tsquery` needs a text search configuration to perform its processing. The configuration parameter default_text_search_config specifies the name of the default configuration, which is the one used by text search functions if an explicit configuration parameter is omitted. It can be set in `postgresql.conf`, or set for an individual session using the `SET` command.

Several predefined text search configurations are available, and you can create custom configurations easily. To facilitate management of text search objects, a set of SQL commands is available, and there are several psql commands that display information about text search objects (Section 12.10).

As an example we will create a configuration `pg`, starting by duplicating the built-in `english` configuration:

```
CREATE TEXT SEARCH CONFIGURATION public.pg ( COPY = pg_catalog.english );
```

We will use a Postgres Pro-specific synonym list and store it in `$SHAREDIR/tsearch_data/pg_dict.syn`. The file contents look like:

```
postgres    pg
pgsql       pg
postgresql  pg
```

We define the synonym dictionary like this:

```
CREATE TEXT SEARCH DICTIONARY pg_dict (
    TEMPLATE = synonym,
```

```
    SYNONYMS = pg_dict
);
```

Next we register the Ispell dictionary `english_ispell`, which has its own configuration files:

```
CREATE TEXT SEARCH DICTIONARY english_ispell (
    TEMPLATE = ispell,
    DictFile = english,
    AffFile = english,
    StopWords = english
);
```

Now we can set up the mappings for words in configuration `pg`:

```
ALTER TEXT SEARCH CONFIGURATION pg
    ALTER MAPPING FOR asciiword, asciihword, hword_asciipart,
                      word, hword, hword_part
    WITH pg_dict, english_ispell, english_stem;
```

We choose not to index or search some token types that the built-in configuration does handle:

```
ALTER TEXT SEARCH CONFIGURATION pg
    DROP MAPPING FOR email, url, url_path, sfloat, float;
```

Now we can test our configuration:

```
SELECT * FROM ts_debug('public.pg', '
Postgres Pro, the highly scalable, SQL compliant, open source object-relational
database management system, is now undergoing beta testing of the next
version of our software.
');
```

The next step is to set the session to use the new configuration, which was created in the `public` schema:

```
=> \dF
   List of text search configurations
 Schema  | Name | Description
---------+------+-------------
 public  | pg   |

SET default_text_search_config = 'public.pg';
SET

SHOW default_text_search_config;
 default_text_search_config
----------------------------
 public.pg
```

12.8. Testing and Debugging Text Search

The behavior of a custom text search configuration can easily become confusing. The functions described in this section are useful for testing text search objects. You can test a complete configuration, or test parsers and dictionaries separately.

12.8.1. Configuration Testing

The function `ts_debug` allows easy testing of a text search configuration.

```
ts_debug([ config regconfig, ] document text,
         OUT alias text,
         OUT description text,
         OUT token text,
```

```
        OUT dictionaries regdictionary[],
        OUT dictionary regdictionary,
        OUT lexemes text[])
        returns setof record
```

`ts_debug` displays information about every token of *document* as produced by the parser and processed by the configured dictionaries. It uses the configuration specified by *config*, or `default_text_search_config` if that argument is omitted.

`ts_debug` returns one row for each token identified in the text by the parser. The columns returned are

- *alias* `text` — short name of the token type
- *description* `text` — description of the token type
- *token* `text` — text of the token
- *dictionaries* `regdictionary[]` — the dictionaries selected by the configuration for this token type
- *dictionary* `regdictionary` — the dictionary that recognized the token, or `NULL` if none did
- *lexemes* `text[]` — the lexeme(s) produced by the dictionary that recognized the token, or `NULL` if none did; an empty array (`{}`) means it was recognized as a stop word

Here is a simple example:

```
SELECT * FROM ts_debug('english', 'a fat  cat sat on a mat - it ate a fat rats');
   alias   |   description   | token |  dictionaries  |  dictionary  | lexemes
-----------+-----------------+-------+----------------+--------------+---------
 asciiword | Word, all ASCII | a     | {english_stem} | english_stem | {}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | fat   | {english_stem} | english_stem | {fat}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | cat   | {english_stem} | english_stem | {cat}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | sat   | {english_stem} | english_stem | {sat}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | on    | {english_stem} | english_stem | {}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | a     | {english_stem} | english_stem | {}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | mat   | {english_stem} | english_stem | {mat}
 blank     | Space symbols   |       | {}             |              |
 blank     | Space symbols   | -     | {}             |              |
 asciiword | Word, all ASCII | it    | {english_stem} | english_stem | {}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | ate   | {english_stem} | english_stem | {ate}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | a     | {english_stem} | english_stem | {}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | fat   | {english_stem} | english_stem | {fat}
 blank     | Space symbols   |       | {}             |              |
 asciiword | Word, all ASCII | rats  | {english_stem} | english_stem | {rat}
```

For a more extensive demonstration, we first create a `public.english` configuration and Ispell dictionary for the English language:

```
CREATE TEXT SEARCH CONFIGURATION public.english ( COPY = pg_catalog.english );

CREATE TEXT SEARCH DICTIONARY english_ispell (
    TEMPLATE = ispell,
    DictFile = english,
    AffFile = english,
    StopWords = english
);
```

```
ALTER TEXT SEARCH CONFIGURATION public.english
   ALTER MAPPING FOR asciiword WITH english_ispell, english_stem;

SELECT * FROM ts_debug('public.english', 'The Brightest supernovaes');
   alias   |   description   |    token    |         dictionaries          |
 dictionary   |   lexemes
-----------+-----------------+-------------+-------------------------------
+----------------+-------------
 asciiword | Word, all ASCII | The         | {english_ispell,english_stem} |
 english_ispell | {}
 blank     | Space symbols   |             | {}                            |
     |
 asciiword | Word, all ASCII | Brightest   | {english_ispell,english_stem} |
 english_ispell | {bright}
 blank     | Space symbols   |             | {}                            |
     |
 asciiword | Word, all ASCII | supernovaes | {english_ispell,english_stem} |
 english_stem   | {supernova}
```

In this example, the word `Brightest` was recognized by the parser as an `ASCII word` (alias `asciiword`). For this token type the dictionary list is `english_ispell` and `english_stem`. The word was recognized by `english_ispell`, which reduced it to the noun `bright`. The word `supernovaes` is unknown to the `english_ispell` dictionary so it was passed to the next dictionary, and, fortunately, was recognized (in fact, `english_stem` is a Snowball dictionary which recognizes everything; that is why it was placed at the end of the dictionary list).

The word `The` was recognized by the `english_ispell` dictionary as a stop word (Section 12.6.1) and will not be indexed. The spaces are discarded too, since the configuration provides no dictionaries at all for them.

You can reduce the width of the output by explicitly specifying which columns you want to see:

```
SELECT alias, token, dictionary, lexemes
FROM ts_debug('public.english', 'The Brightest supernovaes');
   alias   |    token    |   dictionary   |   lexemes
-----------+-------------+----------------+-------------
 asciiword | The         | english_ispell | {}
 blank     |             |                |
 asciiword | Brightest   | english_ispell | {bright}
 blank     |             |                |
 asciiword | supernovaes | english_stem   | {supernova}
```

12.8.2. Parser Testing

The following functions allow direct testing of a text search parser.

```
ts_parse(parser_name text, document text,
         OUT tokid integer, OUT token text) returns setof record
ts_parse(parser_oid oid, document text,
         OUT tokid integer, OUT token text) returns setof record
```

`ts_parse` parses the given *document* and returns a series of records, one for each token produced by parsing. Each record includes a `tokid` showing the assigned token type and a `token` which is the text of the token. For example:

```
SELECT * FROM ts_parse('default', '123 - a number');
 tokid | token
-------+--------
    22 | 123
    12 |
```

```
    12 | -
     1 | a
    12 |
     1 | number
```

```
ts_token_type(parser_name text, OUT tokid integer,
              OUT alias text, OUT description text) returns setof record
ts_token_type(parser_oid oid, OUT tokid integer,
              OUT alias text, OUT description text) returns setof record
```

`ts_token_type` returns a table which describes each type of token the specified parser can recognize. For each token type, the table gives the integer `tokid` that the parser uses to label a token of that type, the `alias` that names the token type in configuration commands, and a short `description`. For example:

```
SELECT * FROM ts_token_type('default');
 tokid |      alias      |               description
-------+-----------------+------------------------------------------
     1 | asciiword       | Word, all ASCII
     2 | word            | Word, all letters
     3 | numword         | Word, letters and digits
     4 | email           | Email address
     5 | url             | URL
     6 | host            | Host
     7 | sfloat          | Scientific notation
     8 | version         | Version number
     9 | hword_numpart   | Hyphenated word part, letters and digits
    10 | hword_part      | Hyphenated word part, all letters
    11 | hword_asciipart | Hyphenated word part, all ASCII
    12 | blank           | Space symbols
    13 | tag             | XML tag
    14 | protocol        | Protocol head
    15 | numhword        | Hyphenated word, letters and digits
    16 | asciihword      | Hyphenated word, all ASCII
    17 | hword           | Hyphenated word, all letters
    18 | url_path        | URL path
    19 | file            | File or path name
    20 | float           | Decimal notation
    21 | int             | Signed integer
    22 | uint            | Unsigned integer
    23 | entity          | XML entity
```

12.8.3. Dictionary Testing

The `ts_lexize` function facilitates dictionary testing.

```
ts_lexize(dict regdictionary, token text) returns text[]
```

`ts_lexize` returns an array of lexemes if the input *`token`* is known to the dictionary, or an empty array if the token is known to the dictionary but it is a stop word, or `NULL` if it is an unknown word.

Examples:

```
SELECT ts_lexize('english_stem', 'stars');
 ts_lexize
-----------
 {star}

SELECT ts_lexize('english_stem', 'a');
 ts_lexize
-----------
```

```
{}
```

Note

The `ts_lexize` function expects a single *token*, not text. Here is a case where this can be confusing:

```
SELECT ts_lexize('thesaurus_astro', 'supernovae stars') is null;
 ?column?
----------
 t
```

The thesaurus dictionary `thesaurus_astro` does know the phrase `supernovae stars`, but `ts_lexize` fails since it does not parse the input text but treats it as a single token. Use `plainto_tsquery` or `to_tsvector` to test thesaurus dictionaries, for example:

```
SELECT plainto_tsquery('supernovae stars');
 plainto_tsquery
-----------------
 'sn'
```

12.9. Preferred Index Types for Text Search

The following kinds of indexes can be used to speed up full text searches: GIN, RUM, and GiST. Note that indexes are not mandatory for full text searching, but in cases where a column is searched on a regular basis, an index is usually desirable.

To create such an index, do one of:

`CREATE INDEX` *`name`* `ON` *`table`* `USING GIN (`*`column`*`);`

Creates a GIN (Generalized Inverted Index)-based index. The *`column`* must be of `tsvector` type.

`CREATE INDEX` *`name`* `ON` *`table`* `USING RUM (`*`column`*`);`

Creates a RUM-based index. The *`column`* must be of `tsvector` type.

`CREATE INDEX` *`name`* `ON` *`table`* `USING GIST (`*`column`* `[ { DEFAULT | tsvector_ops } (siglen =` *`number`*`) ] );`

Creates a GiST (Generalized Search Tree)-based index. The *`column`* can be of `tsvector` or `tsquery` type. Optional integer parameter `siglen` determines signature length in bytes (see below for details).

GIN indexes and RUM indexes, based on the `GIN` access method code, are the preferred text search index type. As inverted indexes, they contain an index entry for each word (lexeme), with a compressed list of matching locations. Multi-word searches can find the first match, then use the index to remove rows that are lacking additional words. GIN indexes store only the words (lexemes) of `tsvector` values, and not their weight labels. Thus a table row recheck is needed when using a query that involves weights.

A GiST index is *lossy*, meaning that the index might produce false matches, and it is necessary to check the actual table row to eliminate such false matches. (Postgres Pro does this automatically when needed.) GiST indexes are lossy because each document is represented in the index by a fixed-length signature. The signature length in bytes is determined by the value of the optional integer parameter `siglen`. The default signature length (when `siglen` is not specified) is 124 bytes, the maximum signature length is 2024 bytes. The signature is generated by hashing each word into a single bit in an n-bit string, with all these bits OR-ed together to produce an n-bit document signature. When two words hash to the same bit position there will be a false match. If all words in the query have matches (real or false) then the table row must be retrieved to see if the match is correct. Longer signatures lead to a more precise search (scanning a smaller fraction of the index and fewer heap pages), at the cost of a larger index.

A GiST index can be covering, i.e., use the `INCLUDE` clause. Included columns can have data types without any GiST operator class. Included attributes will be stored uncompressed.

Lossiness causes performance degradation due to unnecessary fetches of table records that turn out to be false matches. Since random access to table records is slow, this limits the usefulness of GiST indexes. The likelihood of false matches depends on several factors, in particular the number of unique words, so using dictionaries to reduce this number is recommended.

Note that GIN index build time can often be improved by increasing maintenance_work_mem, while GiST index build time is not sensitive to that parameter.

Partitioning of big collections and the proper use of GIN, RUM, and GiST indexes allows the implementation of very fast searches with online update. Partitioning can be done at the database level using table inheritance, or by distributing documents over servers and collecting external search results, e.g., via Foreign Data access. The latter is possible because ranking functions use only local information.

12.10. psql Support

Information about text search configuration objects can be obtained in psql using a set of commands:

```
\dF{d,p,t}[+] [PATTERN]
```

An optional + produces more details.

The optional parameter *PATTERN* can be the name of a text search object, optionally schema-qualified. If *PATTERN* is omitted then information about all visible objects will be displayed. *PATTERN* can be a regular expression and can provide *separate* patterns for the schema and object names. The following examples illustrate this:

```
=> \dF *fulltext*
       List of text search configurations
 Schema |  Name        | Description
--------+--------------+-------------
 public | fulltext_cfg |
```

```
=> \dF *.fulltext*
       List of text search configurations
 Schema   |  Name        | Description
----------+--------------+-------------
 fulltext | fulltext_cfg |
 public   | fulltext_cfg |
```

The available commands are:

```
\dF[+] [PATTERN]
```

List text search configurations (add + for more detail).

```
=> \dF russian
            List of text search configurations
   Schema   |  Name   |            Description
------------+---------+-----------------------------------
 pg_catalog | russian | configuration for russian language

=> \dF+ russian
Text search configuration "pg_catalog.russian"
Parser: "pg_catalog.default"
      Token      | Dictionaries
-----------------+--------------
 asciihword      | english_stem
 asciiword       | english_stem
 email           | simple
 file            | simple
 float           | simple
 host            | simple
```

```
 hword           | russian_stem
 hword_asciipart | english_stem
 hword_numpart   | simple
 hword_part      | russian_stem
 int             | simple
 numhword        | simple
 numword         | simple
 sfloat          | simple
 uint            | simple
 url             | simple
 url_path        | simple
 version         | simple
 word            | russian_stem
```

`\dFd[+] [PATTERN]`

List text search dictionaries (add + for more detail).

```
=> \dFd
                              List of text search dictionaries
   Schema   |      Name       |                        Description
------------+-----------------
+-----------------------------------------------------------
 pg_catalog | arabic_stem     | snowball stemmer for arabic language
 pg_catalog | armenian_stem   | snowball stemmer for armenian language
 pg_catalog | basque_stem     | snowball stemmer for basque language
 pg_catalog | catalan_stem    | snowball stemmer for catalan language
 pg_catalog | danish_stem     | snowball stemmer for danish language
 pg_catalog | dutch_stem      | snowball stemmer for dutch language
 pg_catalog | english_stem    | snowball stemmer for english language
 pg_catalog | finnish_stem    | snowball stemmer for finnish language
 pg_catalog | french_stem     | snowball stemmer for french language
 pg_catalog | german_stem     | snowball stemmer for german language
 pg_catalog | greek_stem      | snowball stemmer for greek language
 pg_catalog | hindi_stem      | snowball stemmer for hindi language
 pg_catalog | hungarian_stem  | snowball stemmer for hungarian language
 pg_catalog | indonesian_stem | snowball stemmer for indonesian language
 pg_catalog | irish_stem      | snowball stemmer for irish language
 pg_catalog | italian_stem    | snowball stemmer for italian language
 pg_catalog | lithuanian_stem | snowball stemmer for lithuanian language
 pg_catalog | nepali_stem     | snowball stemmer for nepali language
 pg_catalog | norwegian_stem  | snowball stemmer for norwegian language
 pg_catalog | portuguese_stem | snowball stemmer for portuguese language
 pg_catalog | romanian_stem   | snowball stemmer for romanian language
 pg_catalog | russian_stem    | snowball stemmer for russian language
 pg_catalog | serbian_stem    | snowball stemmer for serbian language
 pg_catalog | simple          | simple dictionary: just lower case and check for
 stopword
 pg_catalog | spanish_stem    | snowball stemmer for spanish language
 pg_catalog | swedish_stem    | snowball stemmer for swedish language
 pg_catalog | tamil_stem      | snowball stemmer for tamil language
 pg_catalog | turkish_stem    | snowball stemmer for turkish language
 pg_catalog | yiddish_stem    | snowball stemmer for yiddish language
```

`\dFp[+] [PATTERN]`

List text search parsers (add + for more detail).

```
=> \dFp
        List of text search parsers
```

```
   Schema   |  Name   |     Description
------------+---------+---------------------
 pg_catalog | default | default word parser
=> \dFp+
    Text search parser "pg_catalog.default"
     Method      |    Function    | Description
-----------------+----------------+-------------
 Start parse     | prsd_start     |
 Get next token  | prsd_nexttoken |
 End parse       | prsd_end       |
 Get headline    | prsd_headline  |
 Get token types | prsd_lextype   |

        Token types for parser "pg_catalog.default"
   Token name    |               Description
-----------------+------------------------------------------
 asciihword      | Hyphenated word, all ASCII
 asciiword       | Word, all ASCII
 blank           | Space symbols
 email           | Email address
 entity          | XML entity
 file            | File or path name
 float           | Decimal notation
 host            | Host
 hword           | Hyphenated word, all letters
 hword_asciipart | Hyphenated word part, all ASCII
 hword_numpart   | Hyphenated word part, letters and digits
 hword_part      | Hyphenated word part, all letters
 int             | Signed integer
 numhword        | Hyphenated word, letters and digits
 numword         | Word, letters and digits
 protocol        | Protocol head
 sfloat          | Scientific notation
 tag             | XML tag
 uint            | Unsigned integer
 url             | URL
 url_path        | URL path
 version         | Version number
 word            | Word, all letters
(23 rows)
```

`\dFt[+] [PATTERN]`

List text search templates (add + for more detail).

```
=> \dFt
                            List of text search templates
   Schema   |   Name    |                        Description
------------+-----------+-----------------------------------------------------------
 pg_catalog | ispell    | ispell dictionary
 pg_catalog | simple    | simple dictionary: just lower case and check for stopword
 pg_catalog | snowball  | snowball stemmer
 pg_catalog | synonym   | synonym dictionary: replace word by its synonym
 pg_catalog | thesaurus | thesaurus dictionary: phrase by phrase substitution
```

12.11. Limitations

The current limitations of Postgres Pro's text search features are:

- The length of each lexeme must be less than 2 kilobytes

- The length of a `tsvector` (lexemes + positions) must be less than 1 megabyte
- The number of lexemes must be less than 2^{64}
- Position values in `tsvector` must be greater than 0 and no more than 16,383
- The match distance in a *<N>* (FOLLOWED BY) `tsquery` operator cannot be more than 16,384
- No more than 256 positions per lexeme
- The number of nodes (lexemes + operators) in a `tsquery` must be less than 32,768

For comparison, the PostgreSQL 8.1 documentation contained 10,441 unique words, a total of 335,420 words, and the most frequent word “postgresql” was mentioned 6,127 times in 655 documents.

Another example — the PostgreSQL mailing list archives contained 910,989 unique words with 57,491,343 lexemes in 461,020 messages.

Chapter 13. Concurrency Control

This chapter describes the behavior of the Postgres Pro database system when two or more sessions try to access the same data at the same time. The goals in that situation are to allow efficient access for all sessions while maintaining strict data integrity. Every developer of database applications should be familiar with the topics covered in this chapter.

13.1. Introduction

Postgres Pro provides a rich set of tools for developers to manage concurrent access to data. Internally, data consistency is maintained by using a multiversion model (Multiversion Concurrency Control, MVCC). This means that each SQL statement sees a snapshot of data (a *database version*) as it was some time ago, regardless of the current state of the underlying data. This prevents statements from viewing inconsistent data produced by concurrent transactions performing updates on the same data rows, providing *transaction isolation* for each database session. MVCC, by eschewing the locking methodologies of traditional database systems, minimizes lock contention in order to allow for reasonable performance in multiuser environments.

The main advantage of using the MVCC model of concurrency control rather than locking is that in MVCC locks acquired for querying (reading) data do not conflict with locks acquired for writing data, and so reading never blocks writing and writing never blocks reading. Postgres Pro maintains this guarantee even when providing the strictest level of transaction isolation through the use of an innovative *Serializable Snapshot Isolation* (SSI) level.

Table- and row-level locking facilities are also available in Postgres Pro for applications which don't generally need full transaction isolation and prefer to explicitly manage particular points of conflict. However, proper use of MVCC will generally provide better performance than locks. In addition, application-defined advisory locks provide a mechanism for acquiring locks that are not tied to a single transaction.

13.2. Transaction Isolation

The SQL standard defines four levels of transaction isolation. The most strict is Serializable, which is defined by the standard in a paragraph which says that any concurrent execution of a set of Serializable transactions is guaranteed to produce the same effect as running them one at a time in some order. The other three levels are defined in terms of phenomena, resulting from interaction between concurrent transactions, which must not occur at each level. The standard notes that due to the definition of Serializable, none of these phenomena are possible at that level. (This is hardly surprising -- if the effect of the transactions must be consistent with having been run one at a time, how could you see any phenomena caused by interactions?)

The phenomena which are prohibited at various levels are:

dirty read

A transaction reads data written by a concurrent uncommitted transaction.

nonrepeatable read

A transaction re-reads data it has previously read and finds that data has been modified by another transaction (that committed since the initial read).

phantom read

A transaction re-executes a query returning a set of rows that satisfy a search condition and finds that the set of rows satisfying the condition has changed due to another recently-committed transaction.

serialization anomaly

The result of successfully committing a group of transactions is inconsistent with all possible orderings of running those transactions one at a time.

The SQL standard and Postgres Pro-implemented transaction isolation levels are described in Table 13.1.

Table 13.1. Transaction Isolation Levels

Isolation Level	Dirty Read	Nonrepeatable Read	Phantom Read	Serialization Anomaly
Read uncommitted	Allowed, but not in PG	Possible	Possible	Possible
Read committed	Not possible	Possible	Possible	Possible
Repeatable read	Not possible	Not possible	Allowed, but not in PG	Possible
Serializable	Not possible	Not possible	Not possible	Not possible

In Postgres Pro, you can request any of the four standard transaction isolation levels, but internally only three distinct isolation levels are implemented, i.e., Postgres Pro's Read Uncommitted mode behaves like Read Committed. This is because it is the only sensible way to map the standard isolation levels to Postgres Pro's multiversion concurrency control architecture.

The table also shows that Postgres Pro's Repeatable Read implementation does not allow phantom reads. This is acceptable under the SQL standard because the standard specifies which anomalies must *not* occur at certain isolation levels; higher guarantees are acceptable. The behavior of the available isolation levels is detailed in the following subsections.

To set the transaction isolation level of a transaction, use the command SET TRANSACTION.

> **Important**
>
> Some Postgres Pro data types and functions have special rules regarding transactional behavior. In particular, changes made to a sequence (and therefore the counter of a column declared using `serial`) are immediately visible to all other transactions and are not rolled back if the transaction that made the changes aborts. See Section 9.17 and Section 8.1.4.

13.2.1. Read Committed Isolation Level

Read Committed is the default isolation level in Postgres Pro. When a transaction uses this isolation level, a `SELECT` query (without a `FOR UPDATE/SHARE` clause) sees only data committed before the query began; it never sees either uncommitted data or changes committed during query execution by concurrent transactions. In effect, a `SELECT` query sees a snapshot of the database as of the instant the query begins to run. However, `SELECT` does see the effects of previous updates executed within its own transaction, even though they are not yet committed. Also note that two successive `SELECT` commands can see different data, even though they are within a single transaction, if other transactions commit changes after the first `SELECT` starts and before the second `SELECT` starts.

`UPDATE`, `DELETE`, `SELECT FOR UPDATE`, and `SELECT FOR SHARE` commands behave the same as `SELECT` in terms of searching for target rows: they will only find target rows that were committed as of the command start time. However, such a target row might have already been updated (or deleted or locked) by another concurrent transaction by the time it is found. In this case, the would-be updater will wait for the first updating transaction to commit or roll back (if it is still in progress). If the first updater rolls back, then its effects are negated and the second updater can proceed with updating the originally found row. If the first updater commits, the second updater will ignore the row if the first updater deleted it, otherwise it will attempt to apply its operation to the updated version of the row. The search condition of the command (the `WHERE` clause) is re-evaluated to see if the updated version of the row still matches the search condition. If so, the second updater proceeds with its operation using the updated version of the row. In the case of `SELECT FOR UPDATE` and `SELECT FOR SHARE`, this means it is the updated version of the row that is locked and returned to the client.

`INSERT` with an `ON CONFLICT DO UPDATE` clause behaves similarly. In Read Committed mode, each row proposed for insertion will either insert or update. Unless there are unrelated errors, one of those two outcomes is guaranteed. If a conflict originates in another transaction whose effects are not yet visible to the `INSERT` , the `UPDATE` clause will affect that row, even though possibly *no* version of that row is conventionally visible to the command.

`INSERT` with an `ON CONFLICT DO NOTHING` clause may have insertion not proceed for a row due to the outcome of another transaction whose effects are not visible to the `INSERT` snapshot. Again, this is only the case in Read Committed mode.

Because of the above rules, it is possible for an updating command to see an inconsistent snapshot: it can see the effects of concurrent updating commands on the same rows it is trying to update, but it does not see effects of those commands on other rows in the database. This behavior makes Read Committed mode unsuitable for commands that involve complex search conditions; however, it is just right for simpler cases. For example, consider updating bank balances with transactions like:

```
BEGIN;
UPDATE accounts SET balance = balance + 100.00 WHERE acctnum = 12345;
UPDATE accounts SET balance = balance - 100.00 WHERE acctnum = 7534;
COMMIT;
```

If two such transactions concurrently try to change the balance of account 12345, we clearly want the second transaction to start with the updated version of the account's row. Because each command is affecting only a predetermined row, letting it see the updated version of the row does not create any troublesome inconsistency.

More complex usage can produce undesirable results in Read Committed mode. For example, consider a `DELETE` command operating on data that is being both added and removed from its restriction criteria by another command, e.g., assume `website` is a two-row table with `website.hits` equaling `9` and `10`:

```
BEGIN;
UPDATE website SET hits = hits + 1;
-- run from another session:  DELETE FROM website WHERE hits = 10;
COMMIT;
```

The `DELETE` will have no effect even though there is a `website.hits = 10` row before and after the `UPDATE`. This occurs because the pre-update row value `9` is skipped, and when the `UPDATE` completes and `DELETE` obtains a lock, the new row value is no longer `10` but `11`, which no longer matches the criteria.

Because Read Committed mode starts each command with a new snapshot that includes all transactions committed up to that instant, subsequent commands in the same transaction will see the effects of the committed concurrent transaction in any case. The point at issue above is whether or not a *single* command sees an absolutely consistent view of the database.

The partial transaction isolation provided by Read Committed mode is adequate for many applications, and this mode is fast and simple to use; however, it is not sufficient for all cases. Applications that do complex queries and updates might require a more rigorously consistent view of the database than Read Committed mode provides.

13.2.2. Repeatable Read Isolation Level

The *Repeatable Read* isolation level only sees data committed before the transaction began; it never sees either uncommitted data or changes committed during transaction execution by concurrent transactions. (However, the query does see the effects of previous updates executed within its own transaction, even though they are not yet committed.) This is a stronger guarantee than is required by the SQL standard for this isolation level, and prevents all of the phenomena described in Table 13.1 except for serialization anomalies. As mentioned above, this is specifically allowed by the standard, which only describes the *minimum* protections each isolation level must provide.

This level is different from Read Committed in that a query in a repeatable read transaction sees a snapshot as of the start of the first non-transaction-control statement in the *transaction*, not as of the

start of the current statement within the transaction. Thus, successive `SELECT` commands within a *single* transaction see the same data, i.e., they do not see changes made by other transactions that committed after their own transaction started.

Applications using this level must be prepared to retry transactions due to serialization failures.

`UPDATE`, `DELETE`, `SELECT FOR UPDATE`, and `SELECT FOR SHARE` commands behave the same as `SELECT` in terms of searching for target rows: they will only find target rows that were committed as of the transaction start time. However, such a target row might have already been updated (or deleted or locked) by another concurrent transaction by the time it is found. In this case, the repeatable read transaction will wait for the first updating transaction to commit or roll back (if it is still in progress). If the first updater rolls back, then its effects are negated and the repeatable read transaction can proceed with updating the originally found row. But if the first updater commits (and actually updated or deleted the row, not just locked it) then the repeatable read transaction will be rolled back with the message

```
ERROR:  could not serialize access due to concurrent update
```

because a repeatable read transaction cannot modify or lock rows changed by other transactions after the repeatable read transaction began.

When an application receives this error message, it should abort the current transaction and retry the whole transaction from the beginning. The second time through, the transaction will see the previously-committed change as part of its initial view of the database, so there is no logical conflict in using the new version of the row as the starting point for the new transaction's update.

Note that only updating transactions might need to be retried; read-only transactions will never have serialization conflicts.

The Repeatable Read mode provides a rigorous guarantee that each transaction sees a completely stable view of the database. However, this view will not necessarily always be consistent with some serial (one at a time) execution of concurrent transactions of the same level. For example, even a read-only transaction at this level may see a control record updated to show that a batch has been completed but *not* see one of the detail records which is logically part of the batch because it read an earlier revision of the control record. Attempts to enforce business rules by transactions running at this isolation level are not likely to work correctly without careful use of explicit locks to block conflicting transactions.

The Repeatable Read isolation level is implemented using a technique known in academic database literature and in some other database products as *Snapshot Isolation*. Differences in behavior and performance may be observed when compared with systems that use a traditional locking technique that reduces concurrency. Some other systems may even offer Repeatable Read and Snapshot Isolation as distinct isolation levels with different behavior. The permitted phenomena that distinguish the two techniques were not formalized by database researchers until after the SQL standard was developed, and are outside the scope of this manual. For a full treatment, please see berenson95.

> **Note**
>
> Prior to PostgreSQL version 9.1, a request for the Serializable transaction isolation level provided exactly the same behavior described here. To retain the legacy Serializable behavior, Repeatable Read should now be requested.

13.2.3. Serializable Isolation Level

The *Serializable* isolation level provides the strictest transaction isolation. This level emulates serial transaction execution for all committed transactions; as if transactions had been executed one after another, serially, rather than concurrently. However, like the Repeatable Read level, applications using this level must be prepared to retry transactions due to serialization failures. In fact, this isolation level works exactly the same as Repeatable Read except that it monitors for conditions which could make execution of a concurrent set of serializable transactions behave in a manner inconsistent with all possible

serial (one at a time) executions of those transactions. This monitoring does not introduce any blocking beyond that present in repeatable read, but there is some overhead to the monitoring, and detection of the conditions which could cause a *serialization anomaly* will trigger a *serialization failure*.

As an example, consider a table `mytab`, initially containing:

```
 class | value
-------+-------
     1 |    10
     1 |    20
     2 |   100
     2 |   200
```

Suppose that serializable transaction A computes:

```
SELECT SUM(value) FROM mytab WHERE class = 1;
```

and then inserts the result (30) as the `value` in a new row with `class = 2`. Concurrently, serializable transaction B computes:

```
SELECT SUM(value) FROM mytab WHERE class = 2;
```

and obtains the result 300, which it inserts in a new row with `class = 1`. Then both transactions try to commit. If either transaction were running at the Repeatable Read isolation level, both would be allowed to commit; but since there is no serial order of execution consistent with the result, using Serializable transactions will allow one transaction to commit and will roll the other back with this message:

```
ERROR:  could not serialize access due to read/write dependencies among transactions
```

This is because if A had executed before B, B would have computed the sum 330, not 300, and similarly the other order would have resulted in a different sum computed by A.

When relying on Serializable transactions to prevent anomalies, it is important that any data read from a permanent user table not be considered valid until the transaction which read it has successfully committed. This is true even for read-only transactions, except that data read within a *deferrable* read-only transaction is known to be valid as soon as it is read, because such a transaction waits until it can acquire a snapshot guaranteed to be free from such problems before starting to read any data. In all other cases applications must not depend on results read during a transaction that later aborted; instead, they should retry the transaction until it succeeds.

To guarantee true serializability Postgres Pro uses *predicate locking*, which means that it keeps locks which allow it to determine when a write would have had an impact on the result of a previous read from a concurrent transaction, had it run first. In Postgres Pro these locks do not cause any blocking and therefore can *not* play any part in causing a deadlock. They are used to identify and flag dependencies among concurrent Serializable transactions which in certain combinations can lead to serialization anomalies. In contrast, a Read Committed or Repeatable Read transaction which wants to ensure data consistency may need to take out a lock on an entire table, which could block other users attempting to use that table, or it may use `SELECT FOR UPDATE` or `SELECT FOR SHARE` which not only can block other transactions but cause disk access.

Predicate locks in Postgres Pro, like in most other database systems, are based on data actually accessed by a transaction. These will show up in the `pg_locks` system view with a `mode` of `SIReadLock`. The particular locks acquired during execution of a query will depend on the plan used by the query, and multiple finer-grained locks (e.g., tuple locks) may be combined into fewer coarser-grained locks (e.g., page locks) during the course of the transaction to prevent exhaustion of the memory used to track the locks. A `READ ONLY` transaction may be able to release its SIRead locks before completion, if it detects that no conflicts can still occur which could lead to a serialization anomaly. In fact, `READ ONLY` transactions will often be able to establish that fact at startup and avoid taking any predicate locks. If you explicitly request a `SERIALIZABLE READ ONLY DEFERRABLE` transaction, it will block until it can establish this fact. (This is the *only* case where Serializable transactions block but Repeatable Read transactions don't.) On the other hand, SIRead locks often need to be kept past transaction commit, until overlapping read write transactions complete.

Consistent use of Serializable transactions can simplify development. The guarantee that any set of successfully committed concurrent Serializable transactions will have the same effect as if they were run one at a time means that if you can demonstrate that a single transaction, as written, will do the right thing when run by itself, you can have confidence that it will do the right thing in any mix of Serializable transactions, even without any information about what those other transactions might do, or it will not successfully commit. It is important that an environment which uses this technique have a generalized way of handling serialization failures (which always return with an SQLSTATE value of '40001'), because it will be very hard to predict exactly which transactions might contribute to the read/write dependencies and need to be rolled back to prevent serialization anomalies. The monitoring of read/write dependencies has a cost, as does the restart of transactions which are terminated with a serialization failure, but balanced against the cost and blocking involved in use of explicit locks and `SELECT FOR UPDATE` or `SELECT FOR SHARE`, Serializable transactions are the best performance choice for some environments.

While Postgres Pro's Serializable transaction isolation level only allows concurrent transactions to commit if it can prove there is a serial order of execution that would produce the same effect, it doesn't always prevent errors from being raised that would not occur in true serial execution. In particular, it is possible to see unique constraint violations caused by conflicts with overlapping Serializable transactions even after explicitly checking that the key isn't present before attempting to insert it. This can be avoided by making sure that *all* Serializable transactions that insert potentially conflicting keys explicitly check if they can do so first. For example, imagine an application that asks the user for a new key and then checks that it doesn't exist already by trying to select it first, or generates a new key by selecting the maximum existing key and adding one. If some Serializable transactions insert new keys directly without following this protocol, unique constraints violations might be reported even in cases where they could not occur in a serial execution of the concurrent transactions.

For optimal performance when relying on Serializable transactions for concurrency control, these issues should be considered:

- Declare transactions as `READ ONLY` when possible.
- Control the number of active connections, using a connection pool if needed. This is always an important performance consideration, but it can be particularly important in a busy system using Serializable transactions.
- Don't put more into a single transaction than needed for integrity purposes.
- Don't leave connections dangling “idle in transaction” longer than necessary. The configuration parameter idle_in_transaction_session_timeout may be used to automatically disconnect lingering sessions.
- Eliminate explicit locks, `SELECT FOR UPDATE`, and `SELECT FOR SHARE` where no longer needed due to the protections automatically provided by Serializable transactions.
- When the system is forced to combine multiple page-level predicate locks into a single relation-level predicate lock because the predicate lock table is short of memory, an increase in the rate of serialization failures may occur. You can avoid this by increasing max_pred_locks_per_transaction, max_pred_locks_per_relation, and/or max_pred_locks_per_page.
- A sequential scan will always necessitate a relation-level predicate lock. This can result in an increased rate of serialization failures. It may be helpful to encourage the use of index scans by reducing random_page_cost and/or increasing cpu_tuple_cost. Be sure to weigh any decrease in transaction rollbacks and restarts against any overall change in query execution time.

The Serializable isolation level is implemented using a technique known in academic database literature as Serializable Snapshot Isolation, which builds on Snapshot Isolation by adding checks for serialization anomalies. Some differences in behavior and performance may be observed when compared with other systems that use a traditional locking technique. Please see ports12 for detailed information.

13.3. Explicit Locking

Postgres Pro provides various lock modes to control concurrent access to data in tables. These modes can be used for application-controlled locking in situations where MVCC does not give the desired behavior.

Also, most Postgres Pro commands automatically acquire locks of appropriate modes to ensure that referenced tables are not dropped or modified in incompatible ways while the command executes. (For example, TRUNCATE cannot safely be executed concurrently with other operations on the same table, so it obtains an ACCESS EXCLUSIVE lock on the table to enforce that.)

To examine a list of the currently outstanding locks in a database server, use the pg_locks system view. For more information on monitoring the status of the lock manager subsystem, refer to Chapter 27.

13.3.1. Table-Level Locks

The list below shows the available lock modes and the contexts in which they are used automatically by Postgres Pro. You can also acquire any of these locks explicitly with the command LOCK. Remember that all of these lock modes are table-level locks, even if the name contains the word “row”; the names of the lock modes are historical. To some extent the names reflect the typical usage of each lock mode — but the semantics are all the same. The only real difference between one lock mode and another is the set of lock modes with which each conflicts (see Table 13.2). Two transactions cannot hold locks of conflicting modes on the same table at the same time. (However, a transaction never conflicts with itself. For example, it might acquire ACCESS EXCLUSIVE lock and later acquire ACCESS SHARE lock on the same table.) Non-conflicting lock modes can be held concurrently by many transactions. Notice in particular that some lock modes are self-conflicting (for example, an ACCESS EXCLUSIVE lock cannot be held by more than one transaction at a time) while others are not self-conflicting (for example, an ACCESS SHARE lock can be held by multiple transactions).

Table-Level Lock Modes

ACCESS SHARE (AccessShareLock)

Conflicts with the ACCESS EXCLUSIVE lock mode only.

The SELECT command acquires a lock of this mode on referenced tables. In general, any query that only *reads* a table and does not modify it will acquire this lock mode.

ROW SHARE (RowShareLock)

Conflicts with the EXCLUSIVE and ACCESS EXCLUSIVE lock modes.

The SELECT FOR UPDATE and SELECT FOR SHARE commands acquire a lock of this mode on the target table(s) (in addition to ACCESS SHARE locks on any other tables that are referenced but not selected FOR UPDATE/FOR SHARE).

ROW EXCLUSIVE (RowExclusiveLock)

Conflicts with the SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, and ACCESS EXCLUSIVE lock modes.

The commands UPDATE, DELETE, and INSERT acquire this lock mode on the target table (in addition to ACCESS SHARE locks on any other referenced tables). In general, this lock mode will be acquired by any command that *modifies data* in a table.

SHARE UPDATE EXCLUSIVE (ShareUpdateExclusiveLock)

Conflicts with the SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, and ACCESS EXCLUSIVE lock modes. This mode protects a table against concurrent schema changes and VACUUM runs.

Acquired by VACUUM (without FULL), ANALYZE, CREATE INDEX CONCURRENTLY, CREATE STATISTICS, COMMENT ON, REINDEX CONCURRENTLY, and certain ALTER INDEX and ALTER TABLE variants (for full details see the documentation of these commands).

SHARE (ShareLock)

Conflicts with the ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE ROW EXCLUSIVE, EXCLUSIVE, and ACCESS EXCLUSIVE lock modes. This mode protects a table against concurrent data changes.

Acquired by CREATE INDEX (without CONCURRENTLY).

SHARE ROW EXCLUSIVE (ShareRowExclusiveLock)

Conflicts with the ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, and ACCESS EXCLUSIVE lock modes. This mode protects a table against concurrent data changes, and is self-exclusive so that only one session can hold it at a time.

Acquired by CREATE TRIGGER and some forms of ALTER TABLE.

EXCLUSIVE (ExclusiveLock)

Conflicts with the ROW SHARE, ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, and ACCESS EXCLUSIVE lock modes. This mode allows only concurrent ACCESS SHARE locks, i.e., only reads from the table can proceed in parallel with a transaction holding this lock mode.

Acquired by REFRESH MATERIALIZED VIEW CONCURRENTLY.

ACCESS EXCLUSIVE (AccessExclusiveLock)

Conflicts with locks of ACCESS SHARE, ROW SHARE, ROW EXCLUSIVE, SHARE UPDATE EXCLUSIVE, SHARE, SHARE ROW EXCLUSIVE, EXCLUSIVE, and ACCESS EXCLUSIVE mode. This mode guarantees that the holder is the only transaction accessing the table in any way.

Acquired by the DROP TABLE, TRUNCATE, REINDEX, CLUSTER, VACUUM FULL, and REFRESH MATERIALIZED VIEW (without CONCURRENTLY) commands. Many forms of ALTER INDEX and ALTER TABLE also acquire a lock at this level. This is also the default lock mode for LOCK TABLE statements that do not specify a mode explicitly.

> **Tip**
>
> Only an ACCESS EXCLUSIVE lock blocks a SELECT (without FOR UPDATE/SHARE) statement.

Besides, there are two additional lock modes designed to support 1C Enterprise. These modes do not conflict with any other lock modes described above. Their use is possible, but not encouraged, as advisory locks provide the same functionality.

APPLICATION SHARE

Conflicts with the APPLICATION EXCLUSIVE lock mode only.

APPLICATION EXCLUSIVE

Conflicts with the APPLICATION SHARE and APPLICATION EXCLUSIVE lock modes.

Once acquired, a lock is normally held until the end of the transaction. But if a lock is acquired after establishing a savepoint, the lock is released immediately if the savepoint is rolled back to. This is consistent with the principle that ROLLBACK cancels all effects of the commands since the savepoint. The same holds for locks acquired within a PL/pgSQL exception block: an error escape from the block releases locks acquired within it.

Table 13.2. Conflicting Lock Modes

Requested Lock Mode	**Existing Lock Mode**									
	ACCESS SHARE	ROW SHARE	ROW EXCL.	SHARE UPDATE EXCL.	SHARE	SHARE ROW EXCL.	EXCL.	ACCESS EXCL.	APP. SHARE	APP. EXCL.
ACCESS SHARE								X		

Requested Lock Mode	Existing Lock Mode									
	ACCESS SHARE	ROW SHARE	ROW EXCL.	SHARE UPDATE EXCL.	SHARE	SHARE ROW EXCL.	EXCL.	ACCESS EXCL.	APP. SHARE	APP. EXCL.
ROW SHARE							X	X		
ROW EXCL.					X	X	X	X		
SHARE UPDATE EXCL.				X	X	X	X	X		
SHARE			X	X		X	X	X		
SHARE ROW EXCL.			X	X	X	X	X	X		
EXCL.		X	X	X	X	X	X	X		
ACCESS EXCL.	X	X	X	X	X	X	X	X		
APP. SHARE										X
APP. EXCL.									X	X

13.3.2. Row-Level Locks

In addition to table-level locks, there are row-level locks, which are listed as below with the contexts in which they are used automatically by Postgres Pro. See Table 13.3 for a complete table of row-level lock conflicts. Note that a transaction can hold conflicting locks on the same row, even in different subtransactions; but other than that, two transactions can never hold conflicting locks on the same row. Row-level locks do not affect data querying; they block only *writers and lockers* to the same row. Row-level locks are released at transaction end or during savepoint rollback, just like table-level locks.

Row-Level Lock Modes

`FOR UPDATE`

`FOR UPDATE` causes the rows retrieved by the `SELECT` statement to be locked as though for update. This prevents them from being locked, modified or deleted by other transactions until the current transaction ends. That is, other transactions that attempt `UPDATE`, `DELETE`, `SELECT FOR UPDATE`, `SELECT FOR NO KEY UPDATE`, `SELECT FOR SHARE` or `SELECT FOR KEY SHARE` of these rows will be blocked until the current transaction ends; conversely, `SELECT FOR UPDATE` will wait for a concurrent transaction that has run any of those commands on the same row, and will then lock and return the updated row (or no row, if the row was deleted). Within a `REPEATABLE READ` or `SERIALIZABLE` transaction, however, an error will be thrown if a row to be locked has changed since the transaction started. For further discussion see Section 13.4.

The `FOR UPDATE` lock mode is also acquired by any `DELETE` on a row, and also by an `UPDATE` that modifies the values of certain columns. Currently, the set of columns considered for the `UPDATE` case are those that have a unique index on them that can be used in a foreign key (so partial indexes and expressional indexes are not considered), but this may change in the future.

`FOR NO KEY UPDATE`

Behaves similarly to `FOR UPDATE`, except that the lock acquired is weaker: this lock will not block `SELECT FOR KEY SHARE` commands that attempt to acquire a lock on the same rows. This lock mode is also acquired by any `UPDATE` that does not acquire a `FOR UPDATE` lock.

`FOR SHARE`

Behaves similarly to `FOR NO KEY UPDATE`, except that it acquires a shared lock rather than exclusive lock on each retrieved row. A shared lock blocks other transactions from performing `UPDATE`, `DELETE`, `SELECT FOR UPDATE` or `SELECT FOR NO KEY UPDATE` on these rows, but it does not prevent them from performing `SELECT FOR SHARE` or `SELECT FOR KEY SHARE`.

`FOR KEY SHARE`

Behaves similarly to `FOR SHARE`, except that the lock is weaker: `SELECT FOR UPDATE` is blocked, but not `SELECT FOR NO KEY UPDATE`. A key-shared lock blocks other transactions from performing `DELETE` or any `UPDATE` that changes the key values, but not other `UPDATE`, and neither does it prevent `SELECT FOR NO KEY UPDATE`, `SELECT FOR SHARE`, or `SELECT FOR KEY SHARE`.

Postgres Pro doesn't remember any information about modified rows in memory, so there is no limit on the number of rows locked at one time. However, locking a row might cause a disk write, e.g., `SELECT FOR UPDATE` modifies selected rows to mark them locked, and so will result in disk writes.

Table 13.3. Conflicting Row-Level Locks

Requested Lock Mode	**Current Lock Mode**			
	FOR KEY SHARE	**FOR SHARE**	**FOR NO KEY UPDATE**	**FOR UPDATE**
FOR KEY SHARE				X
FOR SHARE			X	X
FOR NO KEY UPDATE		X	X	X
FOR UPDATE	X	X	X	X

13.3.3. Page-Level Locks

In addition to table and row locks, page-level share/exclusive locks are used to control read/write access to table pages in the shared buffer pool. These locks are released immediately after a row is fetched or updated. Application developers normally need not be concerned with page-level locks, but they are mentioned here for completeness.

13.3.4. Deadlocks

The use of explicit locking can increase the likelihood of *deadlocks*, wherein two (or more) transactions each hold locks that the other wants. For example, if transaction 1 acquires an exclusive lock on table A and then tries to acquire an exclusive lock on table B, while transaction 2 has already exclusive-locked table B and now wants an exclusive lock on table A, then neither one can proceed. Postgres Pro automatically detects deadlock situations and resolves them by aborting one of the transactions involved, allowing the other(s) to complete. (Exactly which transaction will be aborted is difficult to predict and should not be relied upon.)

Note that deadlocks can also occur as the result of row-level locks (and thus, they can occur even if explicit locking is not used). Consider the case in which two concurrent transactions modify a table. The first transaction executes:

```
UPDATE accounts SET balance = balance + 100.00 WHERE acctnum = 11111;
```

This acquires a row-level lock on the row with the specified account number. Then, the second transaction executes:

```
UPDATE accounts SET balance = balance + 100.00 WHERE acctnum = 22222;
UPDATE accounts SET balance = balance - 100.00 WHERE acctnum = 11111;
```

The first `UPDATE` statement successfully acquires a row-level lock on the specified row, so it succeeds in updating that row. However, the second `UPDATE` statement finds that the row it is attempting to update has already been locked, so it waits for the transaction that acquired the lock to complete. Transaction two is now waiting on transaction one to complete before it continues execution. Now, transaction one executes:

```
UPDATE accounts SET balance = balance - 100.00 WHERE acctnum = 22222;
```

Transaction one attempts to acquire a row-level lock on the specified row, but it cannot: transaction two already holds such a lock. So it waits for transaction two to complete. Thus, transaction one is blocked on transaction two, and transaction two is blocked on transaction one: a deadlock condition. Postgres Pro will detect this situation and abort one of the transactions.

The best defense against deadlocks is generally to avoid them by being certain that all applications using a database acquire locks on multiple objects in a consistent order. In the example above, if both transactions had updated the rows in the same order, no deadlock would have occurred. One should also ensure that the first lock acquired on an object in a transaction is the most restrictive mode that will be needed for that object. If it is not feasible to verify this in advance, then deadlocks can be handled on-the-fly by retrying transactions that abort due to deadlocks.

So long as no deadlock situation is detected, a transaction seeking either a table-level or row-level lock will wait indefinitely for conflicting locks to be released. This means it is a bad idea for applications to hold transactions open for long periods of time (e.g., while waiting for user input).

13.3.5. Advisory Locks

Postgres Pro provides a means for creating locks that have application-defined meanings. These are called *advisory locks*, because the system does not enforce their use — it is up to the application to use them correctly. Advisory locks can be useful for locking strategies that are an awkward fit for the MVCC model. For example, a common use of advisory locks is to emulate pessimistic locking strategies typical of so-called “flat file” data management systems. While a flag stored in a table could be used for the same purpose, advisory locks are faster, avoid table bloat, and are automatically cleaned up by the server at the end of the session.

There are two ways to acquire an advisory lock in Postgres Pro: at session level or at transaction level. Once acquired at session level, an advisory lock is held until explicitly released or the session ends. Unlike standard lock requests, session-level advisory lock requests do not honor transaction semantics: a lock acquired during a transaction that is later rolled back will still be held following the rollback, and likewise an unlock is effective even if the calling transaction fails later. A lock can be acquired multiple times by its owning process; for each completed lock request there must be a corresponding unlock request before the lock is actually released. Transaction-level lock requests, on the other hand, behave more like regular lock requests: they are automatically released at the end of the transaction, and there is no explicit unlock operation. This behavior is often more convenient than the session-level behavior for short-term usage of an advisory lock. Session-level and transaction-level lock requests for the same advisory lock identifier will block each other in the expected way. If a session already holds a given advisory lock, additional requests by it will always succeed, even if other sessions are awaiting the lock; this statement is true regardless of whether the existing lock hold and new request are at session level or transaction level.

Like all locks in Postgres Pro, a complete list of advisory locks currently held by any session can be found in the `pg_locks` system view.

Both advisory locks and regular locks are stored in a shared memory pool whose size is defined by the configuration variables max_locks_per_transaction and max_connections. Care must be taken not to exhaust this memory or the server will be unable to grant any locks at all. This imposes an upper limit on the number of advisory locks grantable by the server, typically in the tens to hundreds of thousands depending on how the server is configured.

In certain cases using advisory locking methods, especially in queries involving explicit ordering and `LIMIT` clauses, care must be taken to control the locks acquired because of the order in which SQL expressions are evaluated. For example:

```
SELECT pg_advisory_lock(id) FROM foo WHERE id = 12345; -- ok
SELECT pg_advisory_lock(id) FROM foo WHERE id > 12345 LIMIT 100; -- danger!
SELECT pg_advisory_lock(q.id) FROM
(
```

```
  SELECT id FROM foo WHERE id > 12345 LIMIT 100
) q; -- ok
```

In the above queries, the second form is dangerous because the `LIMIT` is not guaranteed to be applied before the locking function is executed. This might cause some locks to be acquired that the application was not expecting, and hence would fail to release (until it ends the session). From the point of view of the application, such locks would be dangling, although still viewable in `pg_locks`.

The functions provided to manipulate advisory locks are described in Section 9.27.10.

13.4. Data Consistency Checks at the Application Level

It is very difficult to enforce business rules regarding data integrity using Read Committed transactions because the view of the data is shifting with each statement, and even a single statement may not restrict itself to the statement's snapshot if a write conflict occurs.

While a Repeatable Read transaction has a stable view of the data throughout its execution, there is a subtle issue with using MVCC snapshots for data consistency checks, involving something known as *read/write conflicts*. If one transaction writes data and a concurrent transaction attempts to read the same data (whether before or after the write), it cannot see the work of the other transaction. The reader then appears to have executed first regardless of which started first or which committed first. If that is as far as it goes, there is no problem, but if the reader also writes data which is read by a concurrent transaction there is now a transaction which appears to have run before either of the previously mentioned transactions. If the transaction which appears to have executed last actually commits first, it is very easy for a cycle to appear in a graph of the order of execution of the transactions. When such a cycle appears, integrity checks will not work correctly without some help.

As mentioned in Section 13.2.3, Serializable transactions are just Repeatable Read transactions which add nonblocking monitoring for dangerous patterns of read/write conflicts. When a pattern is detected which could cause a cycle in the apparent order of execution, one of the transactions involved is rolled back to break the cycle.

13.4.1. Enforcing Consistency with Serializable Transactions

If the Serializable transaction isolation level is used for all writes and for all reads which need a consistent view of the data, no other effort is required to ensure consistency. Software from other environments which is written to use serializable transactions to ensure consistency should “just work” in this regard in Postgres Pro.

When using this technique, it will avoid creating an unnecessary burden for application programmers if the application software goes through a framework which automatically retries transactions which are rolled back with a serialization failure. It may be a good idea to set `default_transaction_isolation` to `serializable`. It would also be wise to take some action to ensure that no other transaction isolation level is used, either inadvertently or to subvert integrity checks, through checks of the transaction isolation level in triggers.

See Section 13.2.3 for performance suggestions.

> **Warning**
>
> This level of integrity protection using Serializable transactions does not yet extend to hot standby mode (Section 26.4). Because of that, those using hot standby may want to use Repeatable Read and explicit locking on the primary.

13.4.2. Enforcing Consistency with Explicit Blocking Locks

When non-serializable writes are possible, to ensure the current validity of a row and protect it against concurrent updates one must use `SELECT FOR UPDATE`, `SELECT FOR SHARE`, or an appropriate `LOCK TABLE` statement. (`SELECT FOR UPDATE` and `SELECT FOR SHARE` lock just the returned rows against concurrent

updates, while LOCK TABLE locks the whole table.) This should be taken into account when porting applications to Postgres Pro from other environments.

Also of note to those converting from other environments is the fact that SELECT FOR UPDATE does not ensure that a concurrent transaction will not update or delete a selected row. To do that in Postgres Pro you must actually update the row, even if no values need to be changed. SELECT FOR UPDATE *temporarily blocks* other transactions from acquiring the same lock or executing an UPDATE or DELETE which would affect the locked row, but once the transaction holding this lock commits or rolls back, a blocked transaction will proceed with the conflicting operation unless an actual UPDATE of the row was performed while the lock was held.

Global validity checks require extra thought under non-serializable MVCC. For example, a banking application might wish to check that the sum of all credits in one table equals the sum of debits in another table, when both tables are being actively updated. Comparing the results of two successive SELECT sum(...) commands will not work reliably in Read Committed mode, since the second query will likely include the results of transactions not counted by the first. Doing the two sums in a single repeatable read transaction will give an accurate picture of only the effects of transactions that committed before the repeatable read transaction started — but one might legitimately wonder whether the answer is still relevant by the time it is delivered. If the repeatable read transaction itself applied some changes before trying to make the consistency check, the usefulness of the check becomes even more debatable, since now it includes some but not all post-transaction-start changes. In such cases a careful person might wish to lock all tables needed for the check, in order to get an indisputable picture of current reality. A SHARE mode (or higher) lock guarantees that there are no uncommitted changes in the locked table, other than those of the current transaction.

Note also that if one is relying on explicit locking to prevent concurrent changes, one should either use Read Committed mode, or in Repeatable Read mode be careful to obtain locks before performing queries. A lock obtained by a repeatable read transaction guarantees that no other transactions modifying the table are still running, but if the snapshot seen by the transaction predates obtaining the lock, it might predate some now-committed changes in the table. A repeatable read transaction's snapshot is actually frozen at the start of its first query or data-modification command (SELECT, INSERT, UPDATE, or DELETE), so it is possible to obtain locks explicitly before the snapshot is frozen.

13.5. Caveats

Some DDL commands, currently only TRUNCATE and the table-rewriting forms of ALTER TABLE, are not MVCC-safe. This means that after the truncation or rewrite commits, the table will appear empty to concurrent transactions, if they are using a snapshot taken before the DDL command committed. This will only be an issue for a transaction that did not access the table in question before the DDL command started — any transaction that has done so would hold at least an ACCESS SHARE table lock, which would block the DDL command until that transaction completes. So these commands will not cause any apparent inconsistency in the table contents for successive queries on the target table, but they could cause visible inconsistency between the contents of the target table and other tables in the database.

Support for the Serializable transaction isolation level has not yet been added to Hot Standby replication targets (described in Section 26.4). The strictest isolation level currently supported in hot standby mode is Repeatable Read. While performing all permanent database writes within Serializable transactions on the primary will ensure that all standbys will eventually reach a consistent state, a Repeatable Read transaction run on the standby can sometimes see a transient state that is inconsistent with any serial execution of the transactions on the primary.

Internal access to the system catalogs is not done using the isolation level of the current transaction. This means that newly created database objects such as tables are visible to concurrent Repeatable Read and Serializable transactions, even though the rows they contain are not. In contrast, queries that explicitly examine the system catalogs don't see rows representing concurrently created database objects, in the higher isolation levels.

13.6. Locking and Indexes

Though Postgres Pro provides nonblocking read/write access to table data, nonblocking read/write access is not currently offered for every index access method implemented in Postgres Pro. The various index types are handled as follows:

B-tree, GiST and SP-GiST indexes

Short-term share/exclusive page-level locks are used for read/write access. Locks are released immediately after each index row is fetched or inserted. These index types provide the highest concurrency without deadlock conditions.

Hash indexes

Share/exclusive hash-bucket-level locks are used for read/write access. Locks are released after the whole bucket is processed. Bucket-level locks provide better concurrency than index-level ones, but deadlock is possible since the locks are held longer than one index operation.

GIN indexes

Short-term share/exclusive page-level locks are used for read/write access. Locks are released immediately after each index row is fetched or inserted. But note that insertion of a GIN-indexed value usually produces several index key insertions per row, so GIN might do substantial work for a single value's insertion.

Currently, B-tree indexes offer the best performance for concurrent applications; since they also have more features than hash indexes, they are the recommended index type for concurrent applications that need to index scalar data. When dealing with non-scalar data, B-trees are not useful, and GiST, SP-GiST or GIN indexes should be used instead.

Chapter 14. Performance Tips

Query performance can be affected by many things. Some of these can be controlled by the user, while others are fundamental to the underlying design of the system. This chapter provides some hints about understanding and tuning Postgres Pro performance.

14.1. Using EXPLAIN

Postgres Pro devises a *query plan* for each query it receives. Choosing the right plan to match the query structure and the properties of the data is absolutely critical for good performance, so the system includes a complex *planner* that tries to choose good plans. You can use the EXPLAIN command to see what query plan the planner creates for any query. Plan-reading is an art that requires some experience to master, but this section attempts to cover the basics.

Examples in this section are drawn from the regression test database after doing a VACUUM ANALYZE, using 9.3 development sources. You should be able to get similar results if you try the examples yourself, but your estimated costs and row counts might vary slightly because ANALYZE's statistics are random samples rather than exact, and because costs are inherently somewhat platform-dependent.

The examples use EXPLAIN's default “text” output format, which is compact and convenient for humans to read. If you want to feed EXPLAIN's output to a program for further analysis, you should use one of its machine-readable output formats (XML, JSON, or YAML) instead.

14.1.1. EXPLAIN Basics

The structure of a query plan is a tree of *plan nodes*. Nodes at the bottom level of the tree are scan nodes: they return raw rows from a table. There are different types of scan nodes for different table access methods: sequential scans, index scans, and bitmap index scans. There are also non-table row sources, such as VALUES clauses and set-returning functions in FROM, which have their own scan node types. If the query requires joining, aggregation, sorting, or other operations on the raw rows, then there will be additional nodes above the scan nodes to perform these operations. Again, there is usually more than one possible way to do these operations, so different node types can appear here too. The output of EXPLAIN has one line for each node in the plan tree, showing the basic node type plus the cost estimates that the planner made for the execution of that plan node. Additional lines might appear, indented from the node's summary line, to show additional properties of the node. The very first line (the summary line for the topmost node) has the estimated total execution cost for the plan; it is this number that the planner seeks to minimize.

Here is a trivial example, just to show what the output looks like:

```
EXPLAIN SELECT * FROM tenk1;

                         QUERY PLAN
-------------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..458.00 rows=10000 width=244)
```

Since this query has no WHERE clause, it must scan all the rows of the table, so the planner has chosen to use a simple sequential scan plan. The numbers that are quoted in parentheses are (left to right):

- Estimated start-up cost. This is the time expended before the output phase can begin, e.g., time to do the sorting in a sort node.
- Estimated total cost. This is stated on the assumption that the plan node is run to completion, i.e., all available rows are retrieved. In practice a node's parent node might stop short of reading all available rows (see the LIMIT example below).
- Estimated number of rows output by this plan node. Again, the node is assumed to be run to completion.
- Estimated average width of rows output by this plan node (in bytes).

The costs are measured in arbitrary units determined by the planner's cost parameters (see Section 19.7.2). Traditional practice is to measure the costs in units of disk page fetches; that is, seq_page_cost is conventionally set to 1.0 and the other cost parameters are set relative to that. The examples in this section are run with the default cost parameters.

It's important to understand that the cost of an upper-level node includes the cost of all its child nodes. It's also important to realize that the cost only reflects things that the planner cares about. In particular, the cost does not consider the time spent transmitting result rows to the client, which could be an important factor in the real elapsed time; but the planner ignores it because it cannot change it by altering the plan. (Every correct plan will output the same row set, we trust.)

The rows value is a little tricky because it is not the number of rows processed or scanned by the plan node, but rather the number emitted by the node. This is often less than the number scanned, as a result of filtering by any WHERE-clause conditions that are being applied at the node. Ideally the top-level rows estimate will approximate the number of rows actually returned, updated, or deleted by the query.

Returning to our example:

```
EXPLAIN SELECT * FROM tenk1;

                         QUERY PLAN
-------------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..458.00 rows=10000 width=244)
```

These numbers are derived very straightforwardly. If you do:

```
SELECT relpages, reltuples FROM pg_class WHERE relname = 'tenk1';
```

you will find that tenk1 has 358 disk pages and 10000 rows. The estimated cost is computed as (disk pages read * seq_page_cost) + (rows scanned * cpu_tuple_cost). By default, seq_page_cost is 1.0 and cpu_tuple_cost is 0.01, so the estimated cost is (358 * 1.0) + (10000 * 0.01) = 458.

Now let's modify the query to add a WHERE condition:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 7000;

                         QUERY PLAN
------------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..483.00 rows=7001 width=244)
   Filter: (unique1 < 7000)
```

Notice that the EXPLAIN output shows the WHERE clause being applied as a “filter” condition attached to the Seq Scan plan node. This means that the plan node checks the condition for each row it scans, and outputs only the ones that pass the condition. The estimate of output rows has been reduced because of the WHERE clause. However, the scan will still have to visit all 10000 rows, so the cost hasn't decreased; in fact it has gone up a bit (by 10000 * cpu_operator_cost, to be exact) to reflect the extra CPU time spent checking the WHERE condition.

The actual number of rows this query would select is 7000, but the rows estimate is only approximate. If you try to duplicate this experiment, you will probably get a slightly different estimate; moreover, it can change after each ANALYZE command, because the statistics produced by ANALYZE are taken from a randomized sample of the table.

Now, let's make the condition more restrictive:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 100;

                                 QUERY PLAN
-----------------------------------------------------------------------------
 Bitmap Heap Scan on tenk1  (cost=5.07..229.20 rows=101 width=244)
   Recheck Cond: (unique1 < 100)
   ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..5.04 rows=101 width=0)
```

```
         Index Cond: (unique1 < 100)
```

Here the planner has decided to use a two-step plan: the child plan node visits an index to find the locations of rows matching the index condition, and then the upper plan node actually fetches those rows from the table itself. Fetching rows separately is much more expensive than reading them sequentially, but because not all the pages of the table have to be visited, this is still cheaper than a sequential scan. (The reason for using two plan levels is that the upper plan node sorts the row locations identified by the index into physical order before reading them, to minimize the cost of separate fetches. The “bitmap” mentioned in the node names is the mechanism that does the sorting.)

Now let's add another condition to the `WHERE` clause:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 100 AND stringu1 = 'xxx';

                                     QUERY PLAN
-------------------------------------------------------------------------------
 Bitmap Heap Scan on tenk1  (cost=5.04..229.43 rows=1 width=244)
   Recheck Cond: (unique1 < 100)
   Filter: (stringu1 = 'xxx'::name)
   ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..5.04 rows=101 width=0)
         Index Cond: (unique1 < 100)
```

The added condition `stringu1 = 'xxx'` reduces the output row count estimate, but not the cost because we still have to visit the same set of rows. Notice that the `stringu1` clause cannot be applied as an index condition, since this index is only on the `unique1` column. Instead it is applied as a filter on the rows retrieved by the index. Thus the cost has actually gone up slightly to reflect this extra checking.

In some cases the planner will prefer a “simple” index scan plan:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 = 42;

                                     QUERY PLAN
-------------------------------------------------------------------------------
 Index Scan using tenk1_unique1 on tenk1  (cost=0.29..8.30 rows=1 width=244)
   Index Cond: (unique1 = 42)
```

In this type of plan the table rows are fetched in index order, which makes them even more expensive to read, but there are so few that the extra cost of sorting the row locations is not worth it. You'll most often see this plan type for queries that fetch just a single row. It's also often used for queries that have an `ORDER BY` condition that matches the index order, because then no extra sorting step is needed to satisfy the `ORDER BY`. In this example, adding `ORDER BY unique1` would use the same plan because the index already implicitly provides the requested ordering.

The planner may implement an `ORDER BY` clause in several ways. The above example shows that such an ordering clause may be implemented implicitly. The planner may also add an explicit `sort` step:

```
EXPLAIN SELECT * FROM tenk1 ORDER BY unique1;
                            QUERY PLAN
-------------------------------------------------------------------
 Sort  (cost=1109.39..1134.39 rows=10000 width=244)
   Sort Key: unique1
   ->  Seq Scan on tenk1  (cost=0.00..445.00 rows=10000 width=244)
```

If a part of the plan guarantees an ordering on a prefix of the required sort keys, then the planner may instead decide to use an `incremental sort` step:

```
EXPLAIN SELECT * FROM tenk1 ORDER BY four, ten LIMIT 100;
                                          QUERY PLAN
-------------------------------------------------------------------
-----------------------------------
 Limit  (cost=521.06..538.05 rows=100 width=244)
   ->  Incremental Sort  (cost=521.06..2220.95 rows=10000 width=244)
         Sort Key: four, ten
```

```
         Presorted Key: four
         ->  Index Scan using index_tenk1_on_four on tenk1  (cost=0.29..1510.08
 rows=10000 width=244)
```

Compared to regular sorts, sorting incrementally allows returning tuples before the entire result set has been sorted, which particularly enables optimizations with `LIMIT` queries. It may also reduce memory usage and the likelihood of spilling sorts to disk, but it comes at the cost of the increased overhead of splitting the result set into multiple sorting batches.

If there are separate indexes on several of the columns referenced in `WHERE`, the planner might choose to use an AND or OR combination of the indexes:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 100 AND unique2 > 9000;

                                     QUERY PLAN
-------------------------------------------------------------------------------
 Bitmap Heap Scan on tenk1  (cost=25.08..60.21 rows=10 width=244)
   Recheck Cond: ((unique1 < 100) AND (unique2 > 9000))
   ->  BitmapAnd  (cost=25.08..25.08 rows=10 width=0)
         ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..5.04 rows=101 width=0)
               Index Cond: (unique1 < 100)
         ->  Bitmap Index Scan on tenk1_unique2  (cost=0.00..19.78 rows=999 width=0)
               Index Cond: (unique2 > 9000)
```

But this requires visiting both indexes, so it's not necessarily a win compared to using just one index and treating the other condition as a filter. If you vary the ranges involved you'll see the plan change accordingly.

Here is an example showing the effects of `LIMIT`:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 100 AND unique2 > 9000 LIMIT 2;

                                     QUERY PLAN
-------------------------------------------------------------------------------
 Limit  (cost=0.29..14.48 rows=2 width=244)
   ->  Index Scan using tenk1_unique2 on tenk1  (cost=0.29..71.27 rows=10 width=244)
         Index Cond: (unique2 > 9000)
         Filter: (unique1 < 100)
```

This is the same query as above, but we added a `LIMIT` so that not all the rows need be retrieved, and the planner changed its mind about what to do. Notice that the total cost and row count of the Index Scan node are shown as if it were run to completion. However, the Limit node is expected to stop after retrieving only a fifth of those rows, so its total cost is only a fifth as much, and that's the actual estimated cost of the query. This plan is preferred over adding a Limit node to the previous plan because the Limit could not avoid paying the startup cost of the bitmap scan, so the total cost would be something over 25 units with that approach.

Let's try joining two tables, using the columns we have been discussing:

```
EXPLAIN SELECT *
FROM tenk1 t1, tenk2 t2
WHERE t1.unique1 < 10 AND t1.unique2 = t2.unique2;

                                      QUERY PLAN
-------------------------------------------------------------------------------
 Nested Loop  (cost=4.65..118.62 rows=10 width=488)
   ->  Bitmap Heap Scan on tenk1 t1  (cost=4.36..39.47 rows=10 width=244)
         Recheck Cond: (unique1 < 10)
         ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..4.36 rows=10 width=0)
               Index Cond: (unique1 < 10)
   ->  Index Scan using tenk2_unique2 on tenk2 t2  (cost=0.29..7.91 rows=1 width=244)
```

```
         Index Cond: (unique2 = t1.unique2)
```

In this plan, we have a nested-loop join node with two table scans as inputs, or children. The indentation of the node summary lines reflects the plan tree structure. The join's first, or “outer”, child is a bitmap scan similar to those we saw before. Its cost and row count are the same as we'd get from `SELECT ... WHERE unique1 < 10` because we are applying the `WHERE` clause `unique1 < 10` at that node. The `t1.unique2 = t2.unique2` clause is not relevant yet, so it doesn't affect the row count of the outer scan. The nested-loop join node will run its second, or “inner” child once for each row obtained from the outer child. Column values from the current outer row can be plugged into the inner scan; here, the `t1.unique2` value from the outer row is available, so we get a plan and costs similar to what we saw above for a simple `SELECT ... WHERE t2.unique2 = constant` case. (The estimated cost is actually a bit lower than what was seen above, as a result of caching that's expected to occur during the repeated index scans on `t2`.) The costs of the loop node are then set on the basis of the cost of the outer scan, plus one repetition of the inner scan for each outer row (10 * 7.91, here), plus a little CPU time for join processing.

In this example the join's output row count is the same as the product of the two scans' row counts, but that's not true in all cases because there can be additional `WHERE` clauses that mention both tables and so can only be applied at the join point, not to either input scan. Here's an example:

```
EXPLAIN SELECT *
FROM tenk1 t1, tenk2 t2
WHERE t1.unique1 < 10 AND t2.unique2 < 10 AND t1.hundred < t2.hundred;

                                      QUERY PLAN
------------------------------------------------------------------------
--------------------------
 Nested Loop  (cost=4.65..49.46 rows=33 width=488)
   Join Filter: (t1.hundred < t2.hundred)
   ->  Bitmap Heap Scan on tenk1 t1  (cost=4.36..39.47 rows=10 width=244)
         Recheck Cond: (unique1 < 10)
         ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..4.36 rows=10 width=0)
               Index Cond: (unique1 < 10)
   ->  Materialize  (cost=0.29..8.51 rows=10 width=244)
         ->  Index Scan using tenk2_unique2 on tenk2 t2  (cost=0.29..8.46 rows=10
 width=244)
               Index Cond: (unique2 < 10)
```

The condition `t1.hundred < t2.hundred` can't be tested in the `tenk2_unique2` index, so it's applied at the join node. This reduces the estimated output row count of the join node, but does not change either input scan.

Notice that here the planner has chosen to “materialize” the inner relation of the join, by putting a Materialize plan node atop it. This means that the `t2` index scan will be done just once, even though the nested-loop join node needs to read that data ten times, once for each row from the outer relation. The Materialize node saves the data in memory as it's read, and then returns the data from memory on each subsequent pass.

When dealing with outer joins, you might see join plan nodes with both “Join Filter” and plain “Filter” conditions attached. Join Filter conditions come from the outer join's `ON` clause, so a row that fails the Join Filter condition could still get emitted as a null-extended row. But a plain Filter condition is applied after the outer-join rules and so acts to remove rows unconditionally. In an inner join there is no semantic difference between these types of filters.

If we change the query's selectivity a bit, we might get a very different join plan:

```
EXPLAIN SELECT *
FROM tenk1 t1, tenk2 t2
WHERE t1.unique1 < 100 AND t1.unique2 = t2.unique2;

                                      QUERY PLAN
```

```
------------------------------------------------------------------------
-----------------------
 Hash Join  (cost=230.47..713.98 rows=101 width=488)
   Hash Cond: (t2.unique2 = t1.unique2)
   ->  Seq Scan on tenk2 t2  (cost=0.00..445.00 rows=10000 width=244)
   ->  Hash  (cost=229.20..229.20 rows=101 width=244)
         ->  Bitmap Heap Scan on tenk1 t1  (cost=5.07..229.20 rows=101 width=244)
               Recheck Cond: (unique1 < 100)
               ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..5.04 rows=101
 width=0)
                     Index Cond: (unique1 < 100)
```

Here, the planner has chosen to use a hash join, in which rows of one table are entered into an in-memory hash table, after which the other table is scanned and the hash table is probed for matches to each row. Again note how the indentation reflects the plan structure: the bitmap scan on `tenk1` is the input to the Hash node, which constructs the hash table. That's then returned to the Hash Join node, which reads rows from its outer child plan and searches the hash table for each one.

Another possible type of join is a merge join, illustrated here:

```
EXPLAIN SELECT *
FROM tenk1 t1, onek t2
WHERE t1.unique1 < 100 AND t1.unique2 = t2.unique2;

                                        QUERY PLAN
------------------------------------------------------------------------
-----------------------
 Merge Join  (cost=198.11..268.19 rows=10 width=488)
   Merge Cond: (t1.unique2 = t2.unique2)
   ->  Index Scan using tenk1_unique2 on tenk1 t1  (cost=0.29..656.28 rows=101
 width=244)
         Filter: (unique1 < 100)
   ->  Sort  (cost=197.83..200.33 rows=1000 width=244)
         Sort Key: t2.unique2
         ->  Seq Scan on onek t2  (cost=0.00..148.00 rows=1000 width=244)
```

Merge join requires its input data to be sorted on the join keys. In this plan the `tenk1` data is sorted by using an index scan to visit the rows in the correct order, but a sequential scan and sort is preferred for `onek`, because there are many more rows to be visited in that table. (Sequential-scan-and-sort frequently beats an index scan for sorting many rows, because of the nonsequential disk access required by the index scan.)

One way to look at variant plans is to force the planner to disregard whatever strategy it thought was the cheapest, using the enable/disable flags described in Section 19.7.1. (This is a crude tool, but useful. See also Section 14.3.) For example, if we're unconvinced that sequential-scan-and-sort is the best way to deal with table `onek` in the previous example, we could try

```
SET enable_sort = off;

EXPLAIN SELECT *
FROM tenk1 t1, onek t2
WHERE t1.unique1 < 100 AND t1.unique2 = t2.unique2;

                                        QUERY PLAN
------------------------------------------------------------------------
-----------------------
 Merge Join  (cost=0.56..292.65 rows=10 width=488)
   Merge Cond: (t1.unique2 = t2.unique2)
   ->  Index Scan using tenk1_unique2 on tenk1 t1  (cost=0.29..656.28 rows=101
 width=244)
```

```
        Filter: (unique1 < 100)
   ->  Index Scan using onek_unique2 on onek t2  (cost=0.28..224.79 rows=1000
 width=244)
```

which shows that the planner thinks that sorting `onek` by index-scanning is about 12% more expensive than sequential-scan-and-sort. Of course, the next question is whether it's right about that. We can investigate that using `EXPLAIN ANALYZE`, as discussed below.

14.1.2. EXPLAIN ANALYZE

It is possible to check the accuracy of the planner's estimates by using `EXPLAIN`'s `ANALYZE` option. With this option, `EXPLAIN` actually executes the query, and then displays the true row counts and true run time accumulated within each plan node, along with the same estimates that a plain `EXPLAIN` shows. For example, we might get a result like this:

```
EXPLAIN ANALYZE SELECT *
FROM tenk1 t1, tenk2 t2
WHERE t1.unique1 < 10 AND t1.unique2 = t2.unique2;

                                                            QUERY PLAN
-------------------------------------------------------------------
-------------------------------------------------------------
 Nested Loop  (cost=4.65..118.62 rows=10 width=488) (actual time=0.128..0.377 rows=10
 loops=1)
   ->  Bitmap Heap Scan on tenk1 t1  (cost=4.36..39.47 rows=10 width=244) (actual
 time=0.057..0.121 rows=10 loops=1)
         Recheck Cond: (unique1 < 10)
         ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..4.36 rows=10 width=0)
 (actual time=0.024..0.024 rows=10 loops=1)
               Index Cond: (unique1 < 10)
   ->  Index Scan using tenk2_unique2 on tenk2 t2  (cost=0.29..7.91 rows=1 width=244)
 (actual time=0.021..0.022 rows=1 loops=10)
         Index Cond: (unique2 = t1.unique2)
 Planning time: 0.181 ms
 Execution time: 0.501 ms
```

Note that the “actual time” values are in milliseconds of real time, whereas the `cost` estimates are expressed in arbitrary units; so they are unlikely to match up. The thing that's usually most important to look for is whether the estimated row counts are reasonably close to reality. In this example the estimates were all dead-on, but that's quite unusual in practice.

In some query plans, it is possible for a subplan node to be executed more than once. For example, the inner index scan will be executed once per outer row in the above nested-loop plan. In such cases, the `loops` value reports the total number of executions of the node, and the actual time and rows values shown are averages per-execution. This is done to make the numbers comparable with the way that the cost estimates are shown. Multiply by the `loops` value to get the total time actually spent in the node. In the above example, we spent a total of 0.220 milliseconds executing the index scans on `tenk2`.

In some cases `EXPLAIN ANALYZE` shows additional execution statistics beyond the plan node execution times and row counts. For example, Sort and Hash nodes provide extra information:

```
EXPLAIN ANALYZE SELECT *
FROM tenk1 t1, tenk2 t2
WHERE t1.unique1 < 100 AND t1.unique2 = t2.unique2 ORDER BY t1.fivethous;

                                                                QUERY PLAN
-------------------------------------------------------------------
-------------------------------------------------------------------------
 Sort  (cost=717.34..717.59 rows=101 width=488) (actual time=7.761..7.774 rows=100
 loops=1)
   Sort Key: t1.fivethous
```

```
   Sort Method: quicksort  Memory: 77kB
   ->  Hash Join  (cost=230.47..713.98 rows=101 width=488) (actual time=0.711..7.427
 rows=100 loops=1)
         Hash Cond: (t2.unique2 = t1.unique2)
         ->  Seq Scan on tenk2 t2  (cost=0.00..445.00 rows=10000 width=244) (actual
 time=0.007..2.583 rows=10000 loops=1)
         ->  Hash  (cost=229.20..229.20 rows=101 width=244) (actual time=0.659..0.659
 rows=100 loops=1)
               Buckets: 1024  Batches: 1  Memory Usage: 28kB
               ->  Bitmap Heap Scan on tenk1 t1  (cost=5.07..229.20 rows=101 width=244)
 (actual time=0.080..0.526 rows=100 loops=1)
                     Recheck Cond: (unique1 < 100)
                     ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..5.04 rows=101
 width=0) (actual time=0.049..0.049 rows=100 loops=1)
                           Index Cond: (unique1 < 100)
 Planning time: 0.194 ms
 Execution time: 8.008 ms
```

The Sort node shows the sort method used (in particular, whether the sort was in-memory or on-disk) and the amount of memory or disk space needed. The Hash node shows the number of hash buckets and batches as well as the peak amount of memory used for the hash table. (If the number of batches exceeds one, there will also be disk space usage involved, but that is not shown.)

Another type of extra information is the number of rows removed by a filter condition:

```
EXPLAIN ANALYZE SELECT * FROM tenk1 WHERE ten < 7;

                                                     QUERY PLAN
--------------------------------------------------------------------
-------------------------------------
 Seq Scan on tenk1  (cost=0.00..483.00 rows=7000 width=244) (actual time=0.016..5.107
 rows=7000 loops=1)
   Filter: (ten < 7)
   Rows Removed by Filter: 3000
 Planning time: 0.083 ms
 Execution time: 5.905 ms
```

These counts can be particularly valuable for filter conditions applied at join nodes. The “Rows Removed” line only appears when at least one scanned row, or potential join pair in the case of a join node, is rejected by the filter condition.

A case similar to filter conditions occurs with “lossy” index scans. For example, consider this search for polygons containing a specific point:

```
EXPLAIN ANALYZE SELECT * FROM polygon_tbl WHERE f1 @> polygon '(0.5,2.0)';

                                                   QUERY PLAN
--------------------------------------------------------------------
----------------------------------
 Seq Scan on polygon_tbl  (cost=0.00..1.05 rows=1 width=32) (actual time=0.044..0.044
 rows=0 loops=1)
   Filter: (f1 @> '((0.5,2))'::polygon)
   Rows Removed by Filter: 4
 Planning time: 0.040 ms
 Execution time: 0.083 ms
```

The planner thinks (quite correctly) that this sample table is too small to bother with an index scan, so we have a plain sequential scan in which all the rows got rejected by the filter condition. But if we force an index scan to be used, we see:

```
SET enable_seqscan TO off;
```

```
EXPLAIN ANALYZE SELECT * FROM polygon_tbl WHERE f1 @> polygon '(0.5,2.0)';

                                                        QUERY PLAN
-------------------------------------------------------------------
-------------------------------------------------------
 Index Scan using gpolygonind on polygon_tbl  (cost=0.13..8.15 rows=1 width=32) (actual
 time=0.062..0.062 rows=0 loops=1)
   Index Cond: (f1 @> '((0.5,2))'::polygon)
   Rows Removed by Index Recheck: 1
 Planning time: 0.034 ms
 Execution time: 0.144 ms
```

Here we can see that the index returned one candidate row, which was then rejected by a recheck of the index condition. This happens because a GiST index is “lossy” for polygon containment tests: it actually returns the rows with polygons that overlap the target, and then we have to do the exact containment test on those rows.

`EXPLAIN` has a `BUFFERS` option that can be used with `ANALYZE` to get even more run time statistics:

```
EXPLAIN (ANALYZE, BUFFERS) SELECT * FROM tenk1 WHERE unique1 < 100 AND unique2 > 9000;

                                                          QUERY PLAN
-------------------------------------------------------------------
-----------------------------------------------------------
 Bitmap Heap Scan on tenk1  (cost=25.08..60.21 rows=10 width=244) (actual
 time=0.323..0.342 rows=10 loops=1)
   Recheck Cond: ((unique1 < 100) AND (unique2 > 9000))
   Buffers: shared hit=15
   ->  BitmapAnd  (cost=25.08..25.08 rows=10 width=0) (actual time=0.309..0.309 rows=0
 loops=1)
         Buffers: shared hit=7
         ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..5.04 rows=101 width=0)
 (actual time=0.043..0.043 rows=100 loops=1)
               Index Cond: (unique1 < 100)
               Buffers: shared hit=2
         ->  Bitmap Index Scan on tenk1_unique2  (cost=0.00..19.78 rows=999 width=0)
 (actual time=0.227..0.227 rows=999 loops=1)
               Index Cond: (unique2 > 9000)
               Buffers: shared hit=5
 Planning time: 0.088 ms
 Execution time: 0.423 ms
```

The numbers provided by `BUFFERS` help to identify which parts of the query are the most I/O-intensive.

Keep in mind that because `EXPLAIN ANALYZE` actually runs the query, any side-effects will happen as usual, even though whatever results the query might output are discarded in favor of printing the `EXPLAIN` data. If you want to analyze a data-modifying query without changing your tables, you can roll the command back afterwards, for example:

```
BEGIN;

EXPLAIN ANALYZE UPDATE tenk1 SET hundred = hundred + 1 WHERE unique1 < 100;

                                                          QUERY PLAN
-------------------------------------------------------------------
-----------------------------------------------------------
 Update on tenk1  (cost=5.08..230.08 rows=0 width=0) (actual time=3.791..3.792 rows=0
 loops=1)
   ->  Bitmap Heap Scan on tenk1  (cost=5.08..230.08 rows=102 width=10) (actual
 time=0.069..0.513 rows=100 loops=1)
```

```
         Recheck Cond: (unique1 < 100)
         Heap Blocks: exact=90
         ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..5.05 rows=102 width=0)
 (actual time=0.036..0.037 rows=300 loops=1)
               Index Cond: (unique1 < 100)
 Planning Time: 0.113 ms
 Execution Time: 3.850 ms

ROLLBACK;
```

As seen in this example, when the query is an `INSERT`, `UPDATE`, or `DELETE` command, the actual work of applying the table changes is done by a top-level Insert, Update, or Delete plan node. The plan nodes underneath this node perform the work of locating the old rows and/or computing the new data. So above, we see the same sort of bitmap table scan we've seen already, and its output is fed to an Update node that stores the updated rows. It's worth noting that although the data-modifying node can take a considerable amount of run time (here, it's consuming the lion's share of the time), the planner does not currently add anything to the cost estimates to account for that work. That's because the work to be done is the same for every correct query plan, so it doesn't affect planning decisions.

When an `UPDATE` or `DELETE` command affects an inheritance hierarchy, the output might look like this:

```
EXPLAIN UPDATE parent SET f2 = f2 + 1 WHERE f1 = 101;
                                                 QUERY PLAN
-------------------------------------------------------------------------
-----------------------------------
 Update on parent  (cost=0.00..24.59 rows=0 width=0)
   Update on parent parent_1
   Update on child1 parent_2
   Update on child2 parent_3
   Update on child3 parent_4
   ->  Result  (cost=0.00..24.59 rows=4 width=14)
         ->  Append  (cost=0.00..24.54 rows=4 width=14)
               ->  Seq Scan on parent parent_1  (cost=0.00..0.00 rows=1 width=14)
                     Filter: (f1 = 101)
               ->  Index Scan using child1_pkey on child1 parent_2  (cost=0.15..8.17
 rows=1 width=14)
                     Index Cond: (f1 = 101)
               ->  Index Scan using child2_pkey on child2 parent_3  (cost=0.15..8.17
 rows=1 width=14)
                     Index Cond: (f1 = 101)
               ->  Index Scan using child3_pkey on child3 parent_4  (cost=0.15..8.17
 rows=1 width=14)
                     Index Cond: (f1 = 101)
```

In this example the Update node needs to consider three child tables as well as the originally-mentioned parent table. So there are four input scanning subplans, one per table. For clarity, the Update node is annotated to show the specific target tables that will be updated, in the same order as the corresponding subplans.

The `Planning time` shown by `EXPLAIN ANALYZE` is the time it took to generate the query plan from the parsed query and optimize it. It does not include parsing or rewriting.

The `Execution time` shown by `EXPLAIN ANALYZE` includes executor start-up and shut-down time, as well as the time to run any triggers that are fired, but it does not include parsing, rewriting, or planning time. Time spent executing `BEFORE` triggers, if any, is included in the time for the related Insert, Update, or Delete node; but time spent executing `AFTER` triggers is not counted there because `AFTER` triggers are fired after completion of the whole plan. The total time spent in each trigger (either `BEFORE` or `AFTER`) is also shown separately. Note that deferred constraint triggers will not be executed until end of transaction and are thus not considered at all by `EXPLAIN ANALYZE`.

14.1.3. Caveats

There are two significant ways in which run times measured by `EXPLAIN ANALYZE` can deviate from normal execution of the same query. First, since no output rows are delivered to the client, network transmission costs and I/O conversion costs are not included. Second, the measurement overhead added by `EXPLAIN ANALYZE` can be significant, especially on machines with slow `gettimeofday()` operating-system calls. You can use the pg_test_timing tool to measure the overhead of timing on your system.

`EXPLAIN` results should not be extrapolated to situations much different from the one you are actually testing; for example, results on a toy-sized table cannot be assumed to apply to large tables. The planner's cost estimates are not linear and so it might choose a different plan for a larger or smaller table. An extreme example is that on a table that only occupies one disk page, you'll nearly always get a sequential scan plan whether indexes are available or not. The planner realizes that it's going to take one disk page read to process the table in any case, so there's no value in expending additional page reads to look at an index. (We saw this happening in the `polygon_tbl` example above.)

There are cases in which the actual and estimated values won't match up well, but nothing is really wrong. One such case occurs when plan node execution is stopped short by a `LIMIT` or similar effect. For example, in the `LIMIT` query we used before,

```
EXPLAIN ANALYZE SELECT * FROM tenk1 WHERE unique1 < 100 AND unique2 > 9000 LIMIT 2;

                                                          QUERY PLAN
-------------------------------------------------------------------
-------------------------------------------------------------
 Limit  (cost=0.29..14.71 rows=2 width=244) (actual time=0.177..0.249 rows=2 loops=1)
   ->  Index Scan using tenk1_unique2 on tenk1  (cost=0.29..72.42 rows=10 width=244)
 (actual time=0.174..0.244 rows=2 loops=1)
         Index Cond: (unique2 > 9000)
         Filter: (unique1 < 100)
         Rows Removed by Filter: 287
 Planning time: 0.096 ms
 Execution time: 0.336 ms
```

the estimated cost and row count for the Index Scan node are shown as though it were run to completion. But in reality the Limit node stopped requesting rows after it got two, so the actual row count is only 2 and the run time is less than the cost estimate would suggest. This is not an estimation error, only a discrepancy in the way the estimates and true values are displayed.

Merge joins also have measurement artifacts that can confuse the unwary. A merge join will stop reading one input if it's exhausted the other input and the next key value in the one input is greater than the last key value of the other input; in such a case there can be no more matches and so no need to scan the rest of the first input. This results in not reading all of one child, with results like those mentioned for `LIMIT`. Also, if the outer (first) child contains rows with duplicate key values, the inner (second) child is backed up and rescanned for the portion of its rows matching that key value. `EXPLAIN ANALYZE` counts these repeated emissions of the same inner rows as if they were real additional rows. When there are many outer duplicates, the reported actual row count for the inner child plan node can be significantly larger than the number of rows that are actually in the inner relation.

BitmapAnd and BitmapOr nodes always report their actual row counts as zero, due to implementation limitations.

Normally, `EXPLAIN` will display every plan node created by the planner. However, there are cases where the executor can determine that certain nodes need not be executed because they cannot produce any rows, based on parameter values that were not available at planning time. (Currently this can only happen for child nodes of an Append or MergeAppend node that is scanning a partitioned table.) When this happens, those plan nodes are omitted from the `EXPLAIN` output and a `Subplans Removed: N` annotation appears instead.

14.2. Statistics Used by the Planner

14.2.1. Single-Column Statistics

As we saw in the previous section, the query planner needs to estimate the number of rows retrieved by a query in order to make good choices of query plans. This section provides a quick look at the statistics that the system uses for these estimates.

One component of the statistics is the total number of entries in each table and index, as well as the number of disk blocks occupied by each table and index. This information is kept in the table pg_class, in the columns reltuples and relpages. We can look at it with queries similar to this one:

```
SELECT relname, relkind, reltuples, relpages
FROM pg_class
WHERE relname LIKE 'tenk1%';

       relname        | relkind | reltuples | relpages
----------------------+---------+-----------+----------
 tenk1                | r       |     10000 |      358
 tenk1_hundred        | i       |     10000 |       30
 tenk1_thous_tenthous | i       |     10000 |       30
 tenk1_unique1        | i       |     10000 |       30
 tenk1_unique2        | i       |     10000 |       30
(5 rows)
```

Here we can see that tenk1 contains 10000 rows, as do its indexes, but the indexes are (unsurprisingly) much smaller than the table.

For efficiency reasons, reltuples and relpages are not updated on-the-fly, and so they usually contain somewhat out-of-date values. They are updated by VACUUM, ANALYZE, and a few DDL commands such as CREATE INDEX. A VACUUM or ANALYZE operation that does not scan the entire table (which is commonly the case) will incrementally update the reltuples count on the basis of the part of the table it did scan, resulting in an approximate value. In any case, the planner will scale the values it finds in pg_class to match the current physical table size, thus obtaining a closer approximation.

Most queries retrieve only a fraction of the rows in a table, due to WHERE clauses that restrict the rows to be examined. The planner thus needs to make an estimate of the *selectivity* of WHERE clauses, that is, the fraction of rows that match each condition in the WHERE clause. The information used for this task is stored in the pg_statistic system catalog. Entries in pg_statistic are updated by the ANALYZE and VACUUM ANALYZE commands, and are always approximate even when freshly updated.

Rather than look at pg_statistic directly, it's better to look at its view pg_stats when examining the statistics manually. pg_stats is designed to be more easily readable. Furthermore, pg_stats is readable by all, whereas pg_statistic is only readable by a superuser. (This prevents unprivileged users from learning something about the contents of other people's tables from the statistics. The pg_stats view is restricted to show only rows about tables that the current user can read.) For example, we might do:

```
SELECT attname, inherited, n_distinct,
       array_to_string(most_common_vals, E'\n') as most_common_vals
FROM pg_stats
WHERE tablename = 'road';

 attname | inherited | n_distinct |          most_common_vals
---------+-----------+------------+------------------------------------
 name    | f         |  -0.363388 | I- 580                          Ramp+
         |           |            | I- 880                          Ramp+
         |           |            | Sp Railroad                         +
         |           |            | I- 580                              +
         |           |            | I- 680                          Ramp
 name    | t         |  -0.284859 | I- 880                          Ramp+
         |           |            | I- 580                          Ramp+
```

```
          |           |             | I- 680                        Ramp+
          |           |             | I- 580                            +
          |           |             | State Hwy 13                  Ramp
(2 rows)
```

Note that two rows are displayed for the same column, one corresponding to the complete inheritance hierarchy starting at the `road` table (`inherited=t`), and another one including only the `road` table itself (`inherited=f`).

The amount of information stored in `pg_statistic` by `ANALYZE`, in particular the maximum number of entries in the `most_common_vals` and `histogram_bounds` arrays for each column, can be set on a column-by-column basis using the `ALTER TABLE SET STATISTICS` command, or globally by setting the default_statistics_target configuration variable. The default limit is presently 100 entries. Raising the limit might allow more accurate planner estimates to be made, particularly for columns with irregular data distributions, at the price of consuming more space in `pg_statistic` and slightly more time to compute the estimates. Conversely, a lower limit might be sufficient for columns with simple data distributions.

Further details about the planner's use of statistics can be found in Chapter 71.

14.2.2. Extended Statistics

It is common to see slow queries running bad execution plans because multiple columns used in the query clauses are correlated. The planner normally assumes that multiple conditions are independent of each other, an assumption that does not hold when column values are correlated. Regular statistics, because of their per-individual-column nature, cannot capture any knowledge about cross-column correlation. However, Postgres Pro has the ability to compute *multivariate statistics*, which can capture such information.

Because the number of possible column combinations is very large, it's impractical to compute multivariate statistics automatically. Instead, *extended statistics objects*, more often called just *statistics objects*, can be created to instruct the server to obtain statistics across interesting sets of columns.

Statistics objects are created using the `CREATE STATISTICS` command. Creation of such an object merely creates a catalog entry expressing interest in the statistics. Actual data collection is performed by `ANALYZE` (either a manual command, or background auto-analyze). The collected values can be examined in the `pg_statistic_ext_data` catalog.

`ANALYZE` computes extended statistics based on the same sample of table rows that it takes for computing regular single-column statistics. Since the sample size is increased by increasing the statistics target for the table or any of its columns (as described in the previous section), a larger statistics target will normally result in more accurate extended statistics, as well as more time spent calculating them.

The following subsections describe the kinds of extended statistics that are currently supported.

14.2.2.1. Functional Dependencies

The simplest kind of extended statistics tracks *functional dependencies*, a concept used in definitions of database normal forms. We say that column `b` is functionally dependent on column `a` if knowledge of the value of `a` is sufficient to determine the value of `b`, that is there are no two rows having the same value of `a` but different values of `b`. In a fully normalized database, functional dependencies should exist only on primary keys and superkeys. However, in practice many data sets are not fully normalized for various reasons; intentional denormalization for performance reasons is a common example. Even in a fully normalized database, there may be partial correlation between some columns, which can be expressed as partial functional dependency.

The existence of functional dependencies directly affects the accuracy of estimates in certain queries. If a query contains conditions on both the independent and the dependent column(s), the conditions on the dependent columns do not further reduce the result size; but without knowledge of the functional dependency, the query planner will assume that the conditions are independent, resulting in underestimating the result size.

To inform the planner about functional dependencies, ANALYZE can collect measurements of cross-column dependency. Assessing the degree of dependency between all sets of columns would be prohibitively expensive, so data collection is limited to those groups of columns appearing together in a statistics object defined with the dependencies option. It is advisable to create dependencies statistics only for column groups that are strongly correlated, to avoid unnecessary overhead in both ANALYZE and later query planning.

Here is an example of collecting functional-dependency statistics:

```
CREATE STATISTICS stts (dependencies) ON city, zip FROM zipcodes;

ANALYZE zipcodes;

SELECT stxname, stxkeys, stxddependencies
  FROM pg_statistic_ext join pg_statistic_ext_data on (oid = stxoid)
  WHERE stxname = 'stts';
 stxname | stxkeys |             stxddependencies
---------+---------+------------------------------------------
 stts    | 1 5     | {"1 => 5": 1.000000, "5 => 1": 0.423130}
(1 row)
```

Here it can be seen that column 1 (zip code) fully determines column 5 (city) so the coefficient is 1.0, while city only determines zip code about 42% of the time, meaning that there are many cities (58%) that are represented by more than a single ZIP code.

When computing the selectivity for a query involving functionally dependent columns, the planner adjusts the per-condition selectivity estimates using the dependency coefficients so as not to produce an underestimate.

14.2.2.1.1. Limitations of Functional Dependencies

Functional dependencies are currently only applied when considering simple equality conditions that compare columns to constant values, and IN clauses with constant values. They are not used to improve estimates for equality conditions comparing two columns or comparing a column to an expression, nor for range clauses, LIKE or any other type of condition.

When estimating with functional dependencies, the planner assumes that conditions on the involved columns are compatible and hence redundant. If they are incompatible, the correct estimate would be zero rows, but that possibility is not considered. For example, given a query like

```
SELECT * FROM zipcodes WHERE city = 'San Francisco' AND zip = '94105';
```

the planner will disregard the city clause as not changing the selectivity, which is correct. However, it will make the same assumption about

```
SELECT * FROM zipcodes WHERE city = 'San Francisco' AND zip = '90210';
```

even though there will really be zero rows satisfying this query. Functional dependency statistics do not provide enough information to conclude that, however.

In many practical situations, this assumption is usually satisfied; for example, there might be a GUI in the application that only allows selecting compatible city and ZIP code values to use in a query. But if that's not the case, functional dependencies may not be a viable option.

14.2.2.2. Multivariate N-Distinct Counts

Single-column statistics store the number of distinct values in each column. Estimates of the number of distinct values when combining more than one column (for example, for GROUP BY a, b) are frequently wrong when the planner only has single-column statistical data, causing it to select bad plans.

To improve such estimates, ANALYZE can collect n-distinct statistics for groups of columns. As before, it's impractical to do this for every possible column grouping, so data is collected only for those groups

of columns appearing together in a statistics object defined with the `ndistinct` option. Data will be collected for each possible combination of two or more columns from the set of listed columns.

Continuing the previous example, the n-distinct counts in a table of ZIP codes might look like the following:

```
CREATE STATISTICS stts2 (ndistinct) ON city, state, zip FROM zipcodes;

ANALYZE zipcodes;

SELECT stxkeys AS k, stxdndistinct AS nd
  FROM pg_statistic_ext join pg_statistic_ext_data on (oid = stxoid)
  WHERE stxname = 'stts2';
-[ RECORD 1 ]-------------------------------------------------------
k  | 1 2 5
nd | {"1, 2": 33178, "1, 5": 33178, "2, 5": 27435, "1, 2, 5": 33178}
(1 row)
```

This indicates that there are three combinations of columns that have 33178 distinct values: ZIP code and state; ZIP code and city; and ZIP code, city and state (the fact that they are all equal is expected given that ZIP code alone is unique in this table). On the other hand, the combination of city and state has only 27435 distinct values.

It's advisable to create `ndistinct` statistics objects only on combinations of columns that are actually used for grouping, and for which misestimation of the number of groups is resulting in bad plans. Otherwise, the `ANALYZE` cycles are just wasted.

14.2.2.3. Multivariate MCV Lists

Another type of statistic stored for each column are most-common value lists. This allows very accurate estimates for individual columns, but may result in significant misestimates for queries with conditions on multiple columns.

To improve such estimates, `ANALYZE` can collect MCV lists on combinations of columns. Similarly to functional dependencies and n-distinct coefficients, it's impractical to do this for every possible column grouping. Even more so in this case, as the MCV list (unlike functional dependencies and n-distinct coefficients) does store the common column values. So data is collected only for those groups of columns appearing together in a statistics object defined with the `mcv` option.

Continuing the previous example, the MCV list for a table of ZIP codes might look like the following (unlike for simpler types of statistics, a function is required for inspection of MCV contents):

```
CREATE STATISTICS stts3 (mcv) ON city, state FROM zipcodes;

ANALYZE zipcodes;

SELECT m.* FROM pg_statistic_ext join pg_statistic_ext_data on (oid = stxoid),
                pg_mcv_list_items(stxdmcv) m WHERE stxname = 'stts3';

 index |         values          | nulls | frequency | base_frequency
-------+-------------------------+-------+-----------+----------------
     0 | {Washington, DC}        | {f,f} |  0.003467 |        2.7e-05
     1 | {Apo, AE}               | {f,f} |  0.003067 |        1.9e-05
     2 | {Houston, TX}           | {f,f} |  0.002167 |       0.000133
     3 | {El Paso, TX}           | {f,f} |     0.002 |       0.000113
     4 | {New York, NY}          | {f,f} |  0.001967 |       0.000114
     5 | {Atlanta, GA}           | {f,f} |  0.001633 |        3.3e-05
     6 | {Sacramento, CA}        | {f,f} |  0.001433 |        7.8e-05
     7 | {Miami, FL}             | {f,f} |    0.0014 |          6e-05
     8 | {Dallas, TX}            | {f,f} |  0.001367 |        8.8e-05
     9 | {Chicago, IL}           | {f,f} |  0.001333 |        5.1e-05
```

```
   ...
(99 rows)
```

This indicates that the most common combination of city and state is Washington in DC, with actual frequency (in the sample) about 0.35%. The base frequency of the combination (as computed from the simple per-column frequencies) is only 0.0027%, resulting in two orders of magnitude under-estimates.

It's advisable to create MCV statistics objects only on combinations of columns that are actually used in conditions together, and for which misestimation of the number of groups is resulting in bad plans. Otherwise, the `ANALYZE` and planning cycles are just wasted.

14.3. Controlling the Planner with Explicit `JOIN` Clauses

It is possible to control the query planner to some extent by using the explicit `JOIN` syntax. To see why this matters, we first need some background.

In a simple join query, such as:

```
SELECT * FROM a, b, c WHERE a.id = b.id AND b.ref = c.id;
```

the planner is free to join the given tables in any order. For example, it could generate a query plan that joins A to B, using the `WHERE` condition `a.id = b.id`, and then joins C to this joined table, using the other `WHERE` condition. Or it could join B to C and then join A to that result. Or it could join A to C and then join them with B — but that would be inefficient, since the full Cartesian product of A and C would have to be formed, there being no applicable condition in the `WHERE` clause to allow optimization of the join. (All joins in the Postgres Pro executor happen between two input tables, so it's necessary to build up the result in one or another of these fashions.) The important point is that these different join possibilities give semantically equivalent results but might have hugely different execution costs. Therefore, the planner will explore all of them to try to find the most efficient query plan.

When a query only involves two or three tables, there aren't many join orders to worry about. But the number of possible join orders grows exponentially as the number of tables expands. Beyond ten or so input tables it's no longer practical to do an exhaustive search of all the possibilities, and even for six or seven tables planning might take an annoyingly long time. When there are too many input tables, the Postgres Pro planner will switch from exhaustive search to a *genetic* probabilistic search through a limited number of possibilities. (The switch-over threshold is set by the geqo_threshold run-time parameter.) The genetic search takes less time, but it won't necessarily find the best possible plan.

When the query involves outer joins, the planner has less freedom than it does for plain (inner) joins. For example, consider:

```
SELECT * FROM a LEFT JOIN (b JOIN c ON (b.ref = c.id)) ON (a.id = b.id);
```

Although this query's restrictions are superficially similar to the previous example, the semantics are different because a row must be emitted for each row of A that has no matching row in the join of B and C. Therefore the planner has no choice of join order here: it must join B to C and then join A to that result. Accordingly, this query takes less time to plan than the previous query. In other cases, the planner might be able to determine that more than one join order is safe. For example, given:

```
SELECT * FROM a LEFT JOIN b ON (a.bid = b.id) LEFT JOIN c ON (a.cid = c.id);
```

it is valid to join A to either B or C first. Currently, only `FULL JOIN` completely constrains the join order. Most practical cases involving `LEFT JOIN` or `RIGHT JOIN` can be rearranged to some extent.

Explicit inner join syntax (`INNER JOIN`, `CROSS JOIN`, or unadorned `JOIN`) is semantically the same as listing the input relations in `FROM`, so it does not constrain the join order.

Even though most kinds of `JOIN` don't completely constrain the join order, it is possible to instruct the Postgres Pro query planner to treat all `JOIN` clauses as constraining the join order anyway. For example, these three queries are logically equivalent:

```
SELECT * FROM a, b, c WHERE a.id = b.id AND b.ref = c.id;
SELECT * FROM a CROSS JOIN b CROSS JOIN c WHERE a.id = b.id AND b.ref = c.id;
```

```
SELECT * FROM a JOIN (b JOIN c ON (b.ref = c.id)) ON (a.id = b.id);
```

But if we tell the planner to honor the JOIN order, the second and third take less time to plan than the first. This effect is not worth worrying about for only three tables, but it can be a lifesaver with many tables.

To force the planner to follow the join order laid out by explicit JOINs, set the join_collapse_limit run-time parameter to 1. (Other possible values are discussed below.)

You do not need to constrain the join order completely in order to cut search time, because it's OK to use JOIN operators within items of a plain FROM list. For example, consider:

```
SELECT * FROM a CROSS JOIN b, c, d, e WHERE ...;
```

With join_collapse_limit = 1, this forces the planner to join A to B before joining them to other tables, but doesn't constrain its choices otherwise. In this example, the number of possible join orders is reduced by a factor of 5.

Constraining the planner's search in this way is a useful technique both for reducing planning time and for directing the planner to a good query plan. If the planner chooses a bad join order by default, you can force it to choose a better order via JOIN syntax — assuming that you know of a better order, that is. Experimentation is recommended.

A closely related issue that affects planning time is collapsing of subqueries into their parent query. For example, consider:

```
SELECT *
FROM x, y,
    (SELECT * FROM a, b, c WHERE something) AS ss
WHERE somethingelse;
```

This situation might arise from use of a view that contains a join; the view's SELECT rule will be inserted in place of the view reference, yielding a query much like the above. Normally, the planner will try to collapse the subquery into the parent, yielding:

```
SELECT * FROM x, y, a, b, c WHERE something AND somethingelse;
```

This usually results in a better plan than planning the subquery separately. (For example, the outer WHERE conditions might be such that joining X to A first eliminates many rows of A, thus avoiding the need to form the full logical output of the subquery.) But at the same time, we have increased the planning time; here, we have a five-way join problem replacing two separate three-way join problems. Because of the exponential growth of the number of possibilities, this makes a big difference. The planner tries to avoid getting stuck in huge join search problems by not collapsing a subquery if more than from_collapse_limit FROM items would result in the parent query. You can trade off planning time against quality of plan by adjusting this run-time parameter up or down.

from_collapse_limit and join_collapse_limit are similarly named because they do almost the same thing: one controls when the planner will “flatten out” subqueries, and the other controls when it will flatten out explicit joins. Typically you would either set join_collapse_limit equal to from_collapse_limit (so that explicit joins and subqueries act similarly) or set join_collapse_limit to 1 (if you want to control join order with explicit joins). But you might set them differently if you are trying to fine-tune the trade-off between planning time and run time.

14.4. Populating a Database

One might need to insert a large amount of data when first populating a database. This section contains some suggestions on how to make this process as efficient as possible.

14.4.1. Disable Autocommit

When using multiple INSERTs, turn off autocommit and just do one commit at the end. (In plain SQL, this means issuing BEGIN at the start and COMMIT at the end. Some client libraries might do this behind your back, in which case you need to make sure the library does it when you want it done.) If you allow each

insertion to be committed separately, Postgres Pro is doing a lot of work for each row that is added. An additional benefit of doing all insertions in one transaction is that if the insertion of one row were to fail then the insertion of all rows inserted up to that point would be rolled back, so you won't be stuck with partially loaded data.

14.4.2. Use `COPY`

Use `COPY` to load all the rows in one command, instead of using a series of `INSERT` commands. The `COPY` command is optimized for loading large numbers of rows; it is less flexible than `INSERT`, but incurs significantly less overhead for large data loads. Since `COPY` is a single command, there is no need to disable autocommit if you use this method to populate a table.

If you cannot use `COPY`, it might help to use `PREPARE` to create a prepared `INSERT` statement, and then use `EXECUTE` as many times as required. This avoids some of the overhead of repeatedly parsing and planning `INSERT`. Different interfaces provide this facility in different ways; look for “prepared statements” in the interface documentation.

Note that loading a large number of rows using `COPY` is almost always faster than using `INSERT`, even if `PREPARE` is used and multiple insertions are batched into a single transaction.

`COPY` is fastest when used within the same transaction as an earlier `CREATE TABLE` or `TRUNCATE` command. In such cases no WAL needs to be written, because in case of an error, the files containing the newly loaded data will be removed anyway. However, this consideration only applies when wal_level is `minimal` as all commands must write WAL otherwise.

14.4.3. Remove Indexes

If you are loading a freshly created table, the fastest method is to create the table, bulk load the table's data using `COPY`, then create any indexes needed for the table. Creating an index on pre-existing data is quicker than updating it incrementally as each row is loaded.

If you are adding large amounts of data to an existing table, it might be a win to drop the indexes, load the table, and then recreate the indexes. Of course, the database performance for other users might suffer during the time the indexes are missing. One should also think twice before dropping a unique index, since the error checking afforded by the unique constraint will be lost while the index is missing.

14.4.4. Remove Foreign Key Constraints

Just as with indexes, a foreign key constraint can be checked “in bulk” more efficiently than row-by-row. So it might be useful to drop foreign key constraints, load data, and re-create the constraints. Again, there is a trade-off between data load speed and loss of error checking while the constraint is missing.

What's more, when you load data into a table with existing foreign key constraints, each new row requires an entry in the server's list of pending trigger events (since it is the firing of a trigger that checks the row's foreign key constraint). Loading many millions of rows can cause the trigger event queue to overflow available memory, leading to intolerable swapping or even outright failure of the command. Therefore it may be *necessary*, not just desirable, to drop and re-apply foreign keys when loading large amounts of data. If temporarily removing the constraint isn't acceptable, the only other recourse may be to split up the load operation into smaller transactions.

14.4.5. Increase `maintenance_work_mem`

Temporarily increasing the maintenance_work_mem configuration variable when loading large amounts of data can lead to improved performance. This will help to speed up `CREATE INDEX` commands and `ALTER TABLE ADD FOREIGN KEY` commands. It won't do much for `COPY` itself, so this advice is only useful when you are using one or both of the above techniques.

14.4.6. Increase `max_wal_size`

Temporarily increasing the max_wal_size configuration variable can also make large data loads faster. This is because loading a large amount of data into Postgres Pro will cause checkpoints to occur more

often than the normal checkpoint frequency (specified by the `checkpoint_timeout` configuration variable). Whenever a checkpoint occurs, all dirty pages must be flushed to disk. By increasing `max_wal_size` temporarily during bulk data loads, the number of checkpoints that are required can be reduced.

14.4.7. Disable WAL Archival and Streaming Replication

When loading large amounts of data into an installation that uses WAL archiving or streaming replication, it might be faster to take a new base backup after the load has completed than to process a large amount of incremental WAL data. To prevent incremental WAL logging while loading, disable archiving and streaming replication, by setting wal_level to `minimal`, archive_mode to `off`, and max_wal_senders to zero. But note that changing these settings requires a server restart, and makes any base backups taken before unavailable for archive recovery and standby server, which may lead to data loss.

Aside from avoiding the time for the archiver or WAL sender to process the WAL data, doing this will actually make certain commands faster, because they do not to write WAL at all if `wal_level` is `minimal` and the current subtransaction (or top-level transaction) created or truncated the table or index they change. (They can guarantee crash safety more cheaply by doing an `fsync` at the end than by writing WAL.)

14.4.8. Run `ANALYZE` Afterwards

Whenever you have significantly altered the distribution of data within a table, running `ANALYZE` is strongly recommended. This includes bulk loading large amounts of data into the table. Running `ANALYZE` (or `VACUUM ANALYZE`) ensures that the planner has up-to-date statistics about the table. With no statistics or obsolete statistics, the planner might make poor decisions during query planning, leading to poor performance on any tables with inaccurate or nonexistent statistics. Note that if the autovacuum daemon is enabled, it might run `ANALYZE` automatically; see Section 24.1.3 and Section 24.1.6 for more information.

14.4.9. Some Notes about pg_dump

Dump scripts generated by pg_dump automatically apply several, but not all, of the above guidelines. To restore a pg_dump dump as quickly as possible, you need to do a few extra things manually. (Note that these points apply while *restoring* a dump, not while *creating* it. The same points apply whether loading a text dump with psql or using pg_restore to load from a pg_dump archive file.)

By default, pg_dump uses `COPY`, and when it is generating a complete schema-and-data dump, it is careful to load data before creating indexes and foreign keys. So in this case several guidelines are handled automatically. What is left for you to do is to:

- Set appropriate (i.e., larger than normal) values for `maintenance_work_mem` and `max_wal_size`.
- If using WAL archiving or streaming replication, consider disabling them during the restore. To do that, set `archive_mode` to `off`, `wal_level` to `minimal`, and `max_wal_senders` to zero before loading the dump. Afterwards, set them back to the right values and take a fresh base backup.
- Experiment with the parallel dump and restore modes of both pg_dump and pg_restore and find the optimal number of concurrent jobs to use. Dumping and restoring in parallel by means of the `-j` option should give you a significantly higher performance over the serial mode.
- Consider whether the whole dump should be restored as a single transaction. To do that, pass the `-1` or `--single-transaction` command-line option to psql or pg_restore. When using this mode, even the smallest of errors will rollback the entire restore, possibly discarding many hours of processing. Depending on how interrelated the data is, that might seem preferable to manual cleanup, or not. `COPY` commands will run fastest if you use a single transaction and have WAL archiving turned off.
- If multiple CPUs are available in the database server, consider using pg_restore's `--jobs` option. This allows concurrent data loading and index creation.
- Run `ANALYZE` afterwards.

A data-only dump will still use `COPY`, but it does not drop or recreate indexes, and it does not normally touch foreign keys. [1] So when loading a data-only dump, it is up to you to drop and recreate indexes and foreign keys if you wish to use those techniques. It's still useful to increase `max_wal_size` while loading the data, but don't bother increasing `maintenance_work_mem`; rather, you'd do that while manually recreating indexes and foreign keys afterwards. And don't forget to `ANALYZE` when you're done; see Section 24.1.3 and Section 24.1.6 for more information.

14.5. Non-Durable Settings

Durability is a database feature that guarantees the recording of committed transactions even if the server crashes or loses power. However, durability adds significant database overhead, so if your site does not require such a guarantee, Postgres Pro can be configured to run much faster. The following are configuration changes you can make to improve performance in such cases. Except as noted below, durability is still guaranteed in case of a crash of the database software; only an abrupt operating system crash creates a risk of data loss or corruption when these settings are used.

- Place the database cluster's data directory in a memory-backed file system (i.e., RAM disk). This eliminates all database disk I/O, but limits data storage to the amount of available memory (and perhaps swap).
- Turn off fsync; there is no need to flush data to disk.
- Turn off synchronous_commit; there might be no need to force WAL writes to disk on every commit. This setting does risk transaction loss (though not data corruption) in case of a crash of the *database*.
- Turn off full_page_writes; there is no need to guard against partial page writes.
- Increase max_wal_size and checkpoint_timeout; this reduces the frequency of checkpoints, but increases the storage requirements of `/pg_wal`.
- Create unlogged tables to avoid WAL writes, though it makes the tables non-crash-safe.

14.6. Autoprepared Statements

Postgres Pro Enterprise provides the *autoprepare* mode that can implicitly prepare frequently used statements to eliminate the cost of their compilation and planning on each subsequent execution.

While providing slightly lower performance gains than explicitly prepared statements, this mode enables you to get prepared plans for cases where explicit `PREPARE` commands are not supported, such as using pgbouncer with a pooling level other than `session`, working with distributed partitioned tables, or running database applications that are not designed to execute prepared statements.

By default, the autoprepare mode is switched off. To enable this feature, assign a non-zero value to the autoprepare_threshold configuration variable, which sets the minimal number of times a statement should be executed to get autoprepared. Once the same query with different literal values is repeated the specified number of times, Postgres Pro builds a generic plan for this query, replacing all constant literals with parameters. The generic plan will be chosen for execution if the estimated time of this plan is lower than an average time of the customized plans. Just like for explicitly prepared statements, generic plans get invalidated when a catalog change occurs.

When this feature is enabled, queries submitted via both simple and extended query protocols could be autoprepared. The extended protocol supports the transmission of parameterized queries, and autopreparing of such queries incurs less overhead. On the other hand, queries received via different protocols can be very diverse in nature, and autopreparing is ineffective for some query types. Hence, the autoprepare_for_protocol parameter allows to enable/disable the statement autopreparing on the protocol level.

If your application issues many different statements, autopreparing them all can cause memory overflow unless you impose any cache restrictions. It is especially important when running multiple active clients

[1] You can get the effect of disabling foreign keys by using the `--disable-triggers` option — but realize that that eliminates, rather than just postpones, foreign key validation, and so it is possible to insert bad data if you use it.

as the cache of autoprepared statements is local to the backend. To avoid cache bloat, you can do the following:

- Limit the number of autoprepared statements per backend using the autoprepare_limit parameter. This setting is recommended for workloads with multiple simple queries.
- Limit the amount of memory that can be allocated for autoprepared statements on a backend using the autoprepare_memory_limit parameter. This setting can incur some overhead when calculating the amount of cache used for autoprepared statements, so it is only recommended for workloads that contain complex queries for which limiting the number of autoprepared statements may be ineffective.

In both cases, most frequently used queries are kept in memory using the LRU strategy. If both parameters are set, Postgres Pro enforces the first reached limit.

Note that the cache of autoprepared statements is fully cleaned up when executing the following commands:

- `DISCARD PLANS`
- `DISCARD ALL`
- Any `ALTER SYSTEM...` command
- Any `SET var` command, both standalone and and inside other commands. For example:

  ```
  ALTER TABLE test ALTER COLUMN a SET STORAGE PLAIN
  ```

- Any DDL command that supports event triggers, such as `CREATE/DROP TABLE`

You can check all autoprepared statements available in the current session in the `pg_autoprepared_statements` system view. It shows the original text of the query, types of the extracted parameters that replace literals, and the query execution counter.

Chapter 15. Parallel Query

Postgres Pro can devise query plans that can leverage multiple CPUs in order to answer queries faster. This feature is known as parallel query. Many queries cannot benefit from parallel query, either due to limitations of the current implementation or because there is no imaginable query plan that is any faster than the serial query plan. However, for queries that can benefit, the speedup from parallel query is often very significant. Many queries can run more than twice as fast when using parallel query, and some queries can run four times faster or even more. Queries that touch a large amount of data but return only a few rows to the user will typically benefit most. This chapter explains some details of how parallel query works and in which situations it can be used so that users who wish to make use of it can understand what to expect.

15.1. How Parallel Query Works

When the optimizer determines that parallel query is the fastest execution strategy for a particular query, it will create a query plan that includes a *Gather* or *Gather Merge* node. Here is a simple example:

```
EXPLAIN SELECT * FROM pgbench_accounts WHERE filler LIKE '%x%';
                                     QUERY PLAN
------------------------------------------------------------------------------------
 Gather  (cost=1000.00..217018.43 rows=1 width=97)
   Workers Planned: 2
   ->  Parallel Seq Scan on pgbench_accounts  (cost=0.00..216018.33 rows=1 width=97)
         Filter: (filler ~~ '%x%'::text)
(4 rows)
```

In all cases, the `Gather` or `Gather Merge` node will have exactly one child plan, which is the portion of the plan that will be executed in parallel. If the `Gather` or `Gather Merge` node is at the very top of the plan tree, then the entire query will execute in parallel. If it is somewhere else in the plan tree, then only the portion of the plan below it will run in parallel. In the example above, the query accesses only one table, so there is only one plan node other than the `Gather` node itself; since that plan node is a child of the `Gather` node, it will run in parallel.

Using EXPLAIN, you can see the number of workers chosen by the planner. When the `Gather` node is reached during query execution, the process that is implementing the user's session will request a number of background worker processes equal to the number of workers chosen by the planner. The number of background workers that the planner will consider using is limited to at most max_parallel_workers_per_gather. The total number of background workers that can exist at any one time is limited by both max_worker_processes and max_parallel_workers. Therefore, it is possible for a parallel query to run with fewer workers than planned, or even with no workers at all. The optimal plan may depend on the number of workers that are available, so this can result in poor query performance. If this occurrence is frequent, consider increasing `max_worker_processes` and `max_parallel_workers` so that more workers can be run simultaneously or alternatively reducing `max_parallel_workers_per_gather` so that the planner requests fewer workers.

Every background worker process that is successfully started for a given parallel query will execute the parallel portion of the plan. The leader will also execute that portion of the plan, but it has an additional responsibility: it must also read all of the tuples generated by the workers. When the parallel portion of the plan generates only a small number of tuples, the leader will often behave very much like an additional worker, speeding up query execution. Conversely, when the parallel portion of the plan generates a large number of tuples, the leader may be almost entirely occupied with reading the tuples generated by the workers and performing any further processing steps that are required by plan nodes above the level of the `Gather` node or `Gather Merge` node. In such cases, the leader will do very little of the work of executing the parallel portion of the plan.

When the node at the top of the parallel portion of the plan is `Gather Merge` rather than `Gather`, it indicates that each process executing the parallel portion of the plan is producing tuples in sorted order, and that the leader is performing an order-preserving merge. In contrast, `Gather` reads tuples from the workers in whatever order is convenient, destroying any sort order that may have existed.

15.2. When Can Parallel Query Be Used?

There are several settings that can cause the query planner not to generate a parallel query plan under any circumstances. In order for any parallel query plans whatsoever to be generated, the following settings must be configured as indicated.

- max_parallel_workers_per_gather must be set to a value that is greater than zero. This is a special case of the more general principle that no more workers should be used than the number configured via `max_parallel_workers_per_gather`.

In addition, the system must not be running in single-user mode. Since the entire database system is running as a single process in this situation, no background workers will be available.

Even when it is in general possible for parallel query plans to be generated, the planner will not generate them for a given query if any of the following are true:

- The query writes any data or locks any database rows. If a query contains a data-modifying operation either at the top level or within a CTE, no parallel plans for that query will be generated. As an exception, the following commands, which create a new table and populate it, can use a parallel plan for the underlying `SELECT` part of the query:
  - `CREATE TABLE ... AS`
  - `SELECT INTO`
  - `CREATE MATERIALIZED VIEW`
  - `REFRESH MATERIALIZED VIEW`
- The query might be suspended during execution. In any situation in which the system thinks that partial or incremental execution might occur, no parallel plan is generated. For example, a cursor created using DECLARE CURSOR will never use a parallel plan. Similarly, a PL/pgSQL loop of the form `FOR x IN query LOOP .. END LOOP` will never use a parallel plan, because the parallel query system is unable to verify that the code in the loop is safe to execute while parallel query is active.
- The query uses any function marked `PARALLEL UNSAFE`. Most system-defined functions are `PARALLEL SAFE`, but user-defined functions are marked `PARALLEL UNSAFE` by default. See the discussion of Section 15.4.
- The query is running inside of another query that is already parallel. For example, if a function called by a parallel query issues an SQL query itself, that query will never use a parallel plan. This is a limitation of the current implementation, but it may not be desirable to remove this limitation, since it could result in a single query using a very large number of processes.

Even when a parallel query plan is generated for a particular query, there are several circumstances under which it will be impossible to execute that plan in parallel at execution time. If this occurs, the leader will execute the portion of the plan below the `Gather` node entirely by itself, almost as if the `Gather` node were not present. This will happen if any of the following conditions are met:

- No background workers can be obtained because of the limitation that the total number of background workers cannot exceed max_worker_processes.
- No background workers can be obtained because of the limitation that the total number of background workers launched for purposes of parallel query cannot exceed max_parallel_workers.
- The client sends an Execute message with a non-zero fetch count. See the discussion of the extended query protocol. Since libpq currently provides no way to send such a message, this can only occur when using a client that does not rely on libpq. If this is a frequent occurrence, it may be a good idea to set max_parallel_workers_per_gather to zero in sessions where it is likely, so as to avoid generating query plans that may be suboptimal when run serially.

15.3. Parallel Plans

Because each worker executes the parallel portion of the plan to completion, it is not possible to simply take an ordinary query plan and run it using multiple workers. Each worker would produce a full copy

of the output result set, so the query would not run any faster than normal but would produce incorrect results. Instead, the parallel portion of the plan must be what is known internally to the query optimizer as a *partial plan*; that is, it must be constructed so that each process that executes the plan will generate only a subset of the output rows in such a way that each required output row is guaranteed to be generated by exactly one of the cooperating processes. Generally, this means that the scan on the driving table of the query must be a parallel-aware scan.

15.3.1. Parallel Scans

The following types of parallel-aware table scans are currently supported.

- In a *parallel sequential scan*, the table's blocks will be divided into ranges and shared among the cooperating processes. Each worker process will complete the scanning of its given range of blocks before requesting an additional range of blocks.
- In a *parallel bitmap heap scan*, one process is chosen as the leader. That process performs a scan of one or more indexes and builds a bitmap indicating which table blocks need to be visited. These blocks are then divided among the cooperating processes as in a parallel sequential scan. In other words, the heap scan is performed in parallel, but the underlying index scan is not.
- In a *parallel index scan* or *parallel index-only scan*, the cooperating processes take turns reading data from the index. Currently, parallel index scans are supported only for btree indexes. Each process will claim a single index block and will scan and return all tuples referenced by that block; other processes can at the same time be returning tuples from a different index block. The results of a parallel btree scan are returned in sorted order within each worker process.

Other scan types, such as scans of non-btree indexes, may support parallel scans in the future.

15.3.2. Parallel Joins

Just as in a non-parallel plan, the driving table may be joined to one or more other tables using a nested loop, hash join, or merge join. The inner side of the join may be any kind of non-parallel plan that is otherwise supported by the planner provided that it is safe to run within a parallel worker. Depending on the join type, the inner side may also be a parallel plan.

- In a *nested loop join*, the inner side is always non-parallel. Although it is executed in full, this is efficient if the inner side is an index scan, because the outer tuples and thus the loops that look up values in the index are divided over the cooperating processes.
- In a *merge join*, the inner side is always a non-parallel plan and therefore executed in full. This may be inefficient, especially if a sort must be performed, because the work and resulting data are duplicated in every cooperating process.
- In a *hash join* (without the "parallel" prefix), the inner side is executed in full by every cooperating process to build identical copies of the hash table. This may be inefficient if the hash table is large or the plan is expensive. In a *parallel hash join*, the inner side is a *parallel hash* that divides the work of building a shared hash table over the cooperating processes.

15.3.3. Parallel Aggregation

Postgres Pro supports parallel aggregation by aggregating in two stages. First, each process participating in the parallel portion of the query performs an aggregation step, producing a partial result for each group of which that process is aware. This is reflected in the plan as a `Partial Aggregate` node. Second, the partial results are transferred to the leader via `Gather` or `Gather Merge`. Finally, the leader re-aggregates the results across all workers in order to produce the final result. This is reflected in the plan as a `Finalize Aggregate` node.

Because the `Finalize Aggregate` node runs on the leader process, queries that produce a relatively large number of groups in comparison to the number of input rows will appear less favorable to the query planner. For example, in the worst-case scenario the number of groups seen by the `Finalize Aggregate` node could be as many as the number of input rows that were seen by all worker processes in the `Partial Aggregate` stage. For such cases, there is clearly going to be no performance benefit to

using parallel aggregation. The query planner takes this into account during the planning process and is unlikely to choose parallel aggregate in this scenario.

Parallel aggregation is not supported in all situations. Each aggregate must be safe for parallelism and must have a combine function. If the aggregate has a transition state of type `internal`, it must have serialization and deserialization functions. See CREATE AGGREGATE for more details. Parallel aggregation is not supported if any aggregate function call contains `DISTINCT` or `ORDER BY` clause and is also not supported for ordered set aggregates or when the query involves `GROUPING SETS`. It can only be used when all joins involved in the query are also part of the parallel portion of the plan.

15.3.4. Parallel Append

Whenever Postgres Pro needs to combine rows from multiple sources into a single result set, it uses an `Append` or `MergeAppend` plan node. This commonly happens when implementing `UNION ALL` or when scanning a partitioned table. Such nodes can be used in parallel plans just as they can in any other plan. However, in a parallel plan, the planner may instead use a `Parallel Append` node.

When an `Append` node is used in a parallel plan, each process will execute the child plans in the order in which they appear, so that all participating processes cooperate to execute the first child plan until it is complete and then move to the second plan at around the same time. When a `Parallel Append` is used instead, the executor will instead spread out the participating processes as evenly as possible across its child plans, so that multiple child plans are executed simultaneously. This avoids contention, and also avoids paying the startup cost of a child plan in those processes that never execute it.

Also, unlike a regular `Append` node, which can only have partial children when used within a parallel plan, a `Parallel Append` node can have both partial and non-partial child plans. Non-partial children will be scanned by only a single process, since scanning them more than once would produce duplicate results. Plans that involve appending multiple results sets can therefore achieve coarse-grained parallelism even when efficient partial plans are not available. For example, consider a query against a partitioned table that can only be implemented efficiently by using an index that does not support parallel scans. The planner might choose a `Parallel Append` of regular `Index Scan` plans; each individual index scan would have to be executed to completion by a single process, but different scans could be performed at the same time by different processes.

enable_parallel_append can be used to disable this feature.

15.3.5. Parallel Plan Tips

If a query that is expected to do so does not produce a parallel plan, you can try reducing parallel_setup_cost or parallel_tuple_cost. Of course, this plan may turn out to be slower than the serial plan that the planner preferred, but this will not always be the case. If you don't get a parallel plan even with very small values of these settings (e.g., after setting them both to zero), there may be some reason why the query planner is unable to generate a parallel plan for your query. See Section 15.2 and Section 15.4 for information on why this may be the case.

When executing a parallel plan, you can use `EXPLAIN (ANALYZE, VERBOSE)` to display per-worker statistics for each plan node. This may be useful in determining whether the work is being evenly distributed between all plan nodes and more generally in understanding the performance characteristics of the plan.

15.4. Parallel Safety

The planner classifies operations involved in a query as either *parallel safe*, *parallel restricted*, or *parallel unsafe*. A parallel safe operation is one that does not conflict with the use of parallel query. A parallel restricted operation is one that cannot be performed in a parallel worker, but that can be performed in the leader while parallel query is in use. Therefore, parallel restricted operations can never occur below a `Gather` or `Gather Merge` node, but can occur elsewhere in a plan that contains such a node. A parallel unsafe operation is one that cannot be performed while parallel query is in use, not even in the leader. When a query contains anything that is parallel unsafe, parallel query is completely disabled for that query.

The following operations are always parallel restricted:

- Scans of common table expressions (CTEs).
- Scans of temporary tables.
- Scans of foreign tables, unless the foreign data wrapper has an `IsForeignScanParallelSafe` API that indicates otherwise.
- Plan nodes to which an `InitPlan` is attached.
- Plan nodes that reference a correlated `SubPlan`.

15.4.1. Parallel Labeling for Functions and Aggregates

The planner cannot automatically determine whether a user-defined function or aggregate is parallel safe, parallel restricted, or parallel unsafe, because this would require predicting every operation that the function could possibly perform. In general, this is equivalent to the Halting Problem and therefore impossible. Even for simple functions where it could conceivably be done, we do not try, since this would be expensive and error-prone. Instead, all user-defined functions are assumed to be parallel unsafe unless otherwise marked. When using CREATE FUNCTION or ALTER FUNCTION, markings can be set by specifying `PARALLEL SAFE`, `PARALLEL RESTRICTED`, or `PARALLEL UNSAFE` as appropriate. When using CREATE AGGREGATE, the `PARALLEL` option can be specified with `SAFE`, `RESTRICTED`, or `UNSAFE` as the corresponding value.

Functions and aggregates must be marked `PARALLEL UNSAFE` if they write to the database, access sequences, change the transaction state even temporarily (e.g., a PL/pgSQL function that establishes an `EXCEPTION` block to catch errors), or make persistent changes to settings. Similarly, functions must be marked `PARALLEL RESTRICTED` if they access temporary tables, client connection state, cursors, prepared statements, or miscellaneous backend-local state that the system cannot synchronize across workers. For example, `setseed` and `random` are parallel restricted for this last reason.

In general, if a function is labeled as being safe when it is restricted or unsafe, or if it is labeled as being restricted when it is in fact unsafe, it may throw errors or produce wrong answers when used in a parallel query. C-language functions could in theory exhibit totally undefined behavior if mislabeled, since there is no way for the system to protect itself against arbitrary C code, but in most likely cases the result will be no worse than for any other function. If in doubt, it is probably best to label functions as `UNSAFE`.

If a function executed within a parallel worker acquires locks that are not held by the leader, for example by querying a table not referenced in the query, those locks will be released at worker exit, not end of transaction. If you write a function that does this, and this behavior difference is important to you, mark such functions as `PARALLEL RESTRICTED` to ensure that they execute only in the leader.

Note that the query planner does not consider deferring the evaluation of parallel-restricted functions or aggregates involved in the query in order to obtain a superior plan. So, for example, if a `WHERE` clause applied to a particular table is parallel restricted, the query planner will not consider performing a scan of that table in the parallel portion of a plan. In some cases, it would be possible (and perhaps even efficient) to include the scan of that table in the parallel portion of the query and defer the evaluation of the `WHERE` clause so that it happens above the `Gather` node. However, the planner does not do this.

Chapter 16. Autonomous Transactions

An autonomous transaction is an independent transaction run within a parent transaction. Unlike subtransactions, which can only be committed as part of the transaction they belong to, autonomous transactions must be committed or rolled back before their parent is finished. While subtransactions are mostly used for error handling and in stored procedures, the main purpose of autonomous transactions is to implement audits, when an attempt to perform a transaction must be logged regardless of whether this transaction has been committed successfully.

> **Note**
>
> Behavior of an autonomous transaction differs from the behavior of an ordinary transaction or a subtransaction. It is recommended to read the Section 16.1 and Section 16.2 sections before working with autonomous transactions.

16.1. Behavior

Although an autonomous transaction is always run inside another transaction, only a single transaction can be active at any given moment; other transactions have to wait until the active transaction is complete. When an autonomous transaction is started, its parent transaction is paused and pushed into the autonomous transaction stack. Once the autonomous transaction is committed or rolled back, the parent transaction is popped from the stack and resumed. You cannot commit the parent transaction until all its autonomous transactions are complete.

Within a single parent transaction, you can start several autonomous ones, which can be both consecutive and nested. By default, Postgres Pro allows running up to 100 autonomous transactions in all sessions simultaneously. You can increase this limit by changing the max_autonomous_transactions configuration parameter. The maximum nesting level is restricted to 128 and cannot be changed.

Autonomous transactions do not support the following scenarios, so they will cause an error if attempted:

- The `FOR UPDATE` locking clause is not supported, so you cannot lock a row in a parent transaction and skip it in the autonomous transaction.
- Temporary namespaces cannot be accessed from autonomous transactions.
- You cannot redefine isolation level for autonomous transactions within PL/pgSQL or PL/Python blocks.
- Logical replication slots cannot be used in autonomous transactions.
- Using foreign data wrappers that rely on PostgreSQL transaction mechanism in autonomous transactions is not supported, except for the adapted `postgres_fdw`. Doing so is likely to cause errors, such as issues with error handling during transaction rollback.
- Autonomous transactions cannot be used together with the following extensions:
  - in_memory
  - online_analyze

Consider the following examples. A continuous line denotes an active transaction, while a dotted line denotes a transaction which has been paused and pushed into the autonomous transaction stack. Time flows downwards.

```
BEGIN; -- starts ordinary transaction T0
|
INSERT INTO t VALUES (1);
:\
: BEGIN AUTONOMOUS TRANSACTION; -- starts autonomous transaction
```

```
: |                             -- T1, pushes T0 into stack
: |
: INSERT INTO t VALUES (2);
: |
: COMMIT AUTONOMOUS TRANSACTION / ROLLBACK AUTONOMOUS TRANSACTION;
: |                             -- ends autonomous transaction
: |                             -- T1, pops transaction T0 from stack
:/
COMMIT / ROLLBACK;              -- ends transaction T0
```

Depending on the two choices between `COMMIT` and `ROLLBACK`, the following query can return four different results:

```
SELECT sum(x) FROM t;
```

A parent transaction can have several autonomous transactions, which can be nested or follow one another:

```
BEGIN;                          -- starts ordinary transaction T0
|
INSERT INTO t VALUES (1);
:\
: BEGIN AUTONOMOUS TRANSACTION;   -- starts autonomous transaction
: |                               -- T1, pushes T0 into stack
: |
: INSERT INTO t VALUES (2);
: |
: COMMIT AUTONOMOUS TRANSACTION / ROLLBACK AUTONOMOUS TRANSACTION;
: |                               -- ends autonomous transaction
: |                               -- T1, pops T0 from stack
:/
|
:\
: BEGIN AUTONOMOUS TRANSACTION;   -- starts autonomous transaction
: |                               -- T2, pushes T0 into stack
: |
: INSERT INTO t VALUES (4);
: :\
: : BEGIN AUTONOMOUS TRANSACTION; -- starts autonomous transaction
: : |                             -- T3, pushes T2 into stack
: : |
: : INSERT INTO t VALUES (6);
: : |
: : COMMIT AUTONOMOUS TRANSACTION / ROLLBACK AUTONOMOUS TRANSACTION;
: : |                             -- ends autonomous transaction
: : |                             -- T3, pops T2 from stack
: :/
: |
: COMMIT AUTONOMOUS TRANSACTION / ROLLBACK AUTONOMOUS TRANSACTION;
: |                               -- ends autonomous transaction
: |                               -- T2, pops T0 from stack
:/
COMMIT / ROLLBACK;                -- ends transaction T0
```

16.2. Visibility

Visibility rules for autonomous transactions are the same as for independent transactions executed via `dblink`. Autonomous transactions do not see the effects of their parent transaction because the latter has not been committed yet. At the same time, if other autonomous transactions precede the active au-

tonomous transaction and are already committed, then the active transaction will see the effects of these transactions. The parent transaction might see the effects of its autonomous transactions, depending on its own isolation level. For example, if the isolation level is Read Committed, the parent transaction will see all changes made by autonomous transactions. However, if the parent transaction is using the Repeatable Read isolation level, the changes made by autonomous transactions will be invisible.

Consider the following example, showing a set of both consequent and nested transactions. Each transaction in the set is labeled with its status. In addition, the transactions that have been already committed are highlighted.

```
- Ordinary transaction T0                [PAUSED]
    - Autonomous transaction A0            [COMMITTED]
    - Autonomous transaction A1            [COMMITTED]
    - Autonomous transaction A2            [PAUSED]
        - Autonomous transaction A2.0          [COMMITTED]
        - Autonomous transaction A2.1          [PAUSED]
            - Autonomous transaction A2.1.0        [ACTIVE]
```

In the above example, the active autonomous transaction `A2.1.0` does not see the effects of the preceding transactions `T0`, `A2`, and `A2.1` that are paused and not committed yet, regardless of their type. However, the active transaction sees the effects of the preceding autonomous transactions `A0`, `A1`, and `A2.0` that have been already committed.

Autonomous transactions can cause single-session deadlocks, since an autonomous transaction can conflict with one of the paused transactions in its session. If an autonomous transaction tries to obtain any resource locked by its parent, a deadlock is reported.

16.3. SQL Grammar Extension for Autonomous Transactions

In Postgres Pro Enterprise, BEGIN/START TRANSACTION, COMMIT/END, and ROLLBACK/ABORT transaction statements are extended with an optional keyword `AUTONOMOUS`. For example:

```
BEGIN [AUTONOMOUS] [TRANSACTION] [ ISOLATION LEVEL isolation-level]
END [AUTONOMOUS] [TRANSACTION]
```

where *isolation-level* can be one of the following: `SERIALIZABLE`, `REPEATABLE READ`, `READ COMMITTED`, or `READ UNCOMMITTED`.

The `AUTONOMOUS` keyword is required to start an autonomous transaction, but can be omitted when completing an autonomous transaction. If you have several nested levels of autonomous transactions, they are completed one by one, starting from the innermost nesting level. The top-level transaction cannot be autonomous.

16.4. PL/pgSQL Grammar Extension for Autonomous Transactions

Block construction in PL/pgSQL is extended by the optional `autonomous` keyword. It is possible to treat the whole function body as an autonomous transaction:

```
CREATE FUNCTION foo(x integer) RETURNS integer AS $$
BEGIN AUTONOMOUS
  RETURN x;
END;
$$ LANGUAGE plpgsql;
```

or create a separate `BEGIN`/`END` block:

```
CREATE OR REPLACE FUNCTION myaudit() RETURNS boolean AS $$
BEGIN AUTONOMOUS
```

```
        BEGIN AUTONOMOUS
        INSERT INTO audit_schedule VALUES ('new audit',now());
        END;
        ... -- do audit itself
        RETURN true;
END;
$$ LANGUAGE plpgsql;
```

> **Note**
>
> You cannot redefine isolation level for autonomous transactions within PL/pgSQL blocks.

If an exception is raised inside a `BEGIN AUTONOMOUS` block, this autonomous transaction is aborted, and the standard exception handling procedure is started, unwinding the stack and executing exception handlers until the exception is caught. Thus, exception handling for autonomous transactions in PL/pgSQL is done in the same way as for Postgres Pro subtransactions.

If an error is caught by an `EXCEPTION` clause, local variables of the PL/pgSQL function remain as they were when the error occurred, but all changes to persistent database state within the block are rolled back.

16.5. PL/Python Extension for Autonomous Transactions

In addition to the `subtransaction` method, PL/Python module provides the `autonomous` method that can be used in the `WITH` clause to start an autonomous transaction:

```
CREATE OR REPLACE FUNCTION pythonomous() RETURNS void AS $$
        plpy.execute("INSERT INTO atx_test VALUES ('asd', 123)")

        try:
                with plpy.autonomous():
                        plpy.execute("INSERT INTO atx_test VALUES ('bsd', 456)")
        except plpy.SPIError, e:
                print("error: %s" % e.args)

        plpy.execute("INSERT INTO atx_test VALUES ('csd', 'csd')")
$$ LANGUAGE plpythonu;
```

> **Note**
>
> You cannot redefine isolation level for autonomous transactions within PL/Python blocks.

Exception handling for autonomous transactions in PL/Python is done in the same way as for subtransactions.

Part III. Server Administration

This part covers topics that are of interest to a Postgres Pro database administrator. This includes installation of the software, set up and configuration of the server, management of users and databases, and maintenance tasks. Anyone who runs a Postgres Pro server, even for personal use, but especially in production, should be familiar with the topics covered in this part.

The information in this part is arranged approximately in the order in which a new user should read it. But the chapters are self-contained and can be read individually as desired. The information in this part is presented in a narrative fashion in topical units. Readers looking for a complete description of a particular command should see Part VI.

The first few chapters are written so they can be understood without prerequisite knowledge, so new users who need to set up their own server can begin their exploration with this part. The rest of this part is about tuning and management; that material assumes that the reader is familiar with the general use of the Postgres Pro database system. Readers are encouraged to look at Part I and Part II for additional information.

Chapter 17. Binary Installation

17.1. Installing Postgres Pro Enterprise on Linux

For Linux-based operating systems, Postgres Pro Enterprise is shipped as binary packages. Each Postgres Pro binary distribution consists of several packages. The package structure differs from vanilla PostgreSQL and offers the following installation modes:

- **Quick installation and setup**. The `postgrespro-ent-14` package installs and configures all the components required for a viable ready-to-use configuration of both server and client components. Choose this option if you are going to install a single Postgres Pro instance only, and you are not worried about possible conflicts with other PostgreSQL-based products.

  > **Important**
  >
  > Installing the `postgrespro-ent-14` package can delete existing installations of Postgres Pro and PostgreSQL-based products. Similarly, this Postgres Pro installation may be automatically removed if you later install another PostgreSQL-based product. Do not use this package for upgrades or migrations, or if you are going to maintain several installations on the same system.

- **Custom installation**. You can select any packages required for your purposes, including development packages. This option needs manual configuration, so a good grasp of Linux and understanding of PostgreSQL architecture are required. This is the only option to choose if you are going to use Postgres Pro in one of the following scenarios:
  - Install several Postgres Pro versions side by side, or together with other PostgreSQL-based products.
  - Perform an upgrade from a previous version, or migrate from a different PostgreSQL-based product.
  - Control Postgres Pro server execution using high availability software, such as pacemaker, instead of the standard system service management facility.

The minimum hardware required to install Postgres Pro, create a database cluster and start the database server are as follows:

- `1-GHz` processor
- `1 GB` of RAM
- `1 GB` of disk space

Additional disk space is required for data or supporting components.

17.1.1. Supported Linux Distributions

> **Note**
>
> This is the last Postgres Pro release that supports Ubuntu 20.04. Starting from the next release, this operating system will no longer be supported.

Postgres Pro binary packages are available for the following Linux-based systems:

- Red Hat Enterprise Linux (RHEL) systems and its derivatives: CentOS 7/8, Rocky Linux 8/9, Red Hat Enterprise Linux 7/8/9, Oracle Linux 7/8/9, ROSA Chrome 2021.2, Red OS Murom 7.3/8, AlterOS 7.5, AlmaLinux 9
- Debian-based systems: Debian 10/11/12, Ubuntu 20.04/22.04/24.04, Astra Linux 1.7/1.8
- ALT 8/9/10/11, ALT SP 8/8.2 and higher, ALT SP Release 10
- SUSE Linux Enterprise Server (SLES) 12/15

- Linux systems for Elbrus CPU architecture: ALT 9/10 for e2kv3/e2kv4, ALT 8.2 SP for e2kv3/e2kv4, ALT SP Release 10, Astra Linux Leningrad 8.1

> **Note**
>
> Postgres Pro binary packages rely on the tzdata library provided by the operating system, so you must ensure that the latest available version is installed. If tzdata is outdated, the time in your database may be incorrect.

17.1.2. Adding Package Repository

Before installing Postgres Pro from binary packages using the package manager of your operating system, you need to add the Postgres Pro package repository.

To add the repository, complete the following steps:

1. Contact the Postgres Pro Enterprise support team to download the `pgpro-repo-add.sh` Bash script. The support team will also provide you with the credentials to access the repository.

   This script adds the repository so that the package manager of your operating system can use it.
2. Make sure that the wget utility is installed and can access the Internet.

   The script requires wget and the Internet access to check the validity of the credentials when adding the repository.

   > **Note**
   >
   > It is not possible to use a SOCKS5 proxy for accessing the Internet as wget does not support this type of proxy.
3. (Optional) Examine the content of the script, if necessary.
4. Run the script as `root` (e. g. using sudo).
5. When prompted, enter the access credentials.

   > **Important**
   >
   > If no credentials are provided or they are invalid, the script will offer to add the repository without credentials.
   >
   > If you proceed without credentials, you will be required to manually provide the credentials later in order to access the repository.

Now you are ready to install Postgres Pro Enterprise using the package manager of your operating system.

17.1.3. Quick Installation and Setup

If you only need to install a single Postgres Pro instance and are not going to use any other PostgreSQL-based products on your system, you can use the quick installation mode. The typical process is as follows:

1. Add the package repository required for your operating system.
2. Install the `postgrespro-ent-14` package. It will bring all the required components via dependencies, create the default database, start the database server, as well as enable server autostart at system boot and make all the provided programs available in `PATH`.

> **Note**
>
> By default, the database configuration is set for the Postgres Pro product being installed. If you need your database configured for a different product, choose custom installation and use the `tune` argument of the `pg-setup initdb` command.

Once the installation completes, you can launch psql on behalf of the `postgres` user and connect to the newly created database, which is located in the `/var/lib/pgpro/ent-14/data` directory.

Since the default database is created using the pg-setup script, the path to its data directory is stored in the `/etc/default/postgrespro-ent-14` file. All the subsequent pg-setup commands, as well as any commands that manage Postgres Pro service, affect this database only. In this file, you can also change the value of `PG_OOM_ADJUST_VALUE` for postmaster child processes (see Section 18.4.4 for details).

17.1.4. Custom Installation

Splitting the distribution into multiple packages enables customizing the installation for different purposes: database servers, client systems, or development workstations. Custom installations need to be configured manually, but give you more flexibility in using the product. You can install several Postgres Pro versions side by side, as well as together with other PostgreSQL-based products. In particular, this may be required when performing upgrades, or migrating from a different PostgreSQL-based product.

To perform a custom installation, complete the following steps:

1. Add the package repository required for your operating system.
2. Choose Postgres Pro packages required for your purposes and install them using the standard installation commands for your Linux distribution. The available packages are listed in Table 17.1.

   As a result, all files get installed into the `/opt/pgpro/ent-14` directory.
3. Run pg-wrapper as root to make the installed client and server programs available via `PATH` and add SQL man pages to the man page configuration file. This utility is provided in the `postgrespro-ent-14-client` package.

   ```
   /opt/pgpro/ent-14/bin/pg-wrapper links update
   ```

   For details on how to handle possible conflicts, see pg-wrapper description.
4. If you chose to install the `postgrespro-ent-14-server` package, make sure to complete the following server setup:
   a. Create the default database by running the helper script pg-setup as root with the `initdb` option:

      ```
      /opt/pgpro/ent-14/bin/pg-setup initdb [--tune=conf] [initdb_options]
      ```

      where:

      - the `tune` command-line argument sets the database configuration.
      - *`initdb_options`* are regular initdb options.

      > **Note**
      >
      > By default, pg-setup initializes the database cluster with checksums enabled. If this is not what you expect, specify the `--no-data-checksums`.

      The `pg-setup` script performs database administration operations as user `postgres`. If you do not specify any initdb options, the default database is created in the `/var/lib/pgpro/ent-14/data` directory, using localization settings specified in the `LANG` environment variable for the current session. All the `LC_*` environment variables are ignored.

Since the default database is created using the pg-setup script, the path to its data directory is stored in the `/etc/default/postgrespro-ent-14` file. All the subsequent pg-setup commands, as well as any commands that manage Postgres Pro service, affect this database only. In this file, you can also change the value of `PG_OOM_ADJUST_VALUE` for postmaster child processes (see Section 18.4.4 for details).

b. Start the server by running `pg-setup` as root, as follows:

```
/opt/pgpro/ent-14/bin/pg-setup service start
```

Like vanilla PostgreSQL, Postgres Pro server runs on behalf of the `postgres` user.

> **Note**
>
> By default, automatic server startup is disabled, so you can manually control the database recovery after a system reboot. Optionally, you can configure the Postgres Pro server to start automatically. For details, see Section 17.1.4.2.

17.1.4.1. Choosing the Packages to Install

The table below lists all the available Postgres Pro Enterprise packages.

Table 17.1. Postgres Pro Enterprise Packages

Package	Description
`postgrespro-ent-14`	Top-level package that installs and configures Postgres Pro for server and client systems. Do not use this package for upgrades or migrations. **Important** Installing the `postgrespro-ent-14` package can delete existing installations of Postgres Pro and PostgreSQL-based products. Similarly, this Postgres Pro installation may be automatically removed if you later install another PostgreSQL-based product.
`postgrespro-ent-14-client`	Standard client applications, such as psql or pg_dump.
`postgrespro-ent-14-libs`	Shared libraries required to deploy client applications, including libpq; runtime libraries for ECPG processor.
`postgrespro-ent-14-server`	Postgres Pro server and PL/pgSQL server-side programming language.
`postgrespro-ent-14-contrib`	Additional extensions and programs deployable on database servers.
`postgrespro-ent-14-devel`	Header files and libraries for developing client applications and server extensions. On Debian-based systems, this package is called `postgrespro-ent-14-dev`.
`postgrespro-ent-14-plperl`	Server-side programming language based on Perl (see Chapter 47).

Package	Description
postgrespro-ent-14-plpython	Server-side programming language based on Python (see Chapter 48).
postgrespro-ent-14-plpython3	Server-side programming language based on Python 3 (see Chapter 48).
postgrespro-ent-14-pltcl	Server-side programming language based on Tcl (see Chapter 46).
postgrespro-ent-14-docs	Documentation (English).
postgrespro-ent-14-docs-ru	Documentation (Russian).
postgrespro-ent-14-test	Test scripts for the server. This package is only available on RHEL-based and SUSE systems.
postgrespro-ent-14-jit	This package provides support for Just-in-Time (JIT) compilation. This package is available only for x86_64 architecture and only for the supported Debian and Ubuntu systems, Astra Linux 1.7/1.8, supported ALT systems, CentOS 7/8, Rocky Linux 8/9, Oracle Linux 7/8/9, AlmaLinux 9, SLES 15 and RHEL 7/8/9. To learn more about enabling and using JIT, see Chapter 31.
mamonsu	mamonsu — a monitoring agent for collecting Postgres Pro and system metrics.
pg-failover-slots-ent-14	pg_failover_slots extension for automatic creation and synchronization of logical replication slots on physical replicas.
pg-portal-modify-ent-14	An extension to modify Postgres Pro cursors.
pg-probackup-ent-14	pg_probackup utility.
pgpro-controldata	pgpro_controldata application to display control information of a PostgreSQL/Postgres Pro database cluster and compatibility information for a cluster and/or server.
pgpro-datactl-ent-14	pgpro_datactl utility to manage Postgres Pro data files.
pgpro-pwr-ent-14	pgpro_pwr extension that enables you to generate workload reports, which help to discover most resource-intensive activities in your database.
pgpro-stats-ent-14	pgpro_stats extension that tracks execution statistics of SQL statements, calculates wait event statistics and provides other useful metrics.

Also, Postgres Pro includes libraries and utilities required for the Postgres Pro server and provided packages. These packages are only provided for the distributions that don't include the required versions of these libraries.

Table 17.2. Third-party libraries and utilities for Postgres Pro Enterprise

Library/utility	Description
apache-age-ent-14	apache-age is a Postgres Pro extension that provides graph database functionality.

Library/utility	Description
liblz4	A library for fast lossless data compression.
freetds	A library that implements TDS protocol. It is used by the tds-fdw extensiion. It includes freetds-devel, freetds-doc and freetds-libs. This package is available only for RHEL 8/9.
zstd	Command-line utility for the libzstd library.
libzstd	A library for fast lossless data compression.
libunwind	A stack unwinding library used by crash_info . This package is provided for RHEL 8.
libbacktrace	A backtrace library used by crash_info . This package is provided for AlterOS 7, ALT 9, ALT SP 8.2, Red OS 7.3/8, RHEL 8/9 and SLES 12.
libsybdb5	A library that implements TDS protocol. This package is available for SLES 15.
perl-IO-Tty, perl-IPC-Run	Two Perl libraries used in the TAP test framework available in the postgrespro-ent-14-devel package for extension developers and engineers. perl-IO-Tty is provided for RED OS Murom 7.3/8, RHEL 8/9, SLES 12, and perl-IPC-Run is provided for RED OS Murom 7.3/8, RHEL 8/9, SLES 12/15.

Besides, there are separate packages providing several external modules that have been pre-built for compatibility with Postgres Pro Enterprise:

Table 17.3. Third-party Packages Built for Postgres Pro Enterprise

Package	Description
oracle-fdw-ent-14	oracle_fdw extension that provides a foreign data wrapper for Oracle. This package is not available for Windows, ALT Linux 8.0 or lower, and Red OS Murom 7.2 or lower.
orafce-ent-14	This package implements in Postgres Pro some of the functions from the Oracle database that are missing (or behaving differently).
pg-filedump-ent-14	pg_filedump utility to format Postgres Pro heap/index/control files into a human-readable form.
pg-hint-plan-ent-14	pg_hint_plan module that controls the execution plan by providing hints to the planner.
pg-repack-ent-14	pg_repack extension and utility for reorganizing tables.
pgbouncer	pgbouncer — a connection pooler for Postgres Pro.
pgpro-pgbadger	pgbadger — Postgres Pro log analyzer that provides detailed reports and graphs.
pldebugger-ent-14	A set of shared libraries that implement an API for debugging PL/pgSQL functions in Postgres Pro.

Package	Description
plv8-ent-14	The shared library PLV8 that provides a Postgres Pro procedural language powered by V8 Javascript Engine. This package is available for the supported Debian and Ubuntu systems, ALT 8/9/10/11, SLES 15, Rosa Enterprise Linux, and RHEL 7/8.
tds-fdw-ent-14	tds_fdw extension that provides a foreign data to connect to Microsoft SQL Server and other databases that use the Tabular Data Stream (TDS) protocol.

Additionally, Postgres Pro provides separate packages with debug information for some operating systems:

- On Debian-based systems, see the postgrespro-ent-14-dbg package.
- On RHEL-based systems, see the postgrespro-ent-14-debuginfo package.
- On ALT Linux systems, all packages containing binary files have the corresponding -debuginfo packages.

Server installations require at least the following packages:

- postgrespro-ent-14-server
- postgrespro-ent-14-client
- postgrespro-ent-14-libs

To use additional Postgres Pro extensions, you must also install the postgrespro-ent-14-contrib package. On Debian-based systems, postgrespro-ent-14-server package depends on postgrespro-ent-14-contrib package, so the latter must always be installed together with the server.

For client installations, it is usually enough to install the postgrespro-ent-14-client and postgrespro-ent-14-libs packages. If you use custom applications and do not need standard client utilities such as psql, you can install the postgrespro-ent-14-libs package only.

Development workstations require at least the following packages:

- postgrespro-ent-14-libs
- postgrespro-ent-14-devel/ postgrespro-ent-14-dev

You may also want to install and configure the server with a test database on development systems. For details on additional configuration that may be required, Section 17.1.5.

17.1.4.2. Enabling Automatic Server Startup

If you are running a custom installation, automatic server startup is disabled by default. Once the default database is created, you can configure the server to start automatically upon system boot using service management solutions available in your operating system or third-party high-availability software. To facilitate this task, postgrespro-ent-14-server package provides the pg-setup script, which is installed in the /opt/pgpro/ent-14/bin directory.

To enable server autostart, run the pg-setup script with the following options:

```
pg-setup service enable
```

If required, you can disable server autostart using the same script:

```
pg-setup service disable
```

Alternatively, you can use system service management solutions directly by running the autostart scripts for SysV-style init.d and systemd provided in the `postgrespro-ent-14-server` package. Depending on your Linux distribution, Postgres Pro supports different service management solutions:

Linux Distribution	Provided Scripts
RHEL 7/8 and compatible distributions, SLES 12/15	systemd unit file
Debian, Ubuntu, ALT 8/9/10/11	Both systemd unit file and SysV-style init.d script

To use systemd for automatic server startup, run the following command:

```
systemctl enable postgrespro-ent-14
```

To use SysV-style init.d script:

- On ALT Linux systems, run the following command:

  ```
  systemctl enable postgrespro-ent-14
  ```

- On Debian systems, use `update-rc.d`. See the corresponding man page for details.

17.1.5. Setting up Development Workstations

While installing `postgrespro-ent-14-libs` and `postgrespro-ent-14-devel`/`postgrespro-ent-14-dev` packages may be enough, it is usually convenient to have the server set up on the development system. For quick setup, you can install `postgrespro-ent-14` package, which automatically configures the provided client and server programs and creates the default database. However, if you are going to use several PostgreSQL-based products simultaneously, follow the custom installation instructions in Section 17.1.4.

To compile programs with Postgres Pro libraries using the pg_config utility shipped with Postgres Pro, make sure it appears before the path to other pg_config versions, if any. Note that on RHEL-based systems pg_config is not added to `PATH` automatically. If you do not have any other pg_config versions on your system, you can use pg-wrapper provided in the `postgrespro-ent-14-client` package to create a symbolic link to pg_config in the standard binary directory.

To compile programs using pkg-config command, add the `/opt/pgpro/ent-14/lib/pkgconfig/` path to the `PKG_CONFIG_PATH` environment variable.

If you would like to compile Postgres Pro extensions that support JIT inlining, make sure to meet the following additional requirements:

- Install LLVM development package and Clang compiler. You must choose the packages of the same version that was used for the `postgrespro-ent-14-jit` to be installed on the server. To determine the required version for the current Postgres Pro release, check the `CLANG` value in the `/opt/pgpro/ent-14/lib/pgxs/src/Makefile.global` file.
- When running `make` or `make install` commands, specify the `with-llvm=yes` option to compile and install bitcode files for your extension. By default, bitcode compilation is disabled as it depends on Clang compiler availability.

17.1.5.1. Using Third-Party Programs with Postgres Pro

To use Postgres Pro server with a client program provided with a third-party product, you can install the version of PostgreSQL libraries that was used to compile this program. For example, if this program is provided with vanilla PostgreSQL, you may need to install the `libpq` or `postgresql-libs` packages available for your Linux distribution. In this case, the program may not be able to use some new features of Postgres Pro server, but it is probably not designed to use them anyway.

If you prefer to use Postgres Pro libraries with a third-party program, or would like to enable support for a new feature that does not require client application change, such as SCRAM authentication, you can recompile your program with Postgres Pro libraries.

Important

If the program is compiled with one version of libpq but used with another, its stable work cannot be guaranteed.

If you are creating `.rpm` or `.deb` packages for your program, it is recommended to do the following:

1. Add `/opt/pgpro/ent-14/bin` to `PATH` inside your build scripts (`.spec` files or `debian/rules`).
2. Specify `postgrespro-ent-14-dev` in the `BuildDepends` or `BuildRequires` tags for your program.

Thus, you can ensure that your package build process calls the right version of pg_config whenever the source package is rebuilt.

17.1.6. Configuring Multiple Postgres Pro Instances

To set up several Postgres Pro server instances with different data directories on Linux, do the following:

1. Install and configure Postgres Pro as explained in Section 17.1.3 or Section 17.1.4.
2. Once the first default database is created, run initdb specifying the path to a different data directory and any other parameters required to initialize another server instance.
3. Specify different ports for your server instances in the corresponding `postgresql.conf` files to avoid conflicts.
4. If required, configure automatic server startup, as follows:
   a. Create a copy of `/etc/init.d/postgrespro-ent-14` or `/lib/systemd/system/postgrespro-ent-14.service` with a different name, specifying the path to the data directory.
   b. Enable automatic server startup using the provided autostart scripts for your system service management facility instead of `pg-setup`, as described in Section 17.1.4.2. Make sure to use the renamed copies of the scripts you created in step 1.

17.1.7. Antivirus Considerations

It is strongly recommended to avoid using antivirus software on systems where Postgres Pro is running because it may cause additional load on your environment and result in unexpected database behavior that would lead to performance and reliability issues. If you need to use antivirus software, make sure to exclude the following directories from virus scanning as they do not contain any executable files:

- `PGDATA` directory that stores main cluster data, usually located in `/var/lib/pgpro/ent-14/data` unless you specified another directory in initdb options
- Paths to created tablespaces

17.2. Installing Postgres Pro Enterprise on Windows

Postgres Pro offers the following installation modes for the supported Windows systems:

- GUI installation using an interactive wizard
- Command-line installation

Additionally, you have to set up the environment for using PL/Perl and PL/Python, if these procedural languages are required for your purposes. For details, see Section 17.2.4.

To avoid confusion, note that there are the following different users on Windows systems:

- Postgres Pro installation is performed on behalf of an operating system user. All the database files belong to this user.
- You must connect to the database cluster on behalf of the user created at installation time to be able to work with the database. This is not an operating system user.
- By default, Postgres Pro service is started on behalf of `NT AUTHORITY\NetworkService`, which is a special Windows Service Account. You can specify another Windows user for starting Postgres Pro

service in the corresponding text box of the installer, if required. The provided user must have the right to start Windows services.

The minimum hardware required to install Postgres Pro, create a database cluster and start the database server are as follows:

- `1-GHz` processor
- `1 GB` of RAM
- `1 GB` of disk space

Additional disk space is required for data or supporting components.

17.2.1. Supported Windows Versions

Postgres Pro is available for the following 64-bit Windows versions:

- Windows 10 or higher
- Windows Server 2012 R2 or higher

17.2.2. GUI Installation

Postgres Pro provides an installer with an interactive wizard that configures and installs Postgres Pro core components, creates the default database, and enables server autostart. The following components have their own installers that should be run separately once the core components are installed:

- `pg_probackup`

To install Postgres Pro core components, run the provided installer as administrator and follow the on-screen instructions. Make sure to take into account the following installation specifics:

- You can install all the Postgres Pro core components, or customize the installation by excluding server or developer components. Client utilities are always installed.
- The selected data directory must be empty. Otherwise, Postgres Pro cannot create the default database. The default data directory is `C:\Program Files\PostgresProEnterprise\14\data`.
- If the Allow external connections check box is selected (default), the installer modifies `postgresql.conf` and `pg_hba.conf` files to allow external connections. Otherwise, Postgres Pro server is listening for connections from the localhost only. If you decide to enable external connections when the installation is complete, you have to modify the Windows Firewall configuration to allow Postgres Pro server to accept connections.
- Make sure to remember the username and password you set up when installing Postgres Pro as it will be required to connect to the Postgres Pro server when using password-based authentication methods.
- By default, Postgres Pro uses `icu` collations. If you are upgrading an installation with the default collation provided by `libc`, such as PostgreSQL, make sure to choose `libc` collation provider in the corresponding drop-down list of the installer.
- Postgres Pro provides a pre-configured psql that you can launch from the Start menu, so you do not have to configure the standard environment variables. However, if you would like to work with Postgres Pro from the standard command prompt without specifying full paths to the binary files, select the Set up environment variables check box.

Once the installation completes, your Postgres Pro instance is ready to use, with server autostart enabled. If you need more than one Postgres Pro instance on the same system, you have to configure them manually. For details, see Section 17.2.5.

17.2.3. Command-Line Installation

To install Postgres Pro from the command line, run the downloaded installer file passing one or more options described in Section 17.2.3.1.

17.2.3.1. Command-Line Options

Installation directory path:

`/D=path`

Silent install:

`/S`

`INI` file that provides the options to customize the server installation:

`/init=ini_file_name`

If you would like to customize the installation, you must create the `INI` file manually, as described in Section 17.2.3.2.

17.2.3.2. INI File Format

You can add the following installation options to the [options] section of the INI file:

- `InstallDir` — path where to install server. If you specified the /D option on the command line, it will be overwritten by the `InstallDir` value.
- `DataDir` — path where to create default database
- `Port` — TCP/IP port to listen. Default: 5432.
- `SuperUser` — name of the database user who will have admin rights in the database
- `Password` — password of the user
- `noExtConnections = 1` — do not allow external connections
- `Coding = UNICODE` — character encoding to use in the database
- `Locale` — locale to use in the database. There can be several different locales for each encoding
- `vcredist = no` — do not install Visual C redistributable libraries (use it only if these libraries are already installed on your system)
- `envvar = 1` — set up environment variables helpful for Postgres Pro: `PGDATA`, `PGDATABASE`, `PGUSER`, `PGPORT`, `PGLOCALEDIR`
- `needoptimization = 0` — disable automatic tuning of configuration parameters based on the available system resources.
- `datachecksums = 0` — disable data checksums for the cluster.
- `serviceaccount` — specify a Windows user for starting Postgres Pro service. The provided user must have the right to start Windows services. By default, Postgres Pro service is started on behalf of `NT AUTHORITY\NetworkService`, which is a special Windows Service Account.
- `servicepassword` — provide the password for the Windows user specified in the `serviceaccount` option.
- `serviceid` — change Postgres Pro service name.
- `islibc = 1` — use `libc` as the provider of the default collation.

17.2.4. Loading Procedural Languages

Postgres Pro distribution for Windows systems includes `PL/Perl` and `PL/Python` procedural languages.

17.2.4.1. Setting up the Environment for PL/Python

To configure the system for using PL/Python, complete the following steps:

1. Download and install the latest available version of Python 3.8 or 2.7 for Windows. Choose the 64-bit version as Postgres Pro server has 64-bit architecture type. You can find the installers at *https://www.python.org/*.
2. Create the PL/Python extension by running the following command in psql:

   ```
   CREATE EXTENSION plpythonu
   ```

> **Tip**
>
> In some cases, when you create a PL/Python function, the connection to the server is lost and the server log shows the following error message:
>
> ```
> ImportError: module site not found
> ```

To avoid this issue, try to specify the Python installation directory in the `PYTHONHOME` environment variable and restart the Postgres Pro service.

17.2.4.2. Setting up the Environment for PL/Perl

To configure the system for using PL/Perl, complete the following steps:

1. Download the MSI package of the 64-bit Strawberry Perl 5.26 from *https://strawberryperl.com/releases.html* and perform the installation.
2. Restart the Postgres Pro server.
3. Create the PL/Perl extension by running the following command in psql:

```
CREATE EXTENSION plperlu
```

17.2.5. Configuring Multiple Postgres Pro Instances

To set up several Postgres Pro server instances with different data directories on Windows, do the following:

1. Install Postgres Pro as explained in Section 17.2.2 or Section 17.2.3. The installed binary files are shared by all Postgres Pro instances, so you need to complete this step only once.
2. Select an empty folder that your new Postgres Pro instance will use as the data directory. For example, `C:\Program Files\PostgresProEnterprise\14\data2`. Make sure to grant Full Control permissions for this folder to the current OS user that will own the database files and the user on behalf of which the server is running (`NT AUTHORITY\NetworkService` by default).
3. Run initdb specifying the path to the new data directory and any other parameters required to initialize another server instance. For example:

   ```
   "C:\Program Files\PostgresProEnterprise\14\bin\initdb.exe" --encoding=UTF8 -U
    "postgres" -D "C:\Program Files\PostgresProEnterprise\14\data2"
   ```

   Alternatively, you can stop the running server and copy the contents of the existing data directory into the newly created folder. In this case, the new Postgres Pro instance inherits all the settings of the original instance, including authentication settings.
4. Modify `postgresql.conf` settings for the new Postgres Pro instance as required. Make sure to specify different ports for your server instances to avoid conflicts.
5. Open the command prompt as Administrator and register a new Postgres Pro service with a unique name, for example, `postgrespro-data2`:

   ```
   "C:\Program Files\PostgresProEnterprise\14\bin\pg_ctl.exe" register -N
    "postgrespro-data2" -U "NT AUTHORITY\NetworkService" -D "C:\Program Files
   \PostgresProEnterprise\14\data2" -w
   ```

   Start the registered service:

   ```
   sc start "postgrespro-data2"
   ```

Once the service is started, your Postgres Pro instance is ready to use. If you need any additional Postgres Pro extensions, make sure to enable them for the new instance as explained in Section 17.3.

17.2.6. Uninstalling Postgres Pro Enterprise

The procedure of uninstalling Postgres Pro Enterprise depends on the number of Postgres Pro instances set up on your system.

If you have a single Postgres Pro instance created at installation time, you only need to run the `C:\Program Files\PostgresProEnterprise\14\uninstall.exe` program. This program automatically stops the server and unregisters the service for this instance.

If you have created any additional Postgres Pro instances, you have to complete the following steps:

1. Stop the server for each instance:

   ```
   "C:\Program Files\PostgresProEnterprise\14\bin\pg_ctl.exe" stop -D "C:\Program Files
   \PostgresProEnterprise\14\data_dir" -m fast -w
   ```

2. Unregister the service for each instance:

   ```
   "C:\Program Files\PostgresProEnterprise\14\bin\pg_ctl.exe" unregister -N
    "postgrespro_service_name"
   ```

3. Run the `C:\Program Files\PostgresProEnterprise\14\uninstall.exe` to uninstall Postgres Pro binary files.

17.2.7. Antivirus Considerations

It is strongly recommended to avoid using antivirus software on systems where Postgres Pro is running because it may cause additional load on your environment and result in unexpected database behavior that would lead to performance and reliability issues. If you need to use antivirus software, make sure to exclude the following directories from virus scanning as they do not contain any executable files:

- `PGDATA` directory that stores main cluster data, usually located in `C:\Program Files\PostgresProEnterprise\14\data` unless you specified another directory in initdb options
- Paths to created tablespaces

17.3. Installing Additional Supplied Modules

Postgres Pro comes with a set of additional server extensions, or modules. On Linux, these extensions are provided in the `postgrespro-contrib` package. On Windows, these extensions are installed together with the server components.

Once you have the binary files installed, you have to enable additional extensions in the database in order to use them. In most cases, you only need to issue the CREATE EXTENSION command. However, some extensions also require shared libraries to be preloaded on server startup. If you want to use such extensions, you need to configure parameter

```
shared_preload_libraries = 'lib1, lib2, lib3'
```

in the `postgresql.conf` file of your Postgres Pro database instance and restart the server before executing the `CREATE EXTENSION` statement.

For the exact installation and configuration instructions for each particular extension, see the corresponding documentation under Appendix F.

To get the list of extensions available in your Postgres Pro installation, you can view the `pg_available_extensions` system catalog.

17.3.1. Installing New Extensions in Certified Product Editions

Working in a highly secured environment brings some restrictions. With a superuser prohibited due to its unlimited access rights, you can opt for regular users (for example, a DBMS Administrator) to handle operations.

While trusted extensions can be installed and manipulated with non-superuser rights, other extensions require an elevated security level. Installation of some extensions in a highly secured environment, for example pg_proaudit, follows a special procedure.

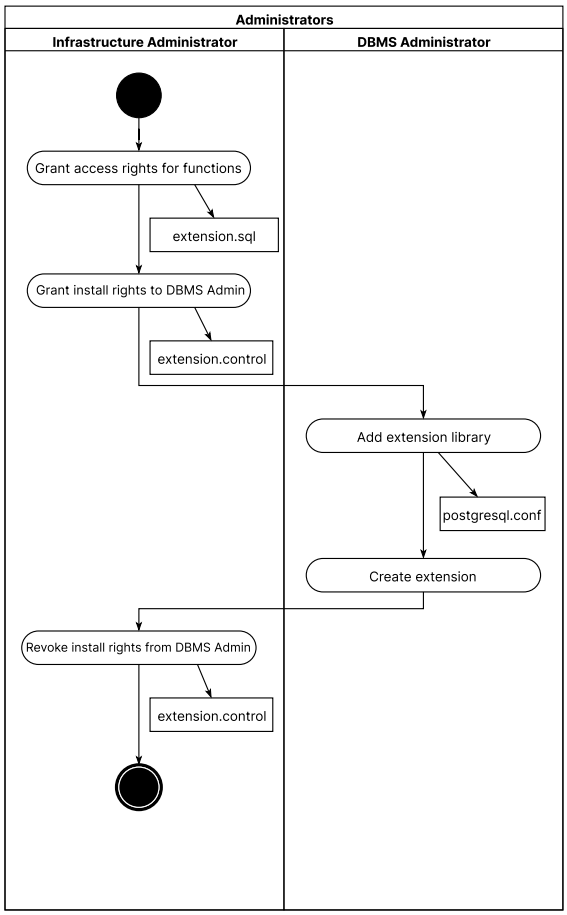
This procedure involves an Infrastructure Administrator and a DBMS Administrator:

- An Infrastructure Administrator is responsible for the overall system security and does not manage Postgres Pro.

- A DBMS Administrator, represented by the `PGPRO_DBMS_ADMIN` role in Postgres Pro, is responsible for configuration, setup, and administration of Postgres Pro DBMS.

The steps that the administrators need to take to install a new extension are shown in Figure 17.1.

Figure 17.1. Steps taken by administrators to install an extension



17.3.1.1. Infrastructure Administrator: Steps to be Taken

Only the Infrastructure Administrator is allowed to modify configuration files of extensions in the `share/extension` directory.

The `.sql` file of an extension contains an SQL interface functions declaration. By default, these functions can be used only by a superuser. Under the extension installation procedure, the Infrastructure Administrator takes the following steps:

1. Adds the `GRANT` clauses to the `.sql` file, as shown below, to allow the DBMS Administrator to use these functions without requesting a superuser to grant such access:

```
-- Create new versions of objects
CREATE FUNCTION pg_proaudit_show()
RETURNS TABLE(db_name text,
  event_type text,
  object_type text,
  object_oid oid,
  role_name text)
AS 'MODULE_PATHNAME', 'pg_proaudit_show_conf'
LANGUAGE C VOLATILE;
REVOKE ALL ON FUNCTION pg_proaudit_show() FROM public;
```

   The Infrastructure Administrator grants rights to a non-superuser:

```
-- Create new versions of objects
CREATE FUNCTION pg_proaudit_show()
RETURNS TABLE(db_name text,
  event_type text,
  object_type text,
  object_oid oid,
  role_name text)
AS 'MODULE_PATHNAME', 'pg_proaudit_show_conf'
LANGUAGE C VOLATILE;
REVOKE ALL ON FUNCTION pg_proaudit_show() FROM public;
GRANT ALL ON FUNCTION pg_proaudit_show() TO PGPRO_DBMS_ADMIN;
```

2. Allows a non-superuser to install the extension by changing or adding the `trusted` property in the `.control` file of the extension, thereby granting a temporary installation permission:

   ```
   trusted = true
   ```

Enabling the usage of foreign data wrappers by the `PGPRO_DBMS_ADMIN` role requires a special security permission. To grant the permission, the Infrastructure Administrator adds the `GRANT USAGE ON FOREIGN DATA WRAPPER` command to a respective `.sql` file of the extension. Below is the example for postgres_fdw:

```
GRANT USAGE ON FOREIGN DATA WRAPPER postgres_fdw TO PGPRO_DBMS_ADMIN;
```

The in_memory extension not only creates the `in_memory_fdw` wrapper, but also automatically creates the `in_memory` server. To grant the usage permission, the Infrastructure Administrator adds the following command to the `in_memory--`*`version_number`*`.sql` file:

```
GRANT USAGE ON FOREIGN SERVER in_memory TO PGPRO_DBMS_ADMIN;
```

17.3.1.2. DBMS Administrator: Steps to be Taken

The DBMS Administrator is allowed to modify Postgres Pro configuration files, except for `pg_hba.conf`, which stores security information. Only the Infrastructure Administrator is allowed to modify the `pg_hba.conf` configuration file. Under the extension installation procedure, the DBMS Administrator takes the following steps:

1. Adds a respective library file to the `shared_preload_libraries` variable of the `postgresql.conf` configuration file and reloads the database server for changes to take effect.
2. Creates the extension using the CREATE EXTENSION command.

17.3.1.3. Infrastructure Administrator: Final Step

To make further use of the extension secure, the Infrastructure Administrator reverts the `trusted` property to the original state:

- If it was not specified, it is deleted.
- If it was `FALSE`, it is changed back to `FALSE`.

17.4. Migrating to Postgres Pro

Different major versions of Postgres Pro, as well as different PostgreSQL-based products based on the same major version, can have binary incompatible databases, so you cannot replace the server binary and continue running. To convert databases that used previous major versions, you must perform a dump/restore using pg_dumpall or use the pg_upgrade utility.

For upgrade instructions specific to a particular release, see the Release Notes for the corresponding Postgres Pro version.

Chapter 18. Server Setup and Operation

This chapter discusses how to set up and run the database server, and its interactions with the operating system.

The directions in this chapter assume that you are working with plain PostgreSQL without any additional infrastructure, for example a copy that you built from source according to the directions in the preceding chapters. If you are working with a pre-packaged or vendor-supplied version of PostgreSQL, it is likely that the packager has made special provisions for installing and starting the database server according to your system's conventions. Consult the package-level documentation for details.

18.1. The Postgres Pro User Account

As with any server daemon that is accessible to the outside world, it is advisable to run Postgres Pro under a separate user account. This user account should only own the data that is managed by the server, and should not be shared with other daemons. (For example, using the user `nobody` is a bad idea.) In particular, it is advisable that this user account not own the Postgres Pro executable files, to ensure that a compromised server process could not modify those executables.

Pre-packaged versions of PostgreSQL will typically create a suitable user account automatically during package installation.

To add a Unix user account to your system, look for a command `useradd` or `adduser`. The user name postgres is often used, and is assumed throughout this book, but you can use another name if you like.

18.2. Creating a Database Cluster

Before you can do anything, you must initialize a database storage area on disk. We call this a *database cluster*. (The SQL standard uses the term catalog cluster.) A database cluster is a collection of databases that is managed by a single instance of a running database server. After initialization, a database cluster will contain a database named `postgres`, which is meant as a default database for use by utilities, users and third party applications. The database server itself does not require the `postgres` database to exist, but many external utility programs assume it exists. Another database created within each cluster during initialization is called `template1`. As the name suggests, this will be used as a template for subsequently created databases; it should not be used for actual work. (See Chapter 22 for information about creating new databases within a cluster.)

In file system terms, a database cluster is a single directory under which all data will be stored. We call this the *data directory* or *data area*. It is completely up to you where you choose to store your data. There is no default, although locations such as `/usr/local/pgsql/data` or `/var/lib/pgsql/data` are popular. The data directory must be initialized before being used, using the program initdbwhich is installed with Postgres Pro.

If you are using a pre-packaged version of PostgreSQL, it may well have a specific convention for where to place the data directory, and it may also provide a script for creating the data directory. In that case you should use that script in preference to running `initdb` directly. Consult the package-level documentation for details.

To initialize a database cluster manually, run `initdb` and specify the desired file system location of the database cluster with the `-D` option, for example:

```
$ initdb -D /usr/local/pgsql/data
```

Note that you must execute this command while logged into the Postgres Pro user account, which is described in the previous section.

> **Tip**
>
> As an alternative to the `-D` option, you can set the environment variable `PGDATA`.

Alternatively, you can run initdb via the pg_ctl program like so:

```
$ pg_ctl -D /usr/local/pgsql/data initdb
```

This may be more intuitive if you are using pg_ctl for starting and stopping the server (see Section 18.3), so that pg_ctl would be the sole command you use for managing the database server instance.

initdb will attempt to create the directory you specify if it does not already exist. Of course, this will fail if initdb does not have permissions to write in the parent directory. It's generally recommendable that the Postgres Pro user own not just the data directory but its parent directory as well, so that this should not be a problem. If the desired parent directory doesn't exist either, you will need to create it first, using root privileges if the grandparent directory isn't writable. So the process might look like this:

```
root# mkdir /usr/local/pgsql
root# chown postgres /usr/local/pgsql
root# su postgres
postgres$ initdb -D /usr/local/pgsql/data
```

initdb will refuse to run if the data directory exists and already contains files; this is to prevent accidentally overwriting an existing installation.

Because the data directory contains all the data stored in the database, it is essential that it be secured from unauthorized access. initdb therefore revokes access permissions from everyone but the Postgres Pro user, and optionally, group. Group access, when enabled, is read-only. This allows an unprivileged user in the same group as the cluster owner to take a backup of the cluster data or perform other operations that only require read access.

Note that enabling or disabling group access on an existing cluster requires the cluster to be shut down and the appropriate mode to be set on all directories and files before restarting Postgres Pro. Otherwise, a mix of modes might exist in the data directory. For clusters that allow access only by the owner, the appropriate modes are 0700 for directories and 0600 for files. For clusters that also allow reads by the group, the appropriate modes are 0750 for directories and 0640 for files.

However, while the directory contents are secure, the default client authentication setup allows any local user to connect to the database and even become the database superuser. If you do not trust other local users, we recommend you use one of initdb's -W, --pwprompt or --pwfile options to assign a password to the database superuser. Also, specify -A scram-sha-256 so that the default trust authentication mode is not used; or modify the generated pg_hba.conf file after running initdb, but *before* you start the server for the first time. (Other reasonable approaches include using peer authentication or file system permissions to restrict connections. See Chapter 20 for more information.)

initdb also initializes the default locale for the database cluster. Normally, it will just take the locale settings in the environment and apply them to the initialized database. It is possible to specify a different locale for the database; more information about that can be found in Section 23.1. The default sort order used within the particular database cluster is set by initdb, and while you can create new databases using different sort order, the order used in the template databases that initdb creates cannot be changed without dropping and recreating them. There is also a performance impact for using locales other than C or POSIX. Therefore, it is important to make this choice correctly the first time.

initdb also sets the default character set encoding for the database cluster. Normally this should be chosen to match the locale setting. For details see Section 23.3.

Non-C and non-POSIX locales rely on the operating system's collation library for character set ordering. This controls the ordering of keys stored in indexes. For this reason, a cluster cannot switch to an incompatible collation library version, either through snapshot restore, binary streaming replication, a different operating system, or an operating system upgrade.

18.2.1. Use of Secondary File Systems

Many installations create their database clusters on file systems (volumes) other than the machine's “root” volume. If you choose to do this, it is not advisable to try to use the secondary volume's topmost

directory (mount point) as the data directory. Best practice is to create a directory within the mount-point directory that is owned by the Postgres Pro user, and then create the data directory within that. This avoids permissions problems, particularly for operations such as pg_upgrade, and it also ensures clean failures if the secondary volume is taken offline.

18.2.2. File Systems

Generally, any file system with POSIX semantics can be used for Postgres Pro. Users prefer different file systems for a variety of reasons, including vendor support, performance, and familiarity. Experience suggests that, all other things being equal, one should not expect major performance or behavior changes merely from switching file systems or making minor file system configuration changes.

18.2.2.1. NFS

It is possible to use an NFS file system for storing the Postgres Pro data directory. Postgres Pro does nothing special for NFS file systems, meaning it assumes NFS behaves exactly like locally-connected drives. Postgres Pro does not use any functionality that is known to have nonstandard behavior on NFS, such as file locking.

The only firm requirement for using NFS with Postgres Pro is that the file system is mounted using the `hard` option. With the `hard` option, processes can "hang" indefinitely if there are network problems, so this configuration will require a careful monitoring setup. The `soft` option will interrupt system calls in case of network problems, but Postgres Pro will not repeat system calls interrupted in this way, so any such interruption will result in an I/O error being reported.

It is not necessary to use the `sync` mount option. The behavior of the `async` option is sufficient, since Postgres Pro issues `fsync` calls at appropriate times to flush the write caches. (This is analogous to how it works on a local file system.) However, it is strongly recommended to use the `sync` export option on the NFS *server* on systems where it exists (mainly Linux). Otherwise, an `fsync` or equivalent on the NFS client is not actually guaranteed to reach permanent storage on the server, which could cause corruption similar to running with the parameter fsync off. The defaults of these mount and export options differ between vendors and versions, so it is recommended to check and perhaps specify them explicitly in any case to avoid any ambiguity.

In some cases, an external storage product can be accessed either via NFS or a lower-level protocol such as iSCSI. In the latter case, the storage appears as a block device and any available file system can be created on it. That approach might relieve the DBA from having to deal with some of the idiosyncrasies of NFS, but of course the complexity of managing remote storage then happens at other levels.

18.3. Starting the Database Server

> **Important**
>
> In binary installations on Linux systems, the default database is located in `/var/lib/pg-pro/ent-14/data`, unless you specify a custom directory. See Section 17.1 for details.

Before anyone can access the database, you must start the database server. The database server program is called `postgres`.

If you are using a pre-packaged version of PostgreSQL, it almost certainly includes provisions for running the server as a background task according to the conventions of your operating system. Using the package's infrastructure to start the server will be much less work than figuring out how to do this yourself. Consult the package-level documentation for details.

The bare-bones way to start the server manually is just to invoke `postgres` directly, specifying the location of the data directory with the `-D` option, for example:

```
$ postgres -D /usr/local/pgsql/data
```

which will leave the server running in the foreground. This must be done while logged into the Postgres Pro user account. Without `-D`, the server will try to use the data directory named by the environment variable `PGDATA`. If that variable is not provided either, it will fail.

Normally it is better to start `postgres` in the background. For this, use the usual Unix shell syntax:

```
$ postgres -D /usr/local/pgsql/data >logfile 2>&1 &
```

It is important to store the server's stdout and stderr output somewhere, as shown above. It will help for auditing purposes and to diagnose problems. (See Section 24.3 for a more thorough discussion of log file handling.)

The `postgres` program also takes a number of other command-line options. For more information, see the postgres reference page and Chapter 19 below.

This shell syntax can get tedious quickly. Therefore the wrapper program pg_ctlis provided to simplify some tasks. For example:

```
pg_ctl start -l logfile
```

will start the server in the background and put the output into the named log file. The `-D` option has the same meaning here as for `postgres`. `pg_ctl` is also capable of stopping the server.

Normally, you will want to start the database server when the computer boots. Autostart scripts are operating-system-specific. There are a few example scripts distributed with PostgreSQL in the `contrib/start-scripts` directory. Installing one will require root privileges.

Different systems have different conventions for starting up daemons at boot time. Many systems have a file `/etc/rc.local` or `/etc/rc.d/rc.local`. Others use `init.d` or `rc.d` directories. Whatever you do, the server must be run by the Postgres Pro user account *and not by root* or any other user. Therefore you probably should form your commands using `su postgres -c '...'`. For example:

```
su postgres -c 'pg_ctl start -D /usr/local/pgsql/data -l serverlog'
```

Here are a few more operating-system-specific suggestions. (In each case be sure to use the proper installation directory and user name where we show generic values.)

- For FreeBSD, look at the file *contrib/start-scripts/freebsd* in the PostgreSQL source distribution.
- On OpenBSD, add the following lines to the file `/etc/rc.local`:

  ```
  if [ -x /usr/local/pgsql/bin/pg_ctl -a -x /usr/local/pgsql/bin/postgres ]; then
      su -l postgres -c '/usr/local/pgsql/bin/pg_ctl start -s -l /var/postgresql/log -
  D /usr/local/pgsql/data'
      echo -n ' postgresql'
  fi
  ```

- On Linux systems add

  ```
  /usr/local/pgsql/bin/pg_ctl start -l logfile -D /usr/local/pgsql/data
  ```

  to `/etc/rc.d/rc.local` or `/etc/rc.local`.

  When using systemd, you can use the following service unit file (e.g., at `/etc/systemd/system/postgresql.service`):

  ```
  [Unit]
  Description=Postgres Pro database server
  Documentation=man:postgres(1)
  After=network-online.target
  Wants=network-online.target

  [Service]
  Type=notify
  ```

```
User=postgres
ExecStart=/usr/local/pgsql/bin/postgres -D /usr/local/pgsql/data
ExecReload=/bin/kill -HUP $MAINPID
KillMode=mixed
KillSignal=SIGINT
TimeoutSec=infinity

[Install]
WantedBy=multi-user.target
```

Using `Type=notify` requires that the server binary was built with `configure --with-systemd`.

Consider carefully the timeout setting. systemd has a default timeout of 90 seconds as of this writing and will kill a process that does not report readiness within that time. But a Postgres Pro server that might have to perform crash recovery at startup could take much longer to become ready. The suggested value of `infinity` disables the timeout logic.

- On NetBSD, use either the FreeBSD or Linux start scripts, depending on preference.
- On Solaris, create a file called `/etc/init.d/postgresql` that contains the following line:

  ```
  su - postgres -c "/usr/local/pgsql/bin/pg_ctl start -l logfile -D /usr/local/pgsql/data"
  ```

  Then, create a symbolic link to it in `/etc/rc3.d` as `S99postgresql`.

While the server is running, its PID is stored in the file `postmaster.pid` in the data directory. This is used to prevent multiple server instances from running in the same data directory and can also be used for shutting down the server.

18.3.1. Server Start-up Failures

There are several common reasons the server might fail to start. Check the server's log file, or start it by hand (without redirecting standard output or standard error) and see what error messages appear. Below we explain some of the most common error messages in more detail.

```
LOG:  could not bind IPv4 address "127.0.0.1": Address already in use
HINT:  Is another postmaster already running on port 5432? If not, wait a few seconds
 and retry.
FATAL:  could not create any TCP/IP sockets
```

This usually means just what it suggests: you tried to start another server on the same port where one is already running. However, if the kernel error message is not `Address already in use` or some variant of that, there might be a different problem. For example, trying to start a server on a reserved port number might draw something like:

```
$ postgres -p 666
LOG:  could not bind IPv4 address "127.0.0.1": Permission denied
HINT:  Is another postmaster already running on port 666? If not, wait a few seconds
 and retry.
FATAL:  could not create any TCP/IP sockets
```

A message like:

```
FATAL:  could not create shared memory segment: Invalid argument
DETAIL:  Failed system call was shmget(key=5440001, size=4011376640, 03600).
```

probably means your kernel's limit on the size of shared memory is smaller than the work area Postgres Pro is trying to create (4011376640 bytes in this example). This is only likely to happen if you have set `shared_memory_type` to `sysv`. In that case, you can try starting the server with a smaller-than-normal number of buffers (shared_buffers), or reconfigure your kernel to increase the allowed shared memory size. You might also see this message when trying to start multiple servers on the same machine, if their total space requested exceeds the kernel limit.

An error like:

```
FATAL:  could not create semaphores: No space left on device
DETAIL:  Failed system call was semget(5440126, 17, 03600).
```

does *not* mean you've run out of disk space. It means your kernel's limit on the number of System V semaphores is smaller than the number Postgres Pro wants to create. As above, you might be able to work around the problem by starting the server with a reduced number of allowed connections (max_connections), but you'll eventually want to increase the kernel limit.

Details about configuring System V IPC facilities are given in Section 18.4.1.

18.3.2. Client Connection Problems

Although the error conditions possible on the client side are quite varied and application-dependent, a few of them might be directly related to how the server was started. Conditions other than those shown below should be documented with the respective client application.

```
psql: error: connection to server at "server.joe.com" (123.123.123.123), port 5432
 failed: Connection refused
        Is the server running on that host and accepting TCP/IP connections?
```

This is the generic “I couldn't find a server to talk to” failure. It looks like the above when TCP/IP communication is attempted. A common mistake is to forget to configure the server to allow TCP/IP connections.

Alternatively, you might get this when attempting Unix-domain socket communication to a local server:

```
psql: error: connection to server on socket "/tmp/.s.PGSQL.5432" failed: No such file
 or directory
        Is the server running locally and accepting connections on that socket?
```

If the server is indeed running, check that the client's idea of the socket path (here `/tmp`) agrees with the server's unix_socket_directories setting.

A connection failure message always shows the server address or socket path name, which is useful in verifying that the client is trying to connect to the right place. If there is in fact no server listening there, the kernel error message will typically be either `Connection refused` or `No such file or directory`, as illustrated. (It is important to realize that `Connection refused` in this context does *not* mean that the server got your connection request and rejected it. That case will produce a different message, as shown in Section 20.15.) Other error messages such as `Connection timed out` might indicate more fundamental problems, like lack of network connectivity, or a firewall blocking the connection.

18.4. Managing Kernel Resources

Postgres Pro can sometimes exhaust various operating system resource limits, especially when multiple copies of the server are running on the same system, or in very large installations. This section explains the kernel resources used by Postgres Pro and the steps you can take to resolve problems related to kernel resource consumption.

18.4.1. Shared Memory and Semaphores

Postgres Pro requires the operating system to provide inter-process communication (IPC) features, specifically shared memory and semaphores. Unix-derived systems typically provide “System V” IPC, “POSIX” IPC, or both. Windows has its own implementation of these features and is not discussed here.

By default, Postgres Pro allocates a very small amount of System V shared memory, as well as a much larger amount of anonymous `mmap` shared memory. Alternatively, a single large System V shared memory region can be used (see shared_memory_type). In addition a significant number of semaphores, which can be either System V or POSIX style, are created at server startup. Currently, POSIX semaphores are used on Linux and FreeBSD systems while other platforms use System V semaphores.

System V IPC features are typically constrained by system-wide allocation limits. When Postgres Pro exceeds one of these limits, the server will refuse to start and should leave an instructive error message describing the problem and what to do about it. (See also Section 18.3.1.) The relevant kernel parameters are named consistently across different systems; Table 18.1 gives an overview. The methods to set them, however, vary. Suggestions for some platforms are given below.

Table 18.1. System V IPC Parameters

Name	Description	Values needed to run one Postgres Pro instance
SHMMAX	Maximum size of shared memory segment (bytes)	at least 1kB, but the default is usually much higher
SHMMIN	Minimum size of shared memory segment (bytes)	1
SHMALL	Total amount of shared memory available (bytes or pages)	same as SHMMAX if bytes, or ceil(SHMMAX/PAGE_SIZE) if pages, plus room for other applications
SHMSEG	Maximum number of shared memory segments per process	only 1 segment is needed, but the default is much higher
SHMMNI	Maximum number of shared memory segments system-wide	like SHMSEG plus room for other applications
SEMMNI	Maximum number of semaphore identifiers (i.e., sets)	at least ceil((max_connections + autovacuum_max_workers + max_wal_senders + max_worker_processes + 6) / 16) plus room for other applications
SEMMNS	Maximum number of semaphores system-wide	ceil((max_connections + autovacuum_max_workers + max_wal_senders + max_worker_processes + 6) / 16) * 17 plus room for other applications
SEMMSL	Maximum number of semaphores per set	at least 17
SEMMAP	Number of entries in semaphore map	see text
SEMVMX	Maximum value of semaphore	at least 1000 (The default is often 32767; do not change unless necessary)

Postgres Pro requires a few bytes of System V shared memory (typically 48 bytes, on 64-bit platforms) for each copy of the server. On most modern operating systems, this amount can easily be allocated. However, if you are running many copies of the server or you explicitly configure the server to use large amounts of System V shared memory (see shared_memory_type and dynamic_shared_memory_type), it may be necessary to increase SHMALL, which is the total amount of System V shared memory system-wide. Note that SHMALL is measured in pages rather than bytes on many systems.

Less likely to cause problems is the minimum size for shared memory segments (SHMMIN), which should be at most approximately 32 bytes for Postgres Pro (it is usually just 1). The maximum number of segments system-wide (SHMMNI) or per-process (SHMSEG) are unlikely to cause a problem unless your system has them set to zero.

When using System V semaphores, Postgres Pro uses one semaphore per allowed connection (max_connections), allowed autovacuum worker process (autovacuum_max_workers), allowed WAL sender process (max_wal_senders), and allowed background process (max_worker_processes), in sets of 16. Each such set will also contain a 17th semaphore which contains a “magic number”, to detect collision with semaphore sets used by other applications. The maximum number of semaphores in the system is set by SEMMNS, which consequently must be at least as high as max_connections plus autovacuum_max_workers plus max_wal_senders, plus max_worker_processes, plus one extra for each 16 allowed connections plus workers (see the formula in Table 18.1). The parameter SEMMNI determines the limit

on the number of semaphore sets that can exist on the system at one time. Hence this parameter must be at least `ceil((max_connections + autovacuum_max_workers + max_wal_senders + max_worker_processes + 6) / 16)`. Lowering the number of allowed connections is a temporary workaround for failures, which are usually confusingly worded "No space left on device", from the function `semget`.

In some cases it might also be necessary to increase `SEMMAP` to be at least on the order of `SEMMNS`. If the system has this parameter (many do not), it defines the size of the semaphore resource map, in which each contiguous block of available semaphores needs an entry. When a semaphore set is freed it is either added to an existing entry that is adjacent to the freed block or it is registered under a new map entry. If the map is full, the freed semaphores get lost (until reboot). Fragmentation of the semaphore space could over time lead to fewer available semaphores than there should be.

Various other settings related to "semaphore undo", such as `SEMMNU` and `SEMUME`, do not affect Postgres Pro.

When using POSIX semaphores, the number of semaphores needed is the same as for System V, that is one semaphore per allowed connection (max_connections), allowed autovacuum worker process (autovacuum_max_workers), allowed WAL sender process (max_wal_senders), and allowed background process (max_worker_processes). On the platforms where this option is preferred, there is no specific kernel limit on the number of POSIX semaphores.

AIX

It should not be necessary to do any special configuration for such parameters as `SHMMAX`, as it appears this is configured to allow all memory to be used as shared memory. That is the sort of configuration commonly used for other databases such as DB/2.

It might, however, be necessary to modify the global `ulimit` information in `/etc/security/limits`, as the default hard limits for file sizes (`fsize`) and numbers of files (`nofiles`) might be too low.

FreeBSD

The default shared memory settings are usually good enough, unless you have set `shared_memory_type` to `sysv`. System V semaphores are not used on this platform.

The default IPC settings can be changed using the `sysctl` or `loader` interfaces. The following parameters can be set using `sysctl`:

```
# sysctl kern.ipc.shmall=32768
# sysctl kern.ipc.shmmax=134217728
```

To make these settings persist over reboots, modify `/etc/sysctl.conf`.

If you have set `shared_memory_type` to `sysv`, you might also want to configure your kernel to lock System V shared memory into RAM and prevent it from being paged out to swap. This can be accomplished using the `sysctl` setting `kern.ipc.shm_use_phys`.

If running in a FreeBSD jail, you should set its `sysvshm` parameter to `new`, so that it has its own separate System V shared memory namespace. (Before FreeBSD 11.0, it was necessary to enable shared access to the host's IPC namespace from jails, and take measures to avoid collisions.)

NetBSD

The default shared memory settings are usually good enough, unless you have set `shared_memory_type` to `sysv`. You will usually want to increase `kern.ipc.semmni` and `kern.ipc.semmns`, as NetBSD's default settings for these are uncomfortably small.

IPC parameters can be adjusted using `sysctl`, for example:

```
# sysctl -w kern.ipc.semmni=100
```

To make these settings persist over reboots, modify `/etc/sysctl.conf`.

If you have set `shared_memory_type` to `sysv`, you might also want to configure your kernel to lock System V shared memory into RAM and prevent it from being paged out to swap. This can be accomplished using the `sysctl` setting `kern.ipc.shm_use_phys`.

OpenBSD

The default shared memory settings are usually good enough, unless you have set `shared_memory_type` to `sysv`. You will usually want to increase `kern.seminfo.semmni` and `kern.seminfo.semmns`, as OpenBSD's default settings for these are uncomfortably small.

IPC parameters can be adjusted using `sysctl`, for example:

```
# sysctl kern.seminfo.semmni=100
```

To make these settings persist over reboots, modify `/etc/sysctl.conf`.

HP-UX

The default settings tend to suffice for normal installations.

IPC parameters can be set in the System Administration Manager (SAM) under Kernel Configuration → Configurable Parameters. Choose Create A New Kernel when you're done.

Linux

The default shared memory settings are usually good enough, unless you have set `shared_memory_type` to `sysv`, and even then only on older kernel versions that shipped with low defaults. System V semaphores are not used on this platform.

The shared memory size settings can be changed via the `sysctl` interface. For example, to allow 16 GB:

```
$ sysctl -w kernel.shmmax=17179869184
$ sysctl -w kernel.shmall=4194304
```

To make these settings persist over reboots, see `/etc/sysctl.conf`.

macOS

The default shared memory and semaphore settings are usually good enough, unless you have set `shared_memory_type` to `sysv`.

The recommended method for configuring shared memory in macOS is to create a file named `/etc/sysctl.conf`, containing variable assignments such as:

```
kern.sysv.shmmax=4194304
kern.sysv.shmmin=1
kern.sysv.shmmni=32
kern.sysv.shmseg=8
kern.sysv.shmall=1024
```

Note that in some macOS versions, *all five* shared-memory parameters must be set in `/etc/sysctl.conf`, else the values will be ignored.

`SHMMAX` can only be set to a multiple of 4096.

`SHMALL` is measured in 4 kB pages on this platform.

It is possible to change all but `SHMMNI` on the fly, using sysctl. But it's still best to set up your preferred values via `/etc/sysctl.conf`, so that the values will be kept across reboots.

Solaris
illumos

The default shared memory and semaphore settings are usually good enough for most Postgres Pro applications. Solaris defaults to a `SHMMAX` of one-quarter of system RAM. To further adjust this setting, use a project setting associated with the `postgres` user. For example, run the following as `root`:

```
projadd -c "Postgres Pro DB User" -K "project.max-shm-memory=(privileged,8GB,deny)"
 -U postgres -G postgres user.postgres
```

This command adds the `user.postgres` project and sets the shared memory maximum for the `postgres` user to 8GB, and takes effect the next time that user logs in, or when you restart Postgres Pro (not reload). The above assumes that Postgres Pro is run by the `postgres` user in the `postgres` group. No server reboot is required.

Other recommended kernel setting changes for database servers which will have a large number of connections are:

```
project.max-shm-ids=(priv,32768,deny)
project.max-sem-ids=(priv,4096,deny)
project.max-msg-ids=(priv,4096,deny)
```

Additionally, if you are running Postgres Pro inside a zone, you may need to raise the zone resource usage limits as well. See "Chapter2: Projects and Tasks" in the *System Administrator's Guide* for more information on `projects` and `prctl`.

18.4.2. systemd RemoveIPC

If systemd is in use, some care must be taken that IPC resources (including shared memory) are not prematurely removed by the operating system. This is especially of concern when installing Postgres Pro from source. Users of distribution packages of Postgres Pro are less likely to be affected, as the `postgres` user is then normally created as a system user.

The setting `RemoveIPC` in `logind.conf` controls whether IPC objects are removed when a user fully logs out. System users are exempt. This setting defaults to on in stock systemd, but some operating system distributions default it to off.

A typical observed effect when this setting is on is that shared memory objects used for parallel query execution are removed at apparently random times, leading to errors and warnings while attempting to open and remove them, like

```
WARNING:  could not remove shared memory segment "/PostgreSQL.1450751626": No such file
 or directory
```

Different types of IPC objects (shared memory vs. semaphores, System V vs. POSIX) are treated slightly differently by systemd, so one might observe that some IPC resources are not removed in the same way as others. But it is not advisable to rely on these subtle differences.

A “user logging out” might happen as part of a maintenance job or manually when an administrator logs in as the `postgres` user or something similar, so it is hard to prevent in general.

What is a “system user” is determined at systemd compile time from the `SYS_UID_MAX` setting in `/etc/login.defs`.

Packaging and deployment scripts should be careful to create the `postgres` user as a system user by using `useradd -r`, `adduser --system`, or equivalent.

Alternatively, if the user account was created incorrectly or cannot be changed, it is recommended to set

```
RemoveIPC=no
```

in `/etc/systemd/logind.conf` or another appropriate configuration file.

> **Caution**
>
> At least one of these two things has to be ensured, or the Postgres Pro server will be very unreliable.

18.4.3. Resource Limits

Unix-like operating systems enforce various kinds of resource limits that might interfere with the operation of your Postgres Pro server. Of particular importance are limits on the number of processes per user, the number of open files per process, and the amount of memory available to each process. Each of these have a “hard” and a “soft” limit. The soft limit is what actually counts but it can be changed by the user up to the hard limit. The hard limit can only be changed by the root user. The system call `setrlimit` is responsible for setting these parameters. The shell's built-in command `ulimit` (Bourne shells) or `limit` (csh) is used to control the resource limits from the command line. On BSD-derived systems the file `/etc/login.conf` controls the various resource limits set during login. See the operating system documentation for details. The relevant parameters are `maxproc`, `openfiles`, and `datasize`. For example:

```
default:\
...
        :datasize-cur=256M:\
        :maxproc-cur=256:\
        :openfiles-cur=256:\
...
```

(`-cur` is the soft limit. Append `-max` to set the hard limit.)

Kernels can also have system-wide limits on some resources.

- On Linux the kernel parameter `fs.file-max` determines the maximum number of open files that the kernel will support. It can be changed with `sysctl -w fs.file-max=`*N*. To make the setting persist across reboots, add an assignment in `/etc/sysctl.conf`. The maximum limit of files per process is fixed at the time the kernel is compiled; see `/usr/src/linux/Documentation/proc.txt` for more information.

The Postgres Pro server uses one process per connection so you should provide for at least as many processes as allowed connections, in addition to what you need for the rest of your system. This is usually not a problem but if you run several servers on one machine things might get tight.

The factory default limit on open files is often set to “socially friendly” values that allow many users to coexist on a machine without using an inappropriate fraction of the system resources. If you run many servers on a machine this is perhaps what you want, but on dedicated servers you might want to raise this limit.

On the other side of the coin, some systems allow individual processes to open large numbers of files; if more than a few processes do so then the system-wide limit can easily be exceeded. If you find this happening, and you do not want to alter the system-wide limit, you can set Postgres Pro's max_files_per_process configuration parameter to limit the consumption of open files.

Another kernel limit that may be of concern when supporting large numbers of client connections is the maximum socket connection queue length. If more than that many connection requests arrive within a very short period, some may get rejected before the postmaster can service the requests, with those clients receiving unhelpful connection failure errors such as “Resource temporarily unavailable” or “Connection refused”. The default queue length limit is 128 on many platforms. To raise it, adjust the appropriate kernel parameter via sysctl, then restart the postmaster. The parameter is variously named `net.core.somaxconn` on Linux, `kern.ipc.soacceptqueue` on newer FreeBSD, and `kern.ipc.somaxconn` on macOS and other BSD variants.

18.4.4. Linux Memory Overcommit

The default virtual memory behavior on Linux is not optimal for Postgres Pro. Because of the way that the kernel implements memory overcommit, the kernel might terminate the Postgres Pro postmaster (the supervisor server process) if the memory demands of either Postgres Pro or another process cause the system to run out of virtual memory.

If this happens, you will see a kernel message that looks like this (consult your system documentation and configuration on where to look for such a message):

```
Out of Memory: Killed process 12345 (postgres).
```

This indicates that the `postgres` process has been terminated due to memory pressure. Although existing database connections will continue to function normally, no new connections will be accepted. To recover, Postgres Pro will need to be restarted.

One way to avoid this problem is to run Postgres Pro on a machine where you can be sure that other processes will not run the machine out of memory. If memory is tight, increasing the swap space of the operating system can help avoid the problem, because the out-of-memory (OOM) killer is invoked only when physical memory and swap space are exhausted.

If Postgres Pro itself is the cause of the system running out of memory, you can avoid the problem by changing your configuration. In some cases, it may help to lower memory-related configuration parameters, particularly `shared_buffers`, `work_mem`, and `hash_mem_multiplier`. In other cases, the problem may be caused by allowing too many connections to the database server itself. In many cases, it may be better to reduce `max_connections` and instead make use of external connection-pooling software.

It is possible to modify the kernel's behavior so that it will not “overcommit” memory. Although this setting will not prevent the *OOM killer* from being invoked altogether, it will lower the chances significantly and will therefore lead to more robust system behavior. This is done by selecting strict overcommit mode via `sysctl`:

```
sysctl -w vm.overcommit_memory=2
```

or placing an equivalent entry in `/etc/sysctl.conf`. You might also wish to modify the related setting `vm.overcommit_ratio`. For details see the kernel documentation file *https://www.kernel.org/doc/Documentation/vm/overcommit-accounting*.

Another approach, which can be used with or without altering `vm.overcommit_memory`, is to set the process-specific *OOM score adjustment* value for the postmaster process to `-1000`, thereby guaranteeing it will not be targeted by the OOM killer. The simplest way to do this is to execute

```
echo -1000 > /proc/self/oom_score_adj
```

in the postmaster's startup script just before invoking the postmaster. Note that this action must be done as root, or it will have no effect; so a root-owned startup script is the easiest place to do it. If you do this, you should also set these environment variables in the startup script before invoking the postmaster:

```
export PG_OOM_ADJUST_FILE=/proc/self/oom_score_adj
export PG_OOM_ADJUST_VALUE=0
```

These settings will cause postmaster child processes to run with the normal OOM score adjustment of zero, so that the OOM killer can still target them at need. You could use some other value for `PG_OOM_ADJUST_VALUE` if you want the child processes to run with some other OOM score adjustment. (`PG_OOM_ADJUST_VALUE` can also be omitted, in which case it defaults to zero.) If you do not set `PG_OOM_ADJUST_FILE`, the child processes will run with the same OOM score adjustment as the postmaster, which is unwise since the whole point is to ensure that the postmaster has a preferential setting.

18.4.5. Linux Huge Pages

Using huge pages reduces overhead when using large contiguous chunks of memory, as Postgres Pro does, particularly when using large values of shared_buffers. To use this feature in Postgres Pro you need a kernel with `CONFIG_HUGETLBFS=y` and `CONFIG_HUGETLB_PAGE=y`. You will also have to configure the operating system to provide enough huge pages of the desired size. To estimate the number of huge pages needed, start Postgres Pro without huge pages enabled and check the postmaster's anonymous shared memory segment size, as well as the system's default and supported huge page sizes, using the `/proc` and `/sys` file systems. This might look like:

```
$ head -1 $PGDATA/postmaster.pid
4170
$ pmap 4170 | awk '/rw-s/ && /zero/ {print $2}'
6490428K
$ grep ^Hugepagesize /proc/meminfo
```

```
Hugepagesize:       2048 kB
$ ls /sys/kernel/mm/hugepages
hugepages-1048576kB  hugepages-2048kB
```

In this example the default is 2MB, but you can also explicitly request either 2MB or 1GB with huge_page_size. Assuming `2MB` huge pages, `6490428` / `2048` gives approximately `3169.154`, so in this example we need at least `3170` huge pages. A larger setting would be appropriate if other programs on the machine also need huge pages. We can set this with:

```
# sysctl -w vm.nr_hugepages=3170
```

Don't forget to add this setting to `/etc/sysctl.conf` so that it is reapplied after reboots. For non-default huge page sizes, we can instead use:

```
# echo 3170 > /sys/kernel/mm/hugepages/hugepages-2048kB/nr_hugepages
```

It is also possible to provide these settings at boot time using kernel parameters such as `hugepagesz=2M hugepages=3170`.

Sometimes the kernel is not able to allocate the desired number of huge pages immediately due to fragmentation, so it might be necessary to repeat the command or to reboot. (Immediately after a reboot, most of the machine's memory should be available to convert into huge pages.) To verify the huge page allocation situation for a given size, use:

```
$ cat /sys/kernel/mm/hugepages/hugepages-2048kB/nr_hugepages
```

It may also be necessary to give the database server's operating system user permission to use huge pages by setting `vm.hugetlb_shm_group` via sysctl, and/or give permission to lock memory with `ulimit -l`.

The default behavior for huge pages in Postgres Pro is to use them when possible, with the system's default huge page size, and to fall back to normal pages on failure. To enforce the use of huge pages, you can set huge_pages to `on` in `postgresql.conf`. Note that with this setting Postgres Pro will fail to start if not enough huge pages are available.

For a detailed description of the Linux huge pages feature have a look at *https://www.kernel.org/doc/Documentation/vm/hugetlbpage.txt*.

18.4.6. Resource Prioritization

Postgres Pro Enterprise provides an experimental feature for resource prioritization.

On systems with limited resources or under heavy load, you may need to prioritize transaction execution, so that some transactions are executed more quickly than the other. For example, you may want to execute simple user queries as fast as possible, even if it delays less urgent tasks, such as complex OLAP queries that may be running at the same time. Postgres Pro Enterprise enables you to configure resource prioritization policy, which can slow down a particular session based on the amount of CPU, I/O read, and I/O write resources this session consumes as compared to other sessions.

By default, resource prioritization is disabled, so all backends have equal access to all the available resources. You can assign weight to each backend to control the amount of resources each session can use within the specified time interval. Depending on the current resource consumption, Postgres Pro Enterprise may suspend backends with lower weight from time to time to ensure that high-priority sessions have more resources available.

To enable prioritization in your database cluster:

1. Configure the time interval for collecting usage statistics for all active backends by setting the usage_tracking_interval parameter in the `postgresql.conf` file and reload the server configuration.

   Once the usage_tracking_interval parameter is set, Postgres Pro Enterprise starts collecting statistics on resource usage at the specified interval.

> **Tip**
>
> Avoid setting usage_tracking_interval to small values as frequent statistics collection can cause overhead.

2. Depending on the resources you need to control, modify one or more of the following parameters for the sessions you would like to prioritize:
   - session_cpu_weight — CPU usage.
   - session_ioread_weight — I/O read throughput.
   - session_iowrite_weight — I/O write throughput.

   These parameters can take weight values `1`, `2`, `4`, and `8`. The higher the value, the more resources the session can use. Sessions with the same weight have the same priority for resource usage, so if you assign equal weights to all sessions, performance is not affected, regardless of the weight value. By default, all sessions have weight `4` for all types of resources.

   For all possible ways of modifying configuration for a particular session, see Section 19.1.

Once you change the weight of one or more sessions, Postgres Pro Enterprise enables prioritization policy based on the assigned weight values and the usage statistics measured for the previous usage_tracking_interval. Thus, session activity is adjusted for each usage tracking interval, if required.

> **Note**
>
> Even though weights for each resource are assigned separately, prioritizing a session by one resource can indirectly affect the session performance with regard to other resources.

18.5. Shutting Down the Server

There are several ways to shut down the database server. Under the hood, they all reduce to sending a signal to the supervisor `postgres` process.

If you are using a pre-packaged version of PostgreSQL, and you used its provisions for starting the server, then you should also use its provisions for stopping the server. Consult the package-level documentation for details.

When managing the server directly, you can control the type of shutdown by sending different signals to the `postgres` process:

SIGTERM

This is the *Smart Shutdown* mode. After receiving SIGTERM, the server disallows new connections, but lets existing sessions end their work normally. It shuts down only after all of the sessions terminate. If the server is in online backup mode, it additionally waits until online backup mode is no longer active. While backup mode is active, new connections will still be allowed, but only to superusers (this exception allows a superuser to connect to terminate online backup mode). If the server is in recovery when a smart shutdown is requested, recovery and streaming replication will be stopped only after all regular sessions have terminated.

SIGINT

This is the *Fast Shutdown* mode. The server disallows new connections and sends all existing server processes SIGTERM, which will cause them to abort their current transactions and exit promptly. It then waits for all server processes to exit and finally shuts down. If the server is in online backup mode, backup mode will be terminated, rendering the backup useless.

SIGQUIT

This is the *Immediate Shutdown* mode. The server will send SIGQUIT to all child processes and wait for them to terminate. If any do not terminate within 5 seconds, they will be sent SIGKILL. The supervisor server process exits as soon as all child processes have exited, without doing normal database shutdown processing. This will lead to recovery (by replaying the WAL log) upon next start-up. This is recommended only in emergencies.

The pg_ctl program provides a convenient interface for sending these signals to shut down the server. Alternatively, you can send the signal directly using `kill` on non-Windows systems. The PID of the `postgres` process can be found using the `ps` program, or from the file `postmaster.pid` in the data directory. For example, to do a fast shutdown:

```
$ kill -INT `head -1 /usr/local/pgsql/data/postmaster.pid`
```

Important

It is best not to use SIGKILL to shut down the server. Doing so will prevent the server from releasing shared memory and semaphores. Furthermore, SIGKILL kills the `postgres` process without letting it relay the signal to its subprocesses, so it might be necessary to kill the individual subprocesses by hand as well.

To terminate an individual session while allowing other sessions to continue, use `pg_terminate_backend()` (see Table 9.86) or send a SIGTERM signal to the child process associated with the session.

18.6. Upgrading a Postgres Pro Cluster

This section discusses how to upgrade your database data from one Postgres Pro release to a newer one.

Current Postgres Pro version numbers consist of three digit groups: two of them are based on the PostgreSQL version, and the third one is the Postgres Pro release number. For example, in the version number 12.11.2, the 12 is the major version number, the 11 is the minor version number, and the 2 is the Postgres Pro release number, meaning this would be the second release after the PostgreSQL release 12.11. For releases before Postgres Pro version 10.0, version numbers consist of four groups, for example, 9.5.3.2. In those cases, the Postgres Pro version consists of the three digit groups of the PostgreSQL version number, e.g., 9.5.3, and the fourth number is the Postgres Pro release number, e.g., 2, meaning this would be the second Postgres Pro release after the PostgreSQL release 9.5.3.

Postgres Pro releases of the same minor version are usually compatible with earlier and later releases. If you are upgrading from Postgres Pro of the same minor version, for example, from 12.11.1 to 12.11.2, it is usually enough to install the new version into your current installation directory. If you are upgrading from Postgres Pro based on another PostgreSQL minor version, for example, from 12.11.1 to 12.15.1, *you should always pay attention to the section labeled "Migration"* in the release notes (Appendix E). Though you can upgrade from one release version to another without upgrading to intervening versions, you should read the release notes of all intervening versions too.

For *major* releases of Postgres Pro, the internal data storage format is subject to change, thus complicating upgrades. The traditional method for moving data to a new major version is to dump and restore the database, though this can be slow. A faster method is pg_upgrade. Replication methods are also available, as discussed below.

New major versions also typically introduce some user-visible incompatibilities, so application programming changes might be required. All user-visible changes are listed in the release notes (Appendix E), including all the necessary instructions for migration in the corresponding section.

Cautious users will want to test their client applications on the new version before switching over fully; therefore, it's often a good idea to set up concurrent installations of old and new versions. When testing a Postgres Pro major upgrade, consider the following categories of possible changes:

Administration

The capabilities available for administrators to monitor and control the server often change and improve in each major release.

SQL

Typically this includes new SQL command capabilities and not changes in behavior, unless specifically mentioned in the release notes.

Library API

Typically libraries like libpq only add new functionality, again unless mentioned in the release notes.

System Catalogs

System catalog changes usually only affect database management tools.

Server C-language API

This involves changes in the backend function API, which is written in the C programming language. Such changes affect code that references backend functions deep inside the server.

18.6.1. Upgrading Data via pg_dumpall

One upgrade method is to dump data from one major version of Postgres Pro and restore it in another — to do this, you must use a *logical* backup tool like pg_dumpall; file system level backup methods will not work. (There are checks in place that prevent you from using a data directory with an incompatible version of Postgres Pro, so no great harm can be done by trying to start the wrong server version on a data directory.)

It is recommended that you use the pg_dump and pg_dumpall programs from the *newer* version of Postgres Pro, to take advantage of enhancements that might have been made in these programs. Current releases of the dump programs can read data from any server version back to 8.0.

These instructions assume that your existing installation is under the `/usr/local/pgsql` directory, and that the data area is in `/usr/local/pgsql/data`. Substitute your paths appropriately.

1. If making a backup, make sure that your database is not being updated. This does not affect the integrity of the backup, but the changed data would of course not be included. If necessary, edit the permissions in the file `/usr/local/pgsql/data/pg_hba.conf` (or equivalent) to disallow access from everyone except you. See Chapter 20 for additional information on access control.

   To back up your database installation, type:

   ```
   pg_dumpall > outputfile
   ```

   To make the backup, you can use the pg_dumpall command from the version you are currently running; see Section 25.1.2 for more details. For best results, however, try to use the pg_dumpall command from Postgres Pro Enterprise 14.18.1, since this version contains bug fixes and improvements over older versions. While this advice might seem idiosyncratic since you haven't installed the new version yet, it is advisable to follow it if you plan to install the new version in parallel with the old version. In that case you can complete the installation normally and transfer the data later. This will also decrease the downtime.

2. Shut down the old server:

   ```
   pg_ctl stop
   ```

   On systems that have Postgres Pro started at boot time, there is probably a start-up file that will accomplish the same thing. For example, on a Red Hat Linux system one might find that this works:

   ```
   /etc/rc.d/init.d/postgresql stop
   ```

   See Chapter 18 for details about starting and stopping the server.

3. If restoring from backup, rename or delete the old installation directory if it is not version-specific. It is a good idea to rename the directory, rather than delete it, in case you have trouble and need to revert to it. Keep in mind the directory might consume significant disk space. To rename the directory, use a command like this:

   mv /usr/local/pgsql /usr/local/pgsql.old

   (Be sure to move the directory as a single unit so relative paths remain unchanged.)
4. Install the new version of Postgres Pro Enterprise.
5. Create a new database cluster if needed. Remember that you must execute these commands while logged in to the special database user account (which you already have if you are upgrading).

   /usr/local/pgsql/bin/initdb -D /usr/local/pgsql/data
6. Restore your previous `pg_hba.conf` and any `postgresql.conf` modifications.
7. Start the database server, again using the special database user account:

   /usr/local/pgsql/bin/postgres -D /usr/local/pgsql/data
8. Finally, restore your data from backup with:

   /usr/local/pgsql/bin/psql -d postgres -f *outputfile*

   using the *new* psql.

The least downtime can be achieved by installing the new server in a different directory and running both the old and the new servers in parallel, on different ports. Then you can use something like:

```
pg_dumpall -p 5432 | psql -d postgres -p 5433
```

to transfer your data.

18.6.2. Upgrading Data via pg_upgrade

The pg_upgrade module allows an installation to be migrated in-place from one major Postgres Pro version to another. Upgrades can be performed in minutes, particularly with `--link` mode. It requires steps similar to pg_dumpall above, e.g., starting/stopping the server, running initdb. The pg_upgrade documentation outlines the necessary steps.

18.6.3. Upgrading Data via Replication

It is also possible to use logical replication methods to create a standby server with the updated version of Postgres Pro. This is possible because logical replication supports replication between different major versions of Postgres Pro. The standby can be on the same computer or a different computer. Once it has synced up with the primary server (running the older version of Postgres Pro), you can switch primaries and make the standby the primary and shut down the older database instance. Such a switch-over results in only several seconds of downtime for an upgrade.

This method of upgrading can be performed using the built-in logical replication facilities as well as using external logical replication systems such as pglogical, Slony, Londiste, and Bucardo.

18.7. Preventing Server Spoofing

While the server is running, it is not possible for a malicious user to take the place of the normal database server. However, when the server is down, it is possible for a local user to spoof the normal server by starting their own server. The spoof server could read passwords and queries sent by clients, but could not return any data because the `PGDATA` directory would still be secure because of directory permissions. Spoofing is possible because any user can start a database server; a client cannot identify an invalid server unless it is specially configured.

One way to prevent spoofing of `local` connections is to use a Unix domain socket directory (unix_socket_directories) that has write permission only for a trusted local user. This prevents a malicious user from creating their own socket file in that directory. If you are concerned that some applications might still reference `/tmp` for the socket file and hence be vulnerable to spoofing, during operating system startup

create a symbolic link `/tmp/.s.PGSQL.5432` that points to the relocated socket file. You also might need to modify your `/tmp` cleanup script to prevent removal of the symbolic link.

Another option for `local` connections is for clients to use `requirepeer` to specify the required owner of the server process connected to the socket.

To prevent spoofing on TCP connections, either use SSL certificates and make sure that clients check the server's certificate, or use GSSAPI encryption (or both, if they're on separate connections).

To prevent spoofing with SSL, the server must be configured to accept only `hostssl` connections (Section 20.1) and have SSL key and certificate files (Section 18.9). The TCP client must connect using `sslmode=verify-ca` or `verify-full` and have the appropriate root certificate file installed (Section 36.19.1).

To prevent spoofing with GSSAPI, the server must be configured to accept only `hostgssenc` connections (Section 20.1) and use `gss` authentication with them. The TCP client must connect using `gssencmode=require`.

18.8. Encryption Options

Postgres Pro offers encryption at several levels, and provides flexibility in protecting data from disclosure due to database server theft, unscrupulous administrators, and insecure networks. Encryption might also be required to secure sensitive data such as medical records or financial transactions.

Password Encryption

Database user passwords are stored as hashes (determined by the setting password_encryption), so the administrator cannot determine the actual password assigned to the user. If SCRAM or MD5 encryption is used for client authentication, the unencrypted password is never even temporarily present on the server because the client encrypts it before being sent across the network. SCRAM is preferred, because it is an Internet standard and is more secure than the PostgreSQL-specific MD5 authentication protocol.

Encryption For Specific Columns

The pgcrypto module allows certain fields to be stored encrypted. This is useful if only some of the data is sensitive. The client supplies the decryption key and the data is decrypted on the server and then sent to the client.

The decrypted data and the decryption key are present on the server for a brief time while it is being decrypted and communicated between the client and server. This presents a brief moment where the data and keys can be intercepted by someone with complete access to the database server, such as the system administrator.

Data Partition Encryption

Storage encryption can be performed at the file system level or the block level. Linux file system encryption options include eCryptfs and EncFS, while FreeBSD uses PEFS. Block level or full disk encryption options include dm-crypt + LUKS on Linux and GEOM modules geli and gbde on FreeBSD. Many other operating systems support this functionality, including Windows.

This mechanism prevents unencrypted data from being read from the drives if the drives or the entire computer is stolen. This does not protect against attacks while the file system is mounted, because when mounted, the operating system provides an unencrypted view of the data. However, to mount the file system, you need some way for the encryption key to be passed to the operating system, and sometimes the key is stored somewhere on the host that mounts the disk.

Encrypting Data Across A Network

SSL connections encrypt all data sent across the network: the password, the queries, and the data returned. The `pg_hba.conf` file allows administrators to specify which hosts can use non-encrypted connections (`host`) and which require SSL-encrypted connections (`hostssl`). Also, clients can specify that they connect to servers only via SSL.

GSSAPI-encrypted connections encrypt all data sent across the network, including queries and data returned. (No password is sent across the network.) The `pg_hba.conf` file allows administrators to specify which hosts can use non-encrypted connections (`host`) and which require GSSAPI-encrypted connections (`hostgssenc`). Also, clients can specify that they connect to servers only on GSSAPI-encrypted connections (`gssencmode=require`).

Stunnel or SSH can also be used to encrypt transmissions.

SSL Host Authentication

It is possible for both the client and server to provide SSL certificates to each other. It takes some extra configuration on each side, but this provides stronger verification of identity than the mere use of passwords. It prevents a computer from pretending to be the server just long enough to read the password sent by the client. It also helps prevent “man in the middle” attacks where a computer between the client and server pretends to be the server and reads and passes all data between the client and server.

Client-Side Encryption

If the system administrator for the server's machine cannot be trusted, it is necessary for the client to encrypt the data; this way, unencrypted data never appears on the database server. Data is encrypted on the client before being sent to the server, and database results have to be decrypted on the client before being used.

18.9. Secure TCP/IP Connections with SSL

Postgres Pro has native support for using SSL connections to encrypt client/server communications for increased security.

18.9.1. Basic Setup

With SSL support compiled in, the Postgres Pro server can be started with SSL enabled by setting the parameter ssl to `on` in `postgresql.conf`. The server will listen for both normal and SSL connections on the same TCP port, and will negotiate with any connecting client on whether to use SSL. By default, this is at the client's option; see Section 20.1 about how to set up the server to require use of SSL for some or all connections.

To start in SSL mode, files containing the server certificate and private key must exist. By default, these files are expected to be named `server.crt` and `server.key`, respectively, in the server's data directory, but other names and locations can be specified using the configuration parameters ssl_cert_file and ssl_key_file.

On Unix systems, the permissions on `server.key` must disallow any access to world or group; achieve this by the command `chmod 0600 server.key`. Alternatively, the file can be owned by root and have group read access (that is, `0640` permissions). That setup is intended for installations where certificate and key files are managed by the operating system. The user under which the Postgres Pro server runs should then be made a member of the group that has access to those certificate and key files.

If the data directory allows group read access then certificate files may need to be located outside of the data directory in order to conform to the security requirements outlined above. Generally, group access is enabled to allow an unprivileged user to backup the database, and in that case the backup software will not be able to read the certificate files and will likely error.

If the private key is protected with a passphrase, the server will prompt for the passphrase and will not start until it has been entered. Using a passphrase by default disables the ability to change the server's SSL configuration without a server restart, but see ssl_passphrase_command_supports_reload. Furthermore, passphrase-protected private keys cannot be used at all on Windows.

The first certificate in `server.crt` must be the server's certificate because it must match the server's private key. The certificates of “intermediate” certificate authorities can also be appended to the file. Doing this avoids the necessity of storing intermediate certificates on clients, assuming the root and

intermediate certificates were created with v3_ca extensions. (This sets the certificate's basic constraint of CA to true.) This allows easier expiration of intermediate certificates.

It is not necessary to add the root certificate to server.crt. Instead, clients must have the root certificate of the server's certificate chain.

18.9.2. OpenSSL Configuration

Postgres Pro reads the system-wide OpenSSL configuration file. By default, this file is named openssl.cnf and is located in the directory reported by openssl version -d. This default can be overridden by setting environment variable OPENSSL_CONF to the name of the desired configuration file.

OpenSSL supports a wide range of ciphers and authentication algorithms, of varying strength. While a list of ciphers can be specified in the OpenSSL configuration file, you can specify ciphers specifically for use by the database server by modifying ssl_ciphers in postgresql.conf.

> **Note**
>
> It is possible to have authentication without encryption overhead by using NULL-SHA or NULL-MD5 ciphers. However, a man-in-the-middle could read and pass communications between client and server. Also, encryption overhead is minimal compared to the overhead of authentication. For these reasons NULL ciphers are not recommended.

18.9.3. Using Client Certificates

To require the client to supply a trusted certificate, place certificates of the root certificate authorities (CAs) you trust in a file in the data directory, set the parameter ssl_ca_file in postgresql.conf to the new file name, and add the authentication option clientcert=verify-ca or clientcert=verify-full to the appropriate hostssl line(s) in pg_hba.conf. A certificate will then be requested from the client during SSL connection startup. (See Section 36.19 for a description of how to set up certificates on the client.)

For a hostssl entry with clientcert=verify-ca, the server will verify that the client's certificate is signed by one of the trusted certificate authorities. If clientcert=verify-full is specified, the server will not only verify the certificate chain, but it will also check whether the username or its mapping matches the cn (Common Name) of the provided certificate. Note that certificate chain validation is always ensured when the cert authentication method is used (see Section 20.12).

Intermediate certificates that chain up to existing root certificates can also appear in the ssl_ca_file file if you wish to avoid storing them on clients (assuming the root and intermediate certificates were created with v3_ca extensions). Certificate Revocation List (CRL) entries are also checked if the parameter ssl_crl_file or ssl_crl_dir is set.

The clientcert authentication option is available for all authentication methods, but only in pg_hba.conf lines specified as hostssl. When clientcert is not specified, the server verifies the client certificate against its CA file only if a client certificate is presented and the CA is configured.

There are two approaches to enforce that users provide a certificate during login.

The first approach makes use of the cert authentication method for hostssl entries in pg_hba.conf, such that the certificate itself is used for authentication while also providing ssl connection security. See Section 20.12 for details. (It is not necessary to specify any clientcert options explicitly when using the cert authentication method.) In this case, the cn (Common Name) provided in the certificate is checked against the user name or an applicable mapping.

The second approach combines any authentication method for hostssl entries with the verification of client certificates by setting the clientcert authentication option to verify-ca or verify-full. The former option only enforces that the certificate is valid, while the latter also ensures that the cn (Common Name) in the certificate matches the user name or an applicable mapping.

18.9.4. SSL Server File Usage

Table 18.2 summarizes the files that are relevant to the SSL setup on the server. (The shown file names are default names. The locally configured names could be different.)

Table 18.2. SSL Server File Usage

File	Contents	Effect
ssl_cert_file (`$PGDATA/server.crt`)	server certificate	sent to client to indicate server's identity
ssl_key_file (`$PGDATA/server.key`)	server private key	proves server certificate was sent by the owner; does not indicate certificate owner is trustworthy
ssl_ca_file	trusted certificate authorities	checks that client certificate is signed by a trusted certificate authority
ssl_crl_file	certificates revoked by certificate authorities	client certificate must not be on this list

The server reads these files at server start and whenever the server configuration is reloaded. On Windows systems, they are also re-read whenever a new backend process is spawned for a new client connection.

If an error in these files is detected at server start, the server will refuse to start. But if an error is detected during a configuration reload, the files are ignored and the old SSL configuration continues to be used. On Windows systems, if an error in these files is detected at backend start, that backend will be unable to establish an SSL connection. In all these cases, the error condition is reported in the server log.

18.9.5. Creating Certificates

To create a simple self-signed certificate for the server, valid for 365 days, use the following OpenSSL command, replacing *dbhost.yourdomain.com* with the server's host name:

```
openssl req -new -x509 -days 365 -nodes -text -out server.crt \
  -keyout server.key -subj "/CN=dbhost.yourdomain.com"
```

Then do:

```
chmod og-rwx server.key
```

because the server will reject the file if its permissions are more liberal than this. For more details on how to create your server private key and certificate, refer to the OpenSSL documentation.

While a self-signed certificate can be used for testing, a certificate signed by a certificate authority (CA) (usually an enterprise-wide root CA) should be used in production.

To create a server certificate whose identity can be validated by clients, first create a certificate signing request (CSR) and a public/private key file:

```
openssl req -new -nodes -text -out root.csr \
  -keyout root.key -subj "/CN=root.yourdomain.com"
chmod og-rwx root.key
```

Then, sign the request with the key to create a root certificate authority (using the default OpenSSL configuration file location on Linux):

```
openssl x509 -req -in root.csr -text -days 3650 \
  -extfile /etc/ssl/openssl.cnf -extensions v3_ca \
  -signkey root.key -out root.crt
```

Finally, create a server certificate signed by the new root certificate authority:

```
openssl req -new -nodes -text -out server.csr \
  -keyout server.key -subj "/CN=dbhost.yourdomain.com"
chmod og-rwx server.key

openssl x509 -req -in server.csr -text -days 365 \
  -CA root.crt -CAkey root.key -CAcreateserial \
  -out server.crt
```

`server.crt` and `server.key` should be stored on the server, and `root.crt` should be stored on the client so the client can verify that the server's leaf certificate was signed by its trusted root certificate. `root.key` should be stored offline for use in creating future certificates.

It is also possible to create a chain of trust that includes intermediate certificates:

```
# root
openssl req -new -nodes -text -out root.csr \
  -keyout root.key -subj "/CN=root.yourdomain.com"
chmod og-rwx root.key
openssl x509 -req -in root.csr -text -days 3650 \
  -extfile /etc/ssl/openssl.cnf -extensions v3_ca \
  -signkey root.key -out root.crt

# intermediate
openssl req -new -nodes -text -out intermediate.csr \
  -keyout intermediate.key -subj "/CN=intermediate.yourdomain.com"
chmod og-rwx intermediate.key
openssl x509 -req -in intermediate.csr -text -days 1825 \
  -extfile /etc/ssl/openssl.cnf -extensions v3_ca \
  -CA root.crt -CAkey root.key -CAcreateserial \
  -out intermediate.crt

# leaf
openssl req -new -nodes -text -out server.csr \
  -keyout server.key -subj "/CN=dbhost.yourdomain.com"
chmod og-rwx server.key
openssl x509 -req -in server.csr -text -days 365 \
  -CA intermediate.crt -CAkey intermediate.key -CAcreateserial \
  -out server.crt
```

`server.crt` and `intermediate.crt` should be concatenated into a certificate file bundle and stored on the server. `server.key` should also be stored on the server. `root.crt` should be stored on the client so the client can verify that the server's leaf certificate was signed by a chain of certificates linked to its trusted root certificate. `root.key` and `intermediate.key` should be stored offline for use in creating future certificates.

18.10. Secure TCP/IP Connections with GSSAPI Encryption

Postgres Pro also has native support for using GSSAPI to encrypt client/server communications for increased security. Support requires that a GSSAPI implementation (such as MIT Kerberos) is installed on both client and server systems, and that support in Postgres Pro is enabled at build time.

18.10.1. Basic Setup

The Postgres Pro server will listen for both normal and GSSAPI-encrypted connections on the same TCP port, and will negotiate with any connecting client whether to use GSSAPI for encryption (and for authentication). By default, this decision is up to the client (which means it can be downgraded by an attacker); see Section 20.1 about setting up the server to require the use of GSSAPI for some or all connections.

When using GSSAPI for encryption, it is common to use GSSAPI for authentication as well, since the underlying mechanism will determine both client and server identities (according to the GSSAPI implementation) in any case. But this is not required; another Postgres Pro authentication method can be chosen to perform additional verification.

Other than configuration of the negotiation behavior, GSSAPI encryption requires no setup beyond that which is necessary for GSSAPI authentication. (For more information on configuring that, see Section 20.6.)

18.11. Secure TCP/IP Connections with SSH Tunnels

It is possible to use SSH to encrypt the network connection between clients and a Postgres Pro server. Done properly, this provides an adequately secure network connection, even for non-SSL-capable clients.

First make sure that an SSH server is running properly on the same machine as the Postgres Pro server and that you can log in using `ssh` as some user; you then can establish a secure tunnel to the remote server. A secure tunnel listens on a local port and forwards all traffic to a port on the remote machine. Traffic sent to the remote port can arrive on its `localhost` address, or different bind address if desired; it does not appear as coming from your local machine. This command creates a secure tunnel from the client machine to the remote machine `foo.com`:

```
ssh -L 63333:localhost:5432 joe@foo.com
```

The first number in the `-L` argument, 63333, is the local port number of the tunnel; it can be any unused port. (IANA reserves ports 49152 through 65535 for private use.) The name or IP address after this is the remote bind address you are connecting to, i.e., `localhost`, which is the default. The second number, 5432, is the remote end of the tunnel, e.g., the port number your database server is using. In order to connect to the database server using this tunnel, you connect to port 63333 on the local machine:

```
psql -h localhost -p 63333 postgres
```

To the database server it will then look as though you are user `joe` on host `foo.com` connecting to the `localhost` bind address, and it will use whatever authentication procedure was configured for connections by that user to that bind address. Note that the server will not think the connection is SSL-encrypted, since in fact it is not encrypted between the SSH server and the Postgres Pro server. This should not pose any extra security risk because they are on the same machine.

In order for the tunnel setup to succeed you must be allowed to connect via `ssh` as `joe@foo.com`, just as if you had attempted to use `ssh` to create a terminal session.

You could also have set up port forwarding as

```
ssh -L 63333:foo.com:5432 joe@foo.com
```

but then the database server will see the connection as coming in on its `foo.com` bind address, which is not opened by the default setting `listen_addresses = 'localhost'`. This is usually not what you want.

If you have to “hop” to the database server via some login host, one possible setup could look like this:

```
ssh -L 63333:db.foo.com:5432 joe@shell.foo.com
```

Note that this way the connection from `shell.foo.com` to `db.foo.com` will not be encrypted by the SSH tunnel. SSH offers quite a few configuration possibilities when the network is restricted in various ways. Please refer to the SSH documentation for details.

> **Tip**
>
> Several other applications exist that can provide secure tunnels using a procedure similar in concept to the one just described.

18.12. Registering Event Log on Windows

To register a Windows event log library with the operating system, issue this command:

regsvr32 *pgsql_library_directory*/pgevent.dll

This creates registry entries used by the event viewer, under the default event source named `Postgres Pro`.

To specify a different event source name (see event_source), use the `/n` and `/i` options:

regsvr32 /n /i:*event_source_name* *pgsql_library_directory*/pgevent.dll

To unregister the event log library from the operating system, issue this command:

regsvr32 /u [/i:*event_source_name*] *pgsql_library_directory*/pgevent.dll

> **Note**
>
> To enable event logging in the database server, modify log_destination to include `eventlog` in `postgresql.conf`.

Chapter 19. Server Configuration

There are many configuration parameters that affect the behavior of the database system. In the first section of this chapter we describe how to interact with configuration parameters. The subsequent sections discuss each parameter in detail.

19.1. Setting Parameters

19.1.1. Parameter Names and Values

All parameter names are case-insensitive. Every parameter takes a value of one of five types: boolean, string, integer, floating point, or enumerated (enum). The type determines the syntax for setting the parameter:

- *Boolean:* Values can be written as `on`, `off`, `true`, `false`, `yes`, `no`, `1`, `0` (all case-insensitive) or any unambiguous prefix of one of these.
- *String:* In general, enclose the value in single quotes, doubling any single quotes within the value. Quotes can usually be omitted if the value is a simple number or identifier, however. (Values that match an SQL keyword require quoting in some contexts.)
- *Numeric (integer and floating point):* Numeric parameters can be specified in the customary integer and floating-point formats; fractional values are rounded to the nearest integer if the parameter is of integer type. Integer parameters additionally accept hexadecimal input (beginning with `0x`) and octal input (beginning with `0`), but these formats cannot have a fraction. Do not use thousands separators. Quotes are not required, except for hexadecimal input.
- *Numeric with Unit:* Some numeric parameters have an implicit unit, because they describe quantities of memory or time. The unit might be bytes, kilobytes, blocks (typically eight kilobytes), milliseconds, seconds, or minutes. An unadorned numeric value for one of these settings will use the setting's default unit, which can be learned from `pg_settings.unit`. For convenience, settings can be given with a unit specified explicitly, for example `'120 ms'` for a time value, and they will be converted to whatever the parameter's actual unit is. Note that the value must be written as a string (with quotes) to use this feature. The unit name is case-sensitive, and there can be whitespace between the numeric value and the unit.
  - Valid memory units are `B` (bytes), `kB` (kilobytes), `MB` (megabytes), `GB` (gigabytes), and `TB` (terabytes). The multiplier for memory units is 1024, not 1000.
  - Valid time units are `us` (microseconds), `ms` (milliseconds), `s` (seconds), `min` (minutes), `h` (hours), and `d` (days).

  If a fractional value is specified with a unit, it will be rounded to a multiple of the next smaller unit if there is one. For example, `30.1 GB` will be converted to `30822 MB` not `32319628902 B`. If the parameter is of integer type, a final rounding to integer occurs after any unit conversion.
- *Enumerated:* Enumerated-type parameters are written in the same way as string parameters, but are restricted to have one of a limited set of values. The values allowable for such a parameter can be found from `pg_settings.enumvals`. Enum parameter values are case-insensitive.

19.1.2. Parameter Interaction via the Configuration File

The most fundamental way to set these parameters is to edit the file `postgresql.conf`, which is normally kept in the data directory. A default copy is installed when the database cluster directory is initialized. An example of what this file might look like is:

```
# This is a comment
log_connections = yes
log_destination = 'syslog'
search_path = '"$user", public'
shared_buffers = 128MB
```

One parameter is specified per line. The equal sign between name and value is optional. Whitespace is insignificant (except within a quoted parameter value) and blank lines are ignored. Hash marks (#) designate the remainder of the line as a comment. Parameter values that are not simple identifiers or numbers must be single-quoted. To embed a single quote in a parameter value, write either two quotes (preferred) or backslash-quote. If the file contains multiple entries for the same parameter, all but the last one are ignored.

Parameters set in this way provide default values for the cluster. The settings seen by active sessions will be these values unless they are overridden. The following sections describe ways in which the administrator or user can override these defaults.

The configuration file is reread whenever the main server process receives a SIGHUP signal; this signal is most easily sent by running `pg_ctl reload` from the command line or by calling the SQL function `pg_reload_conf()`. The main server process also propagates this signal to all currently running server processes, so that existing sessions also adopt the new values (this will happen after they complete any currently-executing client command). Alternatively, you can send the signal to a single server process directly. Some parameters can only be set at server start; any changes to their entries in the configuration file will be ignored until the server is restarted. Invalid parameter settings in the configuration file are likewise ignored (but logged) during SIGHUP processing.

In addition to `postgresql.conf`, a Postgres Pro data directory contains a file `postgresql.auto.conf`, which has the same format as `postgresql.conf` but is intended to be edited automatically, not manually. This file holds settings provided through the `ALTER SYSTEM` command. This file is read whenever `postgresql.conf` is, and its settings take effect in the same way. Settings in `postgresql.auto.conf` override those in `postgresql.conf`.

External tools may also modify `postgresql.auto.conf`. It is not recommended to do this while the server is running, since a concurrent `ALTER SYSTEM` command could overwrite such changes. Such tools might simply append new settings to the end, or they might choose to remove duplicate settings and/or comments (as `ALTER SYSTEM` will).

The system view `pg_file_settings` can be helpful for pre-testing changes to the configuration files, or for diagnosing problems if a SIGHUP signal did not have the desired effects.

19.1.3. Parameter Interaction via SQL

Postgres Pro provides three SQL commands to establish configuration defaults. The already-mentioned `ALTER SYSTEM` command provides an SQL-accessible means of changing global defaults; it is functionally equivalent to editing `postgresql.conf`. In addition, there are two commands that allow setting of defaults on a per-database or per-role basis:

- The `ALTER DATABASE` command allows global settings to be overridden on a per-database basis.
- The `ALTER ROLE` command allows both global and per-database settings to be overridden with user-specific values.

Values set with `ALTER DATABASE` and `ALTER ROLE` are applied only when starting a fresh database session. They override values obtained from the configuration files or server command line, and constitute defaults for the rest of the session. Note that some settings cannot be changed after server start, and so cannot be set with these commands (or the ones listed below).

Once a client is connected to the database, Postgres Pro provides two additional SQL commands (and equivalent functions) to interact with session-local configuration settings:

- The `SHOW` command allows inspection of the current value of any parameter. The corresponding SQL function is `current_setting(setting_name text)` (see Section 9.27.1).
- The `SET` command allows modification of the current value of those parameters that can be set locally to a session; it has no effect on other sessions. The corresponding SQL function is `set_config(setting_name, new_value, is_local)` (see Section 9.27.1).

In addition, the system view `pg_settings` can be used to view and change session-local values:

- Querying this view is similar to using `SHOW ALL` but provides more detail. It is also more flexible, since it's possible to specify filter conditions or join against other relations.
- Using `UPDATE` on this view, specifically updating the `setting` column, is the equivalent of issuing `SET` commands. For example, the equivalent of

  ```
  SET configuration_parameter TO DEFAULT;
  ```

  is:

  ```
  UPDATE pg_settings SET setting = reset_val WHERE name = 'configuration_parameter';
  ```

19.1.4. Parameter Interaction via the Shell

In addition to setting global defaults or attaching overrides at the database or role level, you can pass settings to Postgres Pro via shell facilities. Both the server and libpq client library accept parameter values via the shell.

- During server startup, parameter settings can be passed to the `postgres` command via the `-c` command-line parameter. For example,

  ```
  postgres -c log_connections=yes -c log_destination='syslog'
  ```

  Settings provided in this way override those set via `postgresql.conf` or `ALTER SYSTEM`, so they cannot be changed globally without restarting the server.
- When starting a client session via libpq, parameter settings can be specified using the `PGOPTIONS` environment variable. Settings established in this way constitute defaults for the life of the session, but do not affect other sessions. For historical reasons, the format of `PGOPTIONS` is similar to that used when launching the `postgres` command; specifically, the `-c` flag must be specified. For example,

  ```
  env PGOPTIONS="-c geqo=off -c statement_timeout=5min" psql
  ```

  Other clients and libraries might provide their own mechanisms, via the shell or otherwise, that allow the user to alter session settings without direct use of SQL commands.

19.1.5. Managing Configuration File Contents

Postgres Pro provides several features for breaking down complex `postgresql.conf` files into sub-files. These features are especially useful when managing multiple servers with related, but not identical, configurations.

In addition to individual parameter settings, the `postgresql.conf` file can contain *include directives*, which specify another file to read and process as if it were inserted into the configuration file at this point. This feature allows a configuration file to be divided into physically separate parts. Include directives simply look like:

```
include 'filename'
```

If the file name is not an absolute path, it is taken as relative to the directory containing the referencing configuration file. Inclusions can be nested.

There is also an `include_if_exists` directive, which acts the same as the `include` directive, except when the referenced file does not exist or cannot be read. A regular `include` will consider this an error condition, but `include_if_exists` merely logs a message and continues processing the referencing configuration file.

The `postgresql.conf` file can also contain `include_dir` directives, which specify an entire directory of configuration files to include. These look like

```
include_dir 'directory'
```

Non-absolute directory names are taken as relative to the directory containing the referencing configuration file. Within the specified directory, only non-directory files whose names end with the suffix `.conf` will be included. File names that start with the `.` character are also ignored, to prevent mistakes

since such files are hidden on some platforms. Multiple files within an include directory are processed in file name order (according to C locale rules, i.e., numbers before letters, and uppercase letters before lowercase ones).

Include files or directories can be used to logically separate portions of the database configuration, rather than having a single large `postgresql.conf` file. Consider a company that has two database servers, each with a different amount of memory. There are likely elements of the configuration both will share, for things such as logging. But memory-related parameters on the server will vary between the two. And there might be server specific customizations, too. One way to manage this situation is to break the custom configuration changes for your site into three files. You could add this to the end of your `postgresql.conf` file to include them:

```
include 'shared.conf'
include 'memory.conf'
include 'server.conf'
```

All systems would have the same `shared.conf`. Each server with a particular amount of memory could share the same `memory.conf`; you might have one for all servers with 8GB of RAM, another for those having 16GB. And finally `server.conf` could have truly server-specific configuration information in it.

Another possibility is to create a configuration file directory and put this information into files there. For example, a `conf.d` directory could be referenced at the end of `postgresql.conf`:

```
include_dir 'conf.d'
```

Then you could name the files in the `conf.d` directory like this:

```
00shared.conf
01memory.conf
02server.conf
```

This naming convention establishes a clear order in which these files will be loaded. This is important because only the last setting encountered for a particular parameter while the server is reading configuration files will be used. In this example, something set in `conf.d/02server.conf` would override a value set in `conf.d/01memory.conf`.

You might instead use this approach to naming the files descriptively:

```
00shared.conf
01memory-8GB.conf
02server-foo.conf
```

This sort of arrangement gives a unique name for each configuration file variation. This can help eliminate ambiguity when several servers have their configurations all stored in one place, such as in a version control repository. (Storing database configuration files under version control is another good practice to consider.)

19.2. File Locations

In addition to the `postgresql.conf` file already mentioned, Postgres Pro uses two other manually-edited configuration files, which control client authentication (their use is discussed in Chapter 20). By default, all three configuration files are stored in the database cluster's data directory. The parameters described in this section allow the configuration files to be placed elsewhere. (Doing so can ease administration. In particular it is often easier to ensure that the configuration files are properly backed-up when they are kept separate.)

`data_directory` (`string`)

Specifies the directory to use for data storage. This parameter can only be set at server start.

`config_file` (`string`)

Specifies the main server configuration file (customarily called `postgresql.conf`). This parameter can only be set on the `postgres` command line.

`hba_file` (`string`)

Specifies the configuration file for host-based authentication (customarily called `pg_hba.conf`). This parameter can only be set at server start.

`ident_file` (`string`)

Specifies the configuration file for user name mapping (customarily called `pg_ident.conf`). This parameter can only be set at server start. See also Section 20.2.

`external_pid_file` (`string`)

Specifies the name of an additional process-ID (PID) file that the server should create for use by server administration programs. This parameter can only be set at server start.

In a default installation, none of the above parameters are set explicitly. Instead, the data directory is specified by the `-D` command-line option or the `PGDATA` environment variable, and the configuration files are all found within the data directory.

If you wish to keep the configuration files elsewhere than the data directory, the `postgres -D` command-line option or `PGDATA` environment variable must point to the directory containing the configuration files, and the `data_directory` parameter must be set in `postgresql.conf` (or on the command line) to show where the data directory is actually located. Notice that `data_directory` overrides `-D` and `PGDATA` for the location of the data directory, but not for the location of the configuration files.

If you wish, you can specify the configuration file names and locations individually using the parameters `config_file`, `hba_file` and/or `ident_file`. `config_file` can only be specified on the `postgres` command line, but the others can be set within the main configuration file. If all three parameters plus `data_directory` are explicitly set, then it is not necessary to specify `-D` or `PGDATA`.

When setting any of these parameters, a relative path will be interpreted with respect to the directory in which `postgres` is started.

19.3. Connections and Authentication

19.3.1. Connection Settings

`listen_addresses` (`string`)

Specifies the TCP/IP address(es) on which the server is to listen for connections from client applications. The value takes the form of a comma-separated list of host names and/or numeric IP addresses. The special entry `*` corresponds to all available IP interfaces. The entry `0.0.0.0` allows listening for all IPv4 addresses and `::` allows listening for all IPv6 addresses. If the list is empty, the server does not listen on any IP interface at all, in which case only Unix-domain sockets can be used to connect to it. If the list is not empty, the server will start if it can listen on at least one TCP/IP address. A warning will be emitted for any TCP/IP address which cannot be opened. The default value is localhost, which allows only local TCP/IP “loopback” connections to be made.

While client authentication (Chapter 20) allows fine-grained control over who can access the server, `listen_addresses` controls which interfaces accept connection attempts, which can help prevent repeated malicious connection requests on insecure network interfaces. This parameter can only be set at server start.

`port` (`integer`)

The TCP port the server listens on; 5432 by default. Note that the same port number is used for all IP addresses the server listens on. This parameter can only be set at server start.

`max_connections` (`integer`)

Determines the maximum number of concurrent connections to the database server. The default is typically 100 connections, but might be less if your kernel settings will not support it (as determined during initdb). This parameter can only be set at server start.

When running a standby server, you must set this parameter to the same or higher value than on the primary server. Otherwise, queries will not be allowed in the standby server.

`superuser_reserved_connections` (`integer`)

Determines the number of connection "slots" that are reserved for connections by Postgres Pro superusers. At most max_connections connections can ever be active simultaneously. Whenever the number of active concurrent connections is at least `max_connections` minus `superuser_reserved_connections`, new connections will be accepted only for superusers, and no new replication connections will be accepted.

The default value is three connections. The value must be less than `max_connections`. This parameter can only be set at server start.

`max_sessions` (`integer`)

The maximum number of client sessions that can be handled by one backend when connection pooling is switched on. This parameter does not add any memory or CPU overhead, so specifying a large `max_sessions` value does not affect performance. If the `max_sessions` limit is reached, the backend stops accepting connections. Until one of the connections is terminated, attempts to connect to this backend result in an error.

The default value is 1000. This parameter can only be set at server start.

`session_pool_size` (`integer`)

Enables connection pooling and defines the maximum number of backends that can be used by client sessions for each database.

The default value is zero, so connection pooling is disabled.

`connection_pool_workers` (`integer`)

Number of connection listeners used to read client startup packages. If connection pooling is enabled, Postgres Pro Enterprise server redirects all client startup packages to a connection listener. The listener determines the database and user that the client needs to access and redirects the connection to an appropriate backend, which is selected from the pool in accordance with the session_schedule policy. This approach allows to avoid server slowdown if a client tries to connect via a slow or unreliable network.

The default value is 2.

`dedicated_databases` (`string`)

Specifies the list of databases for which connection pooling is disabled, regardless of the `session_pool_size` value. For such databases, a separate backend is forked for each connection. By default, connection pooling is disabled for `template0`, `template1`, and `postgres` databases.

`dedicated_users` (`string`)

Specifies the list of users for which connection pooling is disabled, regardless of the `session_pool_size` value. For such users, a separate backend is forked for each connection. By default, connection pooling is disabled for the `postgres` user.

`restart_pooler_on_reload` (`boolean`)

Restart connection pool workers once `pg_reload_conf()` is called. The default value is `false`.

`hold_prepared_transactions` (`boolean`)

Do not reschedule the backend while the current session has unfinished prepared transactions. Scheduling several sessions with conflicting prepared transactions on the same backend can cause undetectable deadlocks.

The default value is `off`.

`session_schedule` (`enum`)

Specifies scheduling policy for assigning a session to a backend if connection pooling is enabled:

- `round-robin` — cyclically scatter sessions between pooled backends.
- `random` — choose a backend in the pool at random.
- `load-balancing` — choose the backend with the lowest load average. The backend load average is estimated by the number of ready events at each reschedule iteration.

The default policy is `round-robin`.

`idle_pool_backend_timeout` (`integer`)

Terminate an idle connection pool worker after the specified number of milliseconds. The default value is 0, so pool workers are never terminated.

`unix_socket_directories` (`string`)

Specifies the directory of the Unix-domain socket(s) on which the server is to listen for connections from client applications. Multiple sockets can be created by listing multiple directories separated by commas. Whitespace between entries is ignored; surround a directory name with double quotes if you need to include whitespace or commas in the name. An empty value specifies not listening on any Unix-domain sockets, in which case only TCP/IP sockets can be used to connect to the server.

A value that starts with `@` specifies that a Unix-domain socket in the abstract namespace should be created (currently supported on Linux only). In that case, this value does not specify a "directory" but a prefix from which the actual socket name is computed in the same manner as for the file-system namespace. While the abstract socket name prefix can be chosen freely, since it is not a file-system location, the convention is to nonetheless use file-system-like values such as `@/tmp`.

The default value is normally `/tmp`, but that can be changed at build time. On Windows, the default is empty, which means no Unix-domain socket is created by default. This parameter can only be set at server start.

In addition to the socket file itself, which is named `.s.PGSQL.`*`nnnn`* where *`nnnn`* is the server's port number, an ordinary file named `.s.PGSQL.`*`nnnn`*`.lock` will be created in each of the `unix_socket_directories` directories. Neither file should ever be removed manually. For sockets in the abstract namespace, no lock file is created.

`unix_socket_group` (`string`)

Sets the owning group of the Unix-domain socket(s). (The owning user of the sockets is always the user that starts the server.) In combination with the parameter `unix_socket_permissions` this can be used as an additional access control mechanism for Unix-domain connections. By default this is the empty string, which uses the default group of the server user. This parameter can only be set at server start.

This parameter is not supported on Windows. Any setting will be ignored. Also, sockets in the abstract namespace have no file owner, so this setting is also ignored in that case.

`unix_socket_permissions` (`integer`)

Sets the access permissions of the Unix-domain socket(s). Unix-domain sockets use the usual Unix file system permission set. The parameter value is expected to be a numeric mode specified in the format accepted by the `chmod` and `umask` system calls. (To use the customary octal format the number must start with a `0` (zero).)

The default permissions are `0777`, meaning anyone can connect. Reasonable alternatives are `0770` (only user and group, see also `unix_socket_group`) and `0700` (only user). (Note that for a Unix-

domain socket, only write permission matters, so there is no point in setting or revoking read or execute permissions.)

This access control mechanism is independent of the one described in Chapter 20.

This parameter can only be set at server start.

This parameter is irrelevant on systems, notably Solaris as of Solaris 10, that ignore socket permissions entirely. There, one can achieve a similar effect by pointing `unix_socket_directories` to a directory having search permission limited to the desired audience.

Sockets in the abstract namespace have no file permissions, so this setting is also ignored in that case.

`bonjour` (`boolean`)

Enables advertising the server's existence via Bonjour. The default is off. This parameter can only be set at server start.

`bonjour_name` (`string`)

Specifies the Bonjour service name. The computer name is used if this parameter is set to the empty string `''` (which is the default). This parameter is ignored if the server was not compiled with Bonjour support. This parameter can only be set at server start.

`tcp_keepalives_idle` (`integer`)

Specifies the amount of time with no network activity after which the operating system should send a TCP keepalive message to the client. If this value is specified without units, it is taken as seconds. A value of 0 (the default) selects the operating system's default. This parameter is supported only on systems that support `TCP_KEEPIDLE` or an equivalent socket option, and on Windows; on other systems, it must be zero. In sessions connected via a Unix-domain socket, this parameter is ignored and always reads as zero.

> **Note**
>
> On Windows, setting a value of 0 will set this parameter to 2 hours, since Windows does not provide a way to read the system default value.

`tcp_keepalives_interval` (`integer`)

Specifies the amount of time after which a TCP keepalive message that has not been acknowledged by the client should be retransmitted. If this value is specified without units, it is taken as seconds. A value of 0 (the default) selects the operating system's default. This parameter is supported only on systems that support `TCP_KEEPINTVL` or an equivalent socket option, and on Windows; on other systems, it must be zero. In sessions connected via a Unix-domain socket, this parameter is ignored and always reads as zero.

> **Note**
>
> On Windows, setting a value of 0 will set this parameter to 1 second, since Windows does not provide a way to read the system default value.

`tcp_keepalives_count` (`integer`)

Specifies the number of TCP keepalive messages that can be lost before the server's connection to the client is considered dead. A value of 0 (the default) selects the operating system's default. This parameter is supported only on systems that support `TCP_KEEPCNT` or an equivalent socket option; on other systems, it must be zero. In sessions connected via a Unix-domain socket, this parameter is ignored and always reads as zero.

> **Note**
>
> This parameter is not supported on Windows, and must be zero.

`tcp_user_timeout` (`integer`)

Specifies the amount of time that transmitted data may remain unacknowledged before the TCP connection is forcibly closed. If this value is specified without units, it is taken as milliseconds. A value of 0 (the default) selects the operating system's default. This parameter is supported only on systems that support `TCP_USER_TIMEOUT`; on other systems, it must be zero. In sessions connected via a Unix-domain socket, this parameter is ignored and always reads as zero.

> **Note**
>
> This parameter is not supported on Windows, and must be zero.

`client_connection_check_interval` (`integer`)

Sets the time interval between optional checks that the client is still connected, while running queries. The check is performed by polling the socket, and allows long running queries to be aborted sooner if the kernel reports that the connection is closed.

This option is currently available only on systems that support the non-standard `POLLRDHUP` extension to the `poll` system call, including Linux.

If the value is specified without units, it is taken as milliseconds. The default value is `0`, which disables connection checks. Without connection checks, the server will detect the loss of the connection only at the next interaction with the socket, when it waits for, receives or sends data.

For the kernel itself to detect lost TCP connections reliably and within a known timeframe in all scenarios including network failure, it may also be necessary to adjust the TCP keepalive settings of the operating system, or the tcp_keepalives_idle, tcp_keepalives_interval and tcp_keepalives_count settings of Postgres Pro.

19.3.2. Authentication

`authentication_timeout` (`integer`)

Maximum amount of time allowed to complete client authentication. If a would-be client has not completed the authentication protocol in this much time, the server closes the connection. This prevents hung clients from occupying a connection indefinitely. If this value is specified without units, it is taken as seconds. The default is one minute (`1m`). This parameter can only be set in the `postgresql.conf` file or on the server command line.

`password_encryption` (`enum`)

When a password is specified in CREATE ROLE or ALTER ROLE, this parameter determines the algorithm to use to encrypt the password. Possible values are `scram-sha-256`, which will encrypt the password with SCRAM-SHA-256, and `md5`, which stores the password as an MD5 hash. The default is `scram-sha-256`. Nevertheless, by default pg-setup sets `--auth-host` to `md5` but you can still pass another value in its `initdb` option, if necessary.

Note that older clients might lack support for the SCRAM authentication mechanism, and hence not work with passwords encrypted with SCRAM-SHA-256. See Section 20.5 for more details.

`krb_server_keyfile` (`string`)

Sets the location of the server's Kerberos key file. The default is `FILE:/usr/local/pgsql/etc/krb5.keytab` (where the directory part is whatever was specified as `sysconfdir` at build time; use

`pg_config --sysconfdir` to determine that). If this parameter is set to an empty string, it is ignored and a system-dependent default is used. This parameter can only be set in the `postgresql.conf` file or on the server command line. See Section 20.6 for more information.

`krb_caseins_users` (`boolean`)

Sets whether GSSAPI user names should be treated case-insensitively. The default is `off` (case sensitive). This parameter can only be set in the `postgresql.conf` file or on the server command line.

`db_user_namespace` (`boolean`)

This parameter enables per-database user names. It is off by default. This parameter can only be set in the `postgresql.conf` file or on the server command line.

If this is on, you should create users as *`username@dbname`*. When *`username`* is passed by a connecting client, `@` and the database name are appended to the user name and that database-specific user name is looked up by the server. Note that when you create users with names containing `@` within the SQL environment, you will need to quote the user name.

With this parameter enabled, you can still create ordinary global users. Simply append `@` when specifying the user name in the client, e.g., `joe@`. The `@` will be stripped off before the user name is looked up by the server.

`db_user_namespace` causes the client's and server's user name representation to differ. Authentication checks are always done with the server's user name so authentication methods must be configured for the server's user name, not the client's. Because `md5` uses the user name as salt on both the client and server, `md5` cannot be used with `db_user_namespace`.

> **Note**
>
> This feature is intended as a temporary measure until a complete solution is found. At that time, this option will be removed.

19.3.3. SSL

See Section 18.9 for more information about setting up SSL.

`ssl` (`boolean`)

Enables SSL connections. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is `off`.

`ssl_ca_file` (`string`)

Specifies the name of the file containing the SSL server certificate authority (CA). Relative paths are relative to the data directory. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is empty, meaning no CA file is loaded, and client certificate verification is not performed.

`ssl_cert_file` (`string`)

Specifies the name of the file containing the SSL server certificate. Relative paths are relative to the data directory. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is `server.crt`.

`ssl_crl_file` (`string`)

Specifies the name of the file containing the SSL client certificate revocation list (CRL). Relative paths are relative to the data directory. This parameter can only be set in the `postgresql.conf` file

or on the server command line. The default is empty, meaning no CRL file is loaded (unless ssl_crl_dir is set).

`ssl_crl_dir` (`string`)

Specifies the name of the directory containing the SSL client certificate revocation list (CRL). Relative paths are relative to the data directory. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is empty, meaning no CRLs are used (unless ssl_crl_file is set).

The directory needs to be prepared with the OpenSSL command `openssl rehash` or `c_rehash`. See its documentation for details.

When using this setting, CRLs in the specified directory are loaded on-demand at connection time. New CRLs can be added to the directory and will be used immediately. This is unlike ssl_crl_file, which causes the CRL in the file to be loaded at server start time or when the configuration is reloaded. Both settings can be used together.

`ssl_key_file` (`string`)

Specifies the name of the file containing the SSL server private key. Relative paths are relative to the data directory. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is `server.key`.

`ssl_ciphers` (`string`)

Specifies a list of SSL cipher suites that are allowed to be used by SSL connections. See the ciphers manual page in the OpenSSL package for the syntax of this setting and a list of supported values. Only connections using TLS version 1.2 and lower are affected. There is currently no setting that controls the cipher choices used by TLS version 1.3 connections. The default value is `HIGH:MEDIUM:+3DES:!aNULL`. The default is usually a reasonable choice unless you have specific security requirements.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

Explanation of the default value:

`HIGH`

Cipher suites that use ciphers from `HIGH` group (e.g., AES, Camellia, 3DES)

`MEDIUM`

Cipher suites that use ciphers from `MEDIUM` group (e.g., RC4, SEED)

`+3DES`

The OpenSSL default order for `HIGH` is problematic because it orders 3DES higher than AES128. This is wrong because 3DES offers less security than AES128, and it is also much slower. `+3DES` reorders it after all other `HIGH` and `MEDIUM` ciphers.

`!aNULL`

Disables anonymous cipher suites that do no authentication. Such cipher suites are vulnerable to MITM attacks and therefore should not be used.

Available cipher suite details will vary across OpenSSL versions. Use the command `openssl ciphers -v 'HIGH:MEDIUM:+3DES:!aNULL'` to see actual details for the currently installed OpenSSL version. Note that this list is filtered at run time based on the server key type.

`ssl_prefer_server_ciphers` (`boolean`)

Specifies whether to use the server's SSL cipher preferences, rather than the client's. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is `on`.

Postgres Pro versions before 9.4 do not have this setting and always use the client's preferences. This setting is mainly for backward compatibility with those versions. Using the server's preferences is usually better because it is more likely that the server is appropriately configured.

`ssl_ecdh_curve` (`string`)

Specifies the name of the curve to use in ECDH key exchange. It needs to be supported by all clients that connect. It does not need to be the same curve used by the server's Elliptic Curve key. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is `prime256v1`.

OpenSSL names for the most common curves are: `prime256v1` (NIST P-256), `secp384r1` (NIST P-384), `secp521r1` (NIST P-521). The full list of available curves can be shown with the command `openssl ecparam -list_curves`. Not all of them are usable in TLS though.

`ssl_min_protocol_version` (`enum`)

Sets the minimum SSL/TLS protocol version to use. Valid values are currently: `TLSv1`, `TLSv1.1`, `TLSv1.2`, `TLSv1.3`. Older versions of the OpenSSL library do not support all values; an error will be raised if an unsupported setting is chosen. Protocol versions before TLS 1.0, namely SSL version 2 and 3, are always disabled.

The default is `TLSv1.2`, which satisfies industry best practices as of this writing.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`ssl_max_protocol_version` (`enum`)

Sets the maximum SSL/TLS protocol version to use. Valid values are as for ssl_min_protocol_version, with addition of an empty string, which allows any protocol version. The default is to allow any version. Setting the maximum protocol version is mainly useful for testing or if some component has issues working with a newer protocol.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`ssl_dh_params_file` (`string`)

Specifies the name of the file containing Diffie-Hellman parameters used for so-called ephemeral DH family of SSL ciphers. The default is empty, in which case compiled-in default DH parameters used. Using custom DH parameters reduces the exposure if an attacker manages to crack the well-known compiled-in DH parameters. You can create your own DH parameters file with the command `openssl dhparam -out dhparams.pem 2048`.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`ssl_passphrase_command` (`string`)

Sets an external command to be invoked when a passphrase for decrypting an SSL file such as a private key needs to be obtained. By default, this parameter is empty, which means the built-in prompting mechanism is used.

The command must print the passphrase to the standard output and exit with code 0. In the parameter value, `%p` is replaced by a prompt string. (Write `%%` for a literal `%`.) Note that the prompt string will probably contain whitespace, so be sure to quote adequately. A single newline is stripped from the end of the output if present.

The command does not actually have to prompt the user for a passphrase. It can read it from a file, obtain it from a keychain facility, or similar. It is up to the user to make sure the chosen mechanism is adequately secure.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`ssl_passphrase_command_supports_reload` (`boolean`)

This parameter determines whether the passphrase command set by `ssl_passphrase_command` will also be called during a configuration reload if a key file needs a passphrase. If this parameter is off (the default), then `ssl_passphrase_command` will be ignored during a reload and the SSL configuration will not be reloaded if a passphrase is needed. That setting is appropriate for a command that requires a TTY for prompting, which might not be available when the server is running. Setting this parameter to on might be appropriate if the passphrase is obtained from a file, for example.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.4. Resource Consumption

19.4.1. Memory

`shared_buffers` (`integer`)

Sets the amount of memory the database server uses for shared memory buffers. The default is typically 128 megabytes (`128MB`), but might be less if your kernel settings will not support it (as determined during initdb). This setting must be at least 128 kilobytes. However, settings significantly higher than the minimum are usually needed for good performance. If this value is specified without units, it is taken as blocks, that is `BLCKSZ` bytes, typically 8kB. (Non-default values of `BLCKSZ` change the minimum value.) This parameter can only be set at server start.

If you have a dedicated database server with 1GB or more of RAM, a reasonable starting value for `shared_buffers` is 25% of the memory in your system. There are some workloads where even larger settings for `shared_buffers` are effective, but because Postgres Pro also relies on the operating system cache, it is unlikely that an allocation of more than 40% of RAM to `shared_buffers` will work better than a smaller amount. Larger settings for `shared_buffers` usually require a corresponding increase in `max_wal_size`, in order to spread out the process of writing large quantities of new or changed data over a longer period of time.

On systems with less than 1GB of RAM, a smaller percentage of RAM is appropriate, so as to leave adequate space for the operating system.

`huge_pages` (`enum`)

Controls whether huge pages are requested for the main shared memory area. Valid values are `try` (the default), `on`, and `off`. With `huge_pages` set to `try`, the server will try to request huge pages, but fall back to the default if that fails. With `on`, failure to request huge pages will prevent the server from starting up. With `off`, huge pages will not be requested.

At present, this setting is supported only on Linux and Windows. The setting is ignored on other systems when set to `try`. On Linux, it is only supported when `shared_memory_type` is set to `mmap` (the default).

The use of huge pages results in smaller page tables and less CPU time spent on memory management, increasing performance. For more details about using huge pages on Linux, see Section 18.4.5.

Huge pages are known as large pages on Windows. To use them, you need to assign the user right “Lock pages in memory” to the Windows user account that runs Postgres Pro. You can use Windows Group Policy tool (gpedit.msc) to assign the user right “Lock pages in memory”. To start the database server on the command prompt as a standalone process, not as a Windows service, the command prompt must be run as an administrator or User Access Control (UAC) must be disabled. When the UAC is enabled, the normal command prompt revokes the user right “Lock pages in memory” when started.

Note that this setting only affects the main shared memory area. Operating systems such as Linux, FreeBSD, and Illumos can also use huge pages (also known as “super” pages or “large” pages) automatically for normal memory allocation, without an explicit request from Postgres Pro. On Linux, this is called “transparent huge pages”(THP). That feature has been known to cause performance

degradation with Postgres Pro for some users on some Linux versions, so its use is currently discouraged (unlike explicit use of `huge_pages`).

`xml_parse_huge` (`boolean`)

Allows allocating more memory for processing XML data. By default, the maximum amount of memory allocated per node is 10 MB. With `xml_parse_huge` enabled, this limit is increased to 1 GB.

Default: `off`

`huge_page_size` (`integer`)

Controls the size of huge pages, when they are enabled with huge_pages. The default is zero (`0`). When set to `0`, the default huge page size on the system will be used. This parameter can only be set at server start.

Some commonly available page sizes on modern 64 bit server architectures include: `2MB` and `1GB` (Intel and AMD), `16MB` and `16GB` (IBM POWER), and `64kB`, `2MB`, `32MB` and `1GB` (ARM). For more information about usage and support, see Section 18.4.5.

Non-default settings are currently supported only on Linux.

`temp_buffers` (`integer`)

Sets the maximum amount of memory used for temporary buffers within each database session. These are session-local buffers used only for access to temporary tables. If this value is specified without units, it is taken as blocks, that is `BLCKSZ` bytes, typically 8kB. The default is eight megabytes (`8MB`). (If `BLCKSZ` is not 8kB, the default value scales proportionally to it.) This setting can be changed within individual sessions, but only before the first use of temporary tables within the session; subsequent attempts to change the value will have no effect on that session.

A session will allocate temporary buffers as needed up to the limit given by `temp_buffers`. The cost of setting a large value in sessions that do not actually need many temporary buffers is only a buffer descriptor, or about 64 bytes, per increment in `temp_buffers`. However if a buffer is actually used an additional 8192 bytes will be consumed for it (or in general, `BLCKSZ` bytes).

`max_prepared_transactions` (`integer`)

Sets the maximum number of transactions that can be in the “prepared” state simultaneously (see PREPARE TRANSACTION). Setting this parameter to zero (which is the default) disables the prepared-transaction feature. This parameter can only be set at server start.

If you are not planning to use prepared transactions, this parameter should be set to zero to prevent accidental creation of prepared transactions. If you are using prepared transactions, you will probably want `max_prepared_transactions` to be at least as large as max_connections, so that every session can have a prepared transaction pending.

When running a standby server, you must set this parameter to the same or higher value than on the primary server. Otherwise, queries will not be allowed in the standby server.

`max_autonomous_transactions` (`integer`)

Sets the maximum number of autonomous transactions that can be used simultaneously in all sessions of a Postgres Pro instance. If this value is exceeded, the error is raised that an autonomous transaction cannot be started.

Default: 100

`work_mem` (`integer`)

Sets the base maximum amount of memory to be used by a query operation (such as a sort or hash table) before writing to temporary disk files. If this value is specified without units, it is taken as kilobytes. The default value is four megabytes (`4MB`). Note that a complex query might perform several

sort and hash operations at the same time, with each operation generally being allowed to use as much memory as this value specifies before it starts to write data into temporary files. Also, several running sessions could be doing such operations concurrently. Therefore, the total memory used could be many times the value of work_mem; it is necessary to keep this fact in mind when choosing the value. Sort operations are used for ORDER BY, DISTINCT, and merge joins. Hash tables are used in hash joins, hash-based aggregation, memoize nodes and hash-based processing of IN subqueries.

Hash-based operations are generally more sensitive to memory availability than equivalent sort-based operations. The memory limit for a hash table is computed by multiplying work_mem by hash_mem_multiplier. This makes it possible for hash-based operations to use an amount of memory that exceeds the usual work_mem base amount.

> **Note**
>
> The Postgres Pro planner may incorrectly estimate the hash table size when doing hash-based operations. If the hash table is organized in a such manner that one or several batches are so big that they do not fit into the allocated memory, exceeding the memory limit, and the hash table can not be splitted into more batches, then the planner will try to place each batch into the memory in order to complete the query even if a single batch exceeds the aforementioned limit.
>
> Therefore, the memory consumption could dramatically increase when doing hash-based operations on large datasets that produce hash tables, which can not be splitted into a large number of batches.

hash_mem_multiplier (floating point)

Used to compute the maximum amount of memory that hash-based operations can use. The final limit is determined by multiplying work_mem by hash_mem_multiplier. The default value is 1.0, which makes hash-based operations subject to the same simple work_mem maximum as sort-based operations.

Consider increasing hash_mem_multiplier in environments where spilling by query operations is a regular occurrence, especially when simply increasing work_mem results in memory pressure (memory pressure typically takes the form of intermittent out of memory errors). A setting of 1.5 or 2.0 may be effective with mixed workloads. Higher settings in the range of 2.0 - 8.0 or more may be effective in environments where work_mem has already been increased to 40MB or more.

maintenance_work_mem (integer)

Specifies the maximum amount of memory to be used by maintenance operations, such as VACUUM, CREATE INDEX, and ALTER TABLE ADD FOREIGN KEY. If this value is specified without units, it is taken as kilobytes. It defaults to 64 megabytes (64MB). Since only one of these operations can be executed at a time by a database session, and an installation normally doesn't have many of them running concurrently, it's safe to set this value significantly larger than work_mem. Larger settings might improve performance for vacuuming and for restoring database dumps.

Note that when autovacuum runs, up to autovacuum_max_workers times this memory may be allocated, so be careful not to set the default value too high. It may be useful to control for this by separately setting autovacuum_work_mem.

Note that for the collection of dead tuple identifiers, VACUUM is only able to utilize up to a maximum of 1GB of memory.

autovacuum_work_mem (integer)

Specifies the maximum amount of memory to be used by each autovacuum worker process. If this value is specified without units, it is taken as kilobytes. It defaults to -1, indicating that the value of maintenance_work_mem should be used instead. The setting has no effect on the behavior of VACUUM

when run in other contexts. This parameter can only be set in the postgresql.conf file or on the server command line.

For the collection of dead tuple identifiers, autovacuum is only able to utilize up to a maximum of 1GB of memory, so setting autovacuum_work_mem to a value higher than that has no effect on the number of dead tuples that autovacuum can collect while scanning a table.

logical_decoding_work_mem (integer)

Specifies the maximum amount of memory to be used by logical decoding, before some of the decoded changes are written to local disk. This limits the amount of memory used by logical streaming replication connections. It defaults to 64 megabytes (64MB). Since each replication connection only uses a single buffer of this size, and an installation normally doesn't have many such connections concurrently (as limited by max_wal_senders), it's safe to set this value significantly higher than work_mem, reducing the amount of decoded changes written to disk.

slru_buffers_size_scale (integer)

Specifies the power of two for scaling the size of SLRU shared memory buffers. The buffer size is calculated according to the table below and cannot exceed shared_buffers size / 8kB / 256. For example, if shared_buffers = 128MB, the maximum buffer size would be 128 MB / 8 kB / 256 = 64 elements.

Table 19.1. SLRU Buffers Sizes

Buffer	Value
Multixact offset buffer	32 * (2 ^ slru_buffers_size_scale)
Multixact member buffer	64 * (2 ^ slru_buffers_size_scale)
Sub-transaction buffer	64 * (2 ^ slru_buffers_size_scale)
NOTIFY message buffer	32 * (2 ^ slru_buffers_size_scale)
Serializable transaction conflict buffer	32 * (2 ^ slru_buffers_size_scale)
Clog (transaction status) buffer	128 * (2 ^ slru_buffers_size_scale)
Commit timestamp buffer	128 * (2 ^ slru_buffers_size_scale)

The default value is 2. The valid range is between 0 and 9. This parameter can only be set at server start.

max_stack_depth (integer)

Specifies the maximum safe depth of the server's execution stack. The ideal setting for this parameter is the actual stack size limit enforced by the kernel (as set by ulimit -s or local equivalent), less a safety margin of a megabyte or so. The safety margin is needed because the stack depth is not checked in every routine in the server, but only in key potentially-recursive routines. If this value is specified without units, it is taken as kilobytes. The default setting is two megabytes (2MB), which is conservatively small and unlikely to risk crashes. However, it might be too small to allow execution of complex functions. Only superusers can change this setting.

Setting max_stack_depth higher than the actual kernel limit will mean that a runaway recursive function can crash an individual backend process. On platforms where Postgres Pro can determine the kernel limit, the server will not allow this variable to be set to an unsafe value. However, not all platforms provide the information, so caution is recommended in selecting a value.

shared_memory_type (enum)

Specifies the shared memory implementation that the server should use for the main shared memory region that holds Postgres Pro's shared buffers and other shared data. Possible values are mmap (for anonymous shared memory allocated using mmap), sysv (for System V shared memory allocated via shmget) and windows (for Windows shared memory). Not all values are supported on all platforms; the first supported option is the default for that platform. The use of the sysv option, which is not

the default on any platform, is generally discouraged because it typically requires non-default kernel settings to allow for large allocations (see Section 18.4.1).

`dynamic_shared_memory_type` (`enum`)

Specifies the dynamic shared memory implementation that the server should use. Possible values are `posix` (for POSIX shared memory allocated using `shm_open`), `sysv` (for System V shared memory allocated via `shmget`), `windows` (for Windows shared memory), and `mmap` (to simulate shared memory using memory-mapped files stored in the data directory). Not all values are supported on all platforms; the first supported option is the default for that platform. The use of the `mmap` option, which is not the default on any platform, is generally discouraged because the operating system may write modified pages back to disk repeatedly, increasing system I/O load; however, it may be useful for debugging, when the `pg_dynshmem` directory is stored on a RAM disk, or when other shared memory facilities are not available.

`min_dynamic_shared_memory` (`integer`)

Specifies the amount of memory that should be allocated at server startup for use by parallel queries. When this memory region is insufficient or exhausted by concurrent queries, new parallel queries try to allocate extra shared memory temporarily from the operating system using the method configured with `dynamic_shared_memory_type`, which may be slower due to memory management overheads. Memory that is allocated at startup with `min_dynamic_shared_memory` is affected by the `huge_pages` setting on operating systems where that is supported, and may be more likely to benefit from larger pages on operating systems where that is managed automatically. The default value is `0` (none). This parameter can only be set at server start.

`plan_cache_lru_memsize` (`integer`)

Specifies the maximum amount of memory that can be used by plans of prepared statements. Having such a limit is useful for sessions with multiple prepared statements that may otherwise use too much memory. If this limit is reached, Postgres Pro Enterprise evicts the generic plans of the least recently used statements from memory, keeping only the corresponding parsed queries. If such a statement is called again later, it has to be analyzed and planned again. To keep plans in memory for all prepared statements as long as possible, set this parameter to `0`. If the value for this parameter is specified without units, it is taken as kilobytes. It is worth noting that the total amount of memory used by the saved queries may be larger than the value of this parameter because it takes into account only the generated plans.

If this parameter is set together with plan_cache_lru_size, the first reached limit takes effect.

Default: 8MB

`plan_cache_lru_size` (`integer`)

Same as plan_cache_lru_memsize, but limits the number of prepared statements instead of the memory size. Zero means no limit.

If this parameter is set together with plan_cache_lru_memsize, the first reached limit takes effect.

Default: 0

19.4.2. Disk

`temp_file_limit` (`integer`)

Specifies the maximum amount of disk space that a process can use for temporary files, such as sort and hash temporary files, or the storage file for a held cursor. A transaction attempting to exceed this limit will be canceled. If this value is specified without units, it is taken as kilobytes. `-1` (the default) means no limit. Only superusers can change this setting.

This setting constrains the total space used at any instant by all temporary files used by a given Postgres Pro process. It should be noted that disk space used for explicit temporary tables, as opposed to temporary files used behind-the-scenes in query execution, does *not* count against this limit.

19.4.3. Kernel Resource Usage

`max_files_per_process` (`integer`)

Sets the maximum number of simultaneously open files allowed to each server subprocess. The default is one thousand files. If the kernel is enforcing a safe per-process limit, you don't need to worry about this setting. But on some platforms (notably, most BSD systems), the kernel will allow individual processes to open many more files than the system can actually support if many processes all try to open that many files. If you find yourself seeing “Too many open files” failures, try reducing this setting. This parameter can only be set at server start.

19.4.4. Cost-based Vacuum Delay

During the execution of VACUUM and ANALYZE commands, the system maintains an internal counter that keeps track of the estimated cost of the various I/O operations that are performed. When the accumulated cost reaches a limit (specified by `vacuum_cost_limit`), the process performing the operation will sleep for a short period of time, as specified by `vacuum_cost_delay`. Then it will reset the counter and continue execution.

The intent of this feature is to allow administrators to reduce the I/O impact of these commands on concurrent database activity. There are many situations where it is not important that maintenance commands like `VACUUM` and `ANALYZE` finish quickly; however, it is usually very important that these commands do not significantly interfere with the ability of the system to perform other database operations. Cost-based vacuum delay provides a way for administrators to achieve this.

This feature is disabled by default for manually issued `VACUUM` commands. To enable it, set the `vacuum_cost_delay` variable to a nonzero value.

`vacuum_cost_delay` (`floating point`)

The amount of time that the process will sleep when the cost limit has been exceeded. If this value is specified without units, it is taken as milliseconds. The default value is zero, which disables the cost-based vacuum delay feature. Positive values enable cost-based vacuuming.

When using cost-based vacuuming, appropriate values for `vacuum_cost_delay` are usually quite small, perhaps less than 1 millisecond. While `vacuum_cost_delay` can be set to fractional-millisecond values, such delays may not be measured accurately on older platforms. On such platforms, increasing `VACUUM`'s throttled resource consumption above what you get at 1ms will require changing the other vacuum cost parameters. You should, nonetheless, keep `vacuum_cost_delay` as small as your platform will consistently measure; large delays are not helpful.

`vacuum_cost_page_hit` (`integer`)

The estimated cost for vacuuming a buffer found in the shared buffer cache. It represents the cost to lock the buffer pool, lookup the shared hash table and scan the content of the page. The default value is one.

`vacuum_cost_page_miss` (`integer`)

The estimated cost for vacuuming a buffer that has to be read from disk. This represents the effort to lock the buffer pool, lookup the shared hash table, read the desired block in from the disk and scan its content. The default value is 2.

`vacuum_cost_page_dirty` (`integer`)

The estimated cost charged when vacuum modifies a block that was previously clean. It represents the extra I/O required to flush the dirty block out to disk again. The default value is 20.

`vacuum_cost_limit` (`integer`)

The accumulated cost that will cause the vacuuming process to sleep. The default value is 200.

> **Note**
>
> There are certain operations that hold critical locks and should therefore complete as quickly as possible. Cost-based vacuum delays do not occur during such operations. Therefore it is possible that the cost accumulates far higher than the specified limit. To avoid uselessly long delays in such cases, the actual delay is calculated as `vacuum_cost_delay` * `accumulated_balance` / `vacuum_cost_limit` with a maximum of `vacuum_cost_delay` * 4.

19.4.5. Background Writer

There is a separate server process called the *background writer*, whose function is to issue writes of "dirty" (new or modified) shared buffers. When the number of clean shared buffers appears to be insufficient, the background writer writes some dirty buffers to the file system and marks them as clean. This reduces the likelihood that server processes handling user queries will be unable to find clean buffers and have to write dirty buffers themselves. However, the background writer does cause a net overall increase in I/O load, because while a repeatedly-dirtied page might otherwise be written only once per checkpoint interval, the background writer might write it several times as it is dirtied in the same interval. The parameters discussed in this subsection can be used to tune the behavior for local needs.

`bgwriter_delay` (`integer`)

Specifies the delay between activity rounds for the background writer. In each round the writer issues writes for some number of dirty buffers (controllable by the following parameters). It then sleeps for the length of `bgwriter_delay`, and repeats. When there are no dirty buffers in the buffer pool, though, it goes into a longer sleep regardless of `bgwriter_delay`. If this value is specified without units, it is taken as milliseconds. The default value is 200 milliseconds (`200ms`). Note that on many systems, the effective resolution of sleep delays is 10 milliseconds; setting `bgwriter_delay` to a value that is not a multiple of 10 might have the same results as setting it to the next higher multiple of 10. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`bgwriter_lru_maxpages` (`integer`)

In each round, no more than this many buffers will be written by the background writer. Setting this to zero disables background writing. (Note that checkpoints, which are managed by a separate, dedicated auxiliary process, are unaffected.) The default value is 100 buffers. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`bgwriter_lru_multiplier` (`floating point`)

The number of dirty buffers written in each round is based on the number of new buffers that have been needed by server processes during recent rounds. The average recent need is multiplied by `bgwriter_lru_multiplier` to arrive at an estimate of the number of buffers that will be needed during the next round. Dirty buffers are written until there are that many clean, reusable buffers available. (However, no more than `bgwriter_lru_maxpages` buffers will be written per round.) Thus, a setting of 1.0 represents a "just in time" policy of writing exactly the number of buffers predicted to be needed. Larger values provide some cushion against spikes in demand, while smaller values intentionally leave writes to be done by server processes. The default is 2.0. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`bgwriter_flush_after` (`integer`)

Whenever more than this amount of data has been written by the background writer, attempt to force the OS to issue these writes to the underlying storage. Doing so will limit the amount of dirty data in the kernel's page cache, reducing the likelihood of stalls when an `fsync` is issued at the end of a checkpoint, or when the OS writes data back in larger batches in the background. Often that will result in greatly reduced transaction latency, but there also are some cases, especially with workloads that are bigger than shared_buffers, but smaller than the OS's page cache, where performance might degrade. This setting may have no effect on some platforms. If this value is

specified without units, it is taken as blocks, that is BLCKSZ bytes, typically 8kB. The valid range is between 0, which disables forced writeback, and 2MB. The default is 512kB on Linux, 0 elsewhere. (If BLCKSZ is not 8kB, the default and maximum values scale proportionally to it.) This parameter can only be set in the postgresql.conf file or on the server command line.

Smaller values of bgwriter_lru_maxpages and bgwriter_lru_multiplier reduce the extra I/O load caused by the background writer, but make it more likely that server processes will have to issue writes for themselves, delaying interactive queries.

19.4.6. Asynchronous Behavior

backend_flush_after (integer)

Whenever more than this amount of data has been written by a single backend, attempt to force the OS to issue these writes to the underlying storage. Doing so will limit the amount of dirty data in the kernel's page cache, reducing the likelihood of stalls when an fsync is issued at the end of a checkpoint, or when the OS writes data back in larger batches in the background. Often that will result in greatly reduced transaction latency, but there also are some cases, especially with workloads that are bigger than shared_buffers, but smaller than the OS's page cache, where performance might degrade. This setting may have no effect on some platforms. If this value is specified without units, it is taken as blocks, that is BLCKSZ bytes, typically 8kB. The valid range is between 0, which disables forced writeback, and 2MB. The default is 0, i.e., no forced writeback. (If BLCKSZ is not 8kB, the maximum value scales proportionally to it.)

effective_io_concurrency (integer)

Sets the number of concurrent disk I/O operations that Postgres Pro expects can be executed simultaneously. Raising this value will increase the number of I/O operations that any individual Postgres Pro session attempts to initiate in parallel. The allowed range is 1 to 1000, or zero to disable issuance of asynchronous I/O requests. Currently, this setting only affects bitmap heap scans.

For magnetic drives, a good starting point for this setting is the number of separate drives comprising a RAID 0 stripe or RAID 1 mirror being used for the database. (For RAID 5 the parity drive should not be counted.) However, if the database is often busy with multiple queries issued in concurrent sessions, lower values may be sufficient to keep the disk array busy. A value higher than needed to keep the disks busy will only result in extra CPU overhead. SSDs and other memory-based storage can often process many concurrent requests, so the best value might be in the hundreds.

Asynchronous I/O depends on an effective posix_fadvise function, which some operating systems lack. If the function is not present then setting this parameter to anything but zero will result in an error. On some operating systems (e.g., Solaris), the function is present but does not actually do anything.

The default is 1 on supported systems, otherwise 0. This value can be overridden for tables in a particular tablespace by setting the tablespace parameter of the same name (see ALTER TABLESPACE).

maintenance_io_concurrency (integer)

Similar to effective_io_concurrency, but used for maintenance work that is done on behalf of many client sessions.

The default is 10 on supported systems, otherwise 0. This value can be overridden for tables in a particular tablespace by setting the tablespace parameter of the same name (see ALTER TABLESPACE).

max_worker_processes (integer)

Sets the maximum number of background processes that the system can support. This parameter can only be set at server start. The default is 8.

When running a standby server, you must set this parameter to the same or higher value than on the primary server. Otherwise, queries will not be allowed in the standby server.

When changing this value, consider also adjusting max_parallel_workers, max_parallel_maintenance_workers, and max_parallel_workers_per_gather.

max_parallel_workers_per_gather (integer)

Sets the maximum number of workers that can be started by a single Gather or Gather Merge node. Parallel workers are taken from the pool of processes established by max_worker_processes, limited by max_parallel_workers. Note that the requested number of workers may not actually be available at run time. If this occurs, the plan will run with fewer workers than expected, which may be inefficient. The default value is 2. Setting this value to 0 disables parallel query execution.

Note that parallel queries may consume very substantially more resources than non-parallel queries, because each worker process is a completely separate process which has roughly the same impact on the system as an additional user session. This should be taken into account when choosing a value for this setting, as well as when configuring other settings that control resource utilization, such as work_mem. Resource limits such as work_mem are applied individually to each worker, which means the total utilization may be much higher across all processes than it would normally be for any single process. For example, a parallel query using 4 workers may use up to 5 times as much CPU time, memory, I/O bandwidth, and so forth as a query which uses no workers at all.

For more information on parallel query, see Chapter 15.

max_parallel_maintenance_workers (integer)

Sets the maximum number of parallel workers that can be started by a single utility command. Currently, the parallel utility commands that support the use of parallel workers are CREATE INDEX only when building a B-tree index, and VACUUM without FULL option. Parallel workers are taken from the pool of processes established by max_worker_processes, limited by max_parallel_workers. Note that the requested number of workers may not actually be available at run time. If this occurs, the utility operation will run with fewer workers than expected. The default value is 2. Setting this value to 0 disables the use of parallel workers by utility commands.

Note that parallel utility commands should not consume substantially more memory than equivalent non-parallel operations. This strategy differs from that of parallel query, where resource limits generally apply per worker process. Parallel utility commands treat the resource limit maintenance_work_mem as a limit to be applied to the entire utility command, regardless of the number of parallel worker processes. However, parallel utility commands may still consume substantially more CPU resources and I/O bandwidth.

max_parallel_workers (integer)

Sets the maximum number of workers that the system can support for parallel operations. The default value is 8. When increasing or decreasing this value, consider also adjusting max_parallel_maintenance_workers and max_parallel_workers_per_gather. Also, note that a setting for this value which is higher than max_worker_processes will have no effect, since parallel workers are taken from the pool of worker processes established by that setting.

parallel_leader_participation (boolean)

Allows the leader process to execute the query plan under Gather and Gather Merge nodes instead of waiting for worker processes. The default is on. Setting this value to off reduces the likelihood that workers will become blocked because the leader is not reading tuples fast enough, but requires the leader process to wait for worker processes to start up before the first tuples can be produced. The degree to which the leader can help or hinder performance depends on the plan type, number of workers and query duration.

old_snapshot_threshold (integer)

Sets the minimum amount of time that a query snapshot can be used without risk of a “snapshot too old” error occurring when using the snapshot. Data that has been dead for longer than this threshold is allowed to be vacuumed away. This can help prevent bloat in the face of snapshots which remain in use for a long time. To prevent incorrect results due to cleanup of data which would otherwise be

visible to the snapshot, an error is generated when the snapshot is older than this threshold and the snapshot is used to read a page which has been modified since the snapshot was built.

If this value is specified without units, it is taken as minutes. A value of `-1` (the default) disables this feature, effectively setting the snapshot age limit to infinity. This parameter can only be set at server start.

Useful values for production work probably range from a small number of hours to a few days. Small values (such as `0` or `1min`) are only allowed because they may sometimes be useful for testing. While a setting as high as `60d` is allowed, please note that in many workloads extreme bloat or page-level transaction ID wraparound may occur in much shorter time frames.

When this feature is enabled, freed space at the end of a relation cannot be released to the operating system, since that could remove information needed to detect the “snapshot too old” condition. All space allocated to a relation remains associated with that relation for reuse only within that relation unless explicitly freed (for example, with `VACUUM FULL`).

This setting does not attempt to guarantee that an error will be generated under any particular circumstances. In fact, if the correct results can be generated from (for example) a cursor which has materialized a result set, no error will be generated even if the underlying rows in the referenced table have been vacuumed away. Some tables cannot safely be vacuumed early, and so will not be affected by this setting, such as system catalogs. For such tables this setting will neither reduce bloat nor create a possibility of a “snapshot too old” error on scanning.

19.4.7. Prioritization

`usage_tracking_interval` (`integer`)

Sets the time interval, in seconds, for calculating usage statistics. Based on this statistics, Postgres Pro Enterprise can control resource usage for each session in accordance with the prioritization policy configured by session_cpu_weight, session_ioread_weight, and session_iowrite_weight parameters.

When set to a positive value, this parameter starts a background worker that collects statistics on CPU time, the number of local and shared blocks read by the backends, and the number of local and shared blocks dirtied by the backends. Avoid setting this parameter to a small value as frequent statistic collection can cause overhead.

The default value is zero, which disables statistics collection and resource prioritization.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`session_cpu_weight` (`integer`)

Sets CPU usage weight for the current session. Possible values are `1`, `2`, `4`, and `8`. The higher the value, the more resources the session can use as compared to sessions with lower weights.

The usage_tracking_interval parameter must be set to a positive value for this setting to take effect. Resource usage is planned based on the statistics collected for the previous interval defined by usage_tracking_interval. If all sessions have the same weight, Postgres Pro Enterprise does not prioritize resource usage.

Default: `4`

`session_ioread_weight` (`integer`)

Sets the weight for reading local and shared blocks for the current session. Possible values are `1`, `2`, `4`, and `8`. The higher the value, the more resources the session can use as compared to sessions with lower weights.

The usage_tracking_interval parameter must be set to a positive value for this setting to take effect. Resource usage is planned based on the statistics collected for the previous interval defined by us-

age_tracking_interval. If all sessions have the same weight, Postgres Pro Enterprise does not prioritize resource usage.

Default: 4

session_iowrite_weight (integer)

Sets the weight for writing to local and shared blocks for the current session. Possible values are 1, 2, 4, and 8. The higher the value, the more resources the session can use as compared to sessions with lower weights.

The usage_tracking_interval parameter must be set to a positive value for this setting to take effect. Resource usage is planned based on the statistics collected for the previous interval defined by usage_tracking_interval. If all sessions have the same weight, Postgres Pro Enterprise does not prioritize resource usage.

Default: 4

19.5. Write Ahead Log

For additional information on tuning these settings, see Section 29.5.

19.5.1. Settings

wal_level (enum)

wal_level determines how much information is written to the WAL. The default value is replica, which writes enough data to support WAL archiving and replication, including running read-only queries on a standby server. minimal removes all logging except the information required to recover from a crash or immediate shutdown. Finally, logical adds information necessary to support logical decoding. Each level includes the information logged at all lower levels. This parameter can only be set at server start.

The minimal level generates the least WAL volume. It logs no row information for permanent relations in transactions that create or rewrite them. This can make operations much faster (see Section 14.4.7). Operations that initiate this optimization include:

```
ALTER ... SET TABLESPACE
CLUSTER
CREATE TABLE
REFRESH MATERIALIZED VIEW (without CONCURRENTLY)
REINDEX
TRUNCATE
```

However, minimal WAL does not contain sufficient information for point-in-time recovery, so replica or higher must be used to enable continuous archiving (archive_mode) and streaming binary replication. In fact, the server will not even start in this mode if max_wal_senders is non-zero. Note that changing wal_level to minimal makes previous base backups unusable for point-in-time recovery and standby servers.

In logical level, the same information is logged as with replica, plus information needed to extract logical change sets from the WAL. Using a level of logical will increase the WAL volume, particularly if many tables are configured for REPLICA IDENTITY FULL and many UPDATE and DELETE statements are executed.

In releases prior to 9.6, this parameter also allowed the values archive and hot_standby. These are still accepted but mapped to replica.

fsync (boolean)

If this parameter is on, the Postgres Pro server will try to make sure that updates are physically written to disk, by issuing fsync() system calls or various equivalent methods (see wal_sync_method).

This ensures that the database cluster can recover to a consistent state after an operating system or hardware crash.

While turning off `fsync` is often a performance benefit, this can result in unrecoverable data corruption in the event of a power failure or system crash. Thus it is only advisable to turn off `fsync` if you can easily recreate your entire database from external data.

Examples of safe circumstances for turning off `fsync` include the initial loading of a new database cluster from a backup file, using a database cluster for processing a batch of data after which the database will be thrown away and recreated, or for a read-only database clone which gets recreated frequently and is not used for failover. High quality hardware alone is not a sufficient justification for turning off `fsync`.

For reliable recovery when changing `fsync` off to on, it is necessary to force all modified buffers in the kernel to durable storage. This can be done while the cluster is shutdown or while `fsync` is on by running `initdb --sync-only`, running `sync`, unmounting the file system, or rebooting the server.

In many situations, turning off synchronous_commit for noncritical transactions can provide much of the potential performance benefit of turning off `fsync`, without the attendant risks of data corruption.

`fsync` can only be set in the `postgresql.conf` file or on the server command line. If you turn this parameter off, also consider turning off full_page_writes.

`synchronous_commit` (`enum`)

Specifies how much WAL processing must complete before the database server returns a “success” indication to the client. Valid values are `remote_apply`, `on` (the default), `remote_write`, `local`, and `off`.

If `synchronous_standby_names` is empty, the only meaningful settings are `on` and `off`; `remote_apply`, `remote_write` and `local` all provide the same local synchronization level as `on`. The local behavior of all non-`off` modes is to wait for local flush of WAL to disk. In `off` mode, there is no waiting, so there can be a delay between when success is reported to the client and when the transaction is later guaranteed to be safe against a server crash. (The maximum delay is three times wal_writer_delay.) Unlike fsync, setting this parameter to `off` does not create any risk of database inconsistency: an operating system or database crash might result in some recent allegedly-committed transactions being lost, but the database state will be just the same as if those transactions had been aborted cleanly. So, turning `synchronous_commit` off can be a useful alternative when performance is more important than exact certainty about the durability of a transaction. For more discussion see Section 29.4.

If synchronous_standby_names is non-empty, `synchronous_commit` also controls whether transaction commits will wait for their WAL records to be processed on the standby server(s).

When set to `remote_apply`, commits will wait until replies from the current synchronous standby(s) indicate they have received the commit record of the transaction and applied it, so that it has become visible to queries on the standby(s), and also written to durable storage on the standbys. This will cause much larger commit delays than previous settings since it waits for WAL replay. When set to `on`, commits wait until replies from the current synchronous standby(s) indicate they have received the commit record of the transaction and flushed it to durable storage. This ensures the transaction will not be lost unless both the primary and all synchronous standbys suffer corruption of their database storage. When set to `remote_write`, commits will wait until replies from the current synchronous standby(s) indicate they have received the commit record of the transaction and written it to their file systems. This setting ensures data preservation if a standby instance of Postgres Pro crashes, but not if the standby suffers an operating-system-level crash because the data has not necessarily reached durable storage on the standby. The setting `local` causes commits to wait for local flush to disk, but not for replication. This is usually not desirable when synchronous replication is in use, but is provided for completeness.

This parameter can be changed at any time; the behavior for any one transaction is determined by the setting in effect when it commits. It is therefore possible, and useful, to have some transactions

commit synchronously and others asynchronously. For example, to make a single multistatement transaction commit asynchronously when the default is the opposite, issue `SET LOCAL synchronous_commit TO OFF` within the transaction.

Table 19.2 summarizes the capabilities of the `synchronous_commit` settings.

Table 19.2. synchronous_commit Modes

synchronous_commit setting	local durable commit	standby durable commit after PG crash	standby durable commit after OS crash	standby query consistency
remote_apply	•	•	•	•
on	•	•	•	
remote_write	•	•		
local	•			
off				

`wal_sync_method` (`enum`)

Method used for forcing WAL updates out to disk. If `fsync` is off then this setting is irrelevant, since WAL file updates will not be forced out at all. Possible values are:

- `open_datasync` (write WAL files with `open()` option `O_DSYNC`)
- `fdatasync` (call `fdatasync()` at each commit)
- `fsync` (call `fsync()` at each commit)
- `fsync_writethrough` (call `fsync()` at each commit, forcing write-through of any disk write cache)
- `open_sync` (write WAL files with `open()` option `O_SYNC`)

The `open_*` options also use `O_DIRECT` if available. Not all of these choices are available on all platforms. The default is the first method in the above list that is supported by the platform, except that `fdatasync` is the default on Linux and FreeBSD. The default is not necessarily ideal; it might be necessary to change this setting or other aspects of your system configuration in order to create a crash-safe configuration or achieve optimal performance. These aspects are discussed in Section 29.1. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`full_page_writes` (`boolean`)

When this parameter is on, the Postgres Pro server writes the entire content of each disk page to WAL during the first modification of that page after a checkpoint. This is needed because a page write that is in process during an operating system crash might be only partially completed, leading to an on-disk page that contains a mix of old and new data. The row-level change data normally stored in WAL will not be enough to completely restore such a page during post-crash recovery. Storing the full page image guarantees that the page can be correctly restored, but at the price of increasing the amount of data that must be written to WAL. (Because WAL replay always starts from a checkpoint, it is sufficient to do this during the first change of each page after a checkpoint. Therefore, one way to reduce the cost of full-page writes is to increase the checkpoint interval parameters.)

Turning this parameter off speeds normal operation, but might lead to either unrecoverable data corruption, or silent data corruption, after a system failure. The risks are similar to turning off `fsync`, though smaller, and it should be turned off only based on the same circumstances recommended for that parameter.

Turning off this parameter does not affect use of WAL archiving for point-in-time recovery (PITR) (see Section 25.3).

This parameter can only be set in the postgresql.conf file or on the server command line. The default is on.

wal_log_hints (boolean)

When this parameter is on, the Postgres Pro server writes the entire content of each disk page to WAL during the first modification of that page after a checkpoint, even for non-critical modifications of so-called hint bits.

If data checksums are enabled, hint bit updates are always WAL-logged and this setting is ignored. You can use this setting to test how much extra WAL-logging would occur if your database had data checksums enabled.

This parameter can only be set at server start. The default value is off.

wal_compression (boolean)

When this parameter is on, the Postgres Pro server compresses full page images written to WAL when full_page_writes is on or during a base backup. A compressed page image will be decompressed during WAL replay. The default value is off. Only superusers can change this setting.

Turning this parameter on can reduce the WAL volume without increasing the risk of unrecoverable data corruption, but at the cost of some extra CPU spent on the compression during WAL logging and on the decompression during WAL replay.

wal_init_zero (boolean)

If set to on (the default), this option causes new WAL files to be filled with zeroes. On some file systems, this ensures that space is allocated before we need to write WAL records. However, *Copy-On-Write* (COW) file systems may not benefit from this technique, so the option is given to skip the unnecessary work. If set to off, only the final byte is written when the file is created so that it has the expected size.

wal_recycle (boolean)

If set to on (the default), this option causes WAL files to be recycled by renaming them, avoiding the need to create new ones. On COW file systems, it may be faster to create new ones, so the option is given to disable this behavior.

wal_buffers (integer)

The amount of shared memory used for WAL data that has not yet been written to disk. The default setting of -1 selects a size equal to 1/32nd (about 3%) of shared_buffers, but not less than 64kB nor more than the size of one WAL segment, typically 16MB. This value can be set manually if the automatic choice is too large or too small, but any positive value less than 32kB will be treated as 32kB. If this value is specified without units, it is taken as WAL blocks, that is XLOG_BLCKSZ bytes, typically 8kB. This parameter can only be set at server start.

The contents of the WAL buffers are written out to disk at every transaction commit, so extremely large values are unlikely to provide a significant benefit. However, setting this value to at least a few megabytes can improve write performance on a busy server where many clients are committing at once. The auto-tuning selected by the default setting of -1 should give reasonable results in most cases.

wal_writer_delay (integer)

Specifies how often the WAL writer flushes WAL, in time terms. After flushing WAL the writer sleeps for the length of time given by wal_writer_delay, unless woken up sooner by an asynchronously committing transaction. If the last flush happened less than wal_writer_delay ago and less than wal_writer_flush_after worth of WAL has been produced since, then WAL is only written to the operating system, not flushed to disk. If this value is specified without units, it is taken as milliseconds. The default value is 200 milliseconds (200ms). Note that on many systems, the effective resolution of sleep delays is 10 milliseconds; setting wal_writer_delay to a value that is not a multiple

of 10 might have the same results as setting it to the next higher multiple of 10. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`wal_writer_flush_after` (`integer`)

Specifies how often the WAL writer flushes WAL, in volume terms. If the last flush happened less than `wal_writer_delay` ago and less than `wal_writer_flush_after` worth of WAL has been produced since, then WAL is only written to the operating system, not flushed to disk. If `wal_writer_flush_after` is set to `0` then WAL data is always flushed immediately. If this value is specified without units, it is taken as WAL blocks, that is `XLOG_BLCKSZ` bytes, typically 8kB. The default is `1MB`. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`wal_skip_threshold` (`integer`)

When `wal_level` is `minimal` and a transaction commits after creating or rewriting a permanent relation, this setting determines how to persist the new data. If the data is smaller than this setting, write it to the WAL log; otherwise, use an fsync of affected files. Depending on the properties of your storage, raising or lowering this value might help if such commits are slowing concurrent transactions. If this value is specified without units, it is taken as kilobytes. The default is two megabytes (`2MB`).

`commit_delay` (`integer`)

Setting `commit_delay` adds a time delay before a WAL flush is initiated. This can improve group commit throughput by allowing a larger number of transactions to commit via a single WAL flush, if system load is high enough that additional transactions become ready to commit within the given interval. However, it also increases latency by up to the `commit_delay` for each WAL flush. Because the delay is just wasted if no other transactions become ready to commit, a delay is only performed if at least `commit_siblings` other transactions are active when a flush is about to be initiated. Also, no delays are performed if `fsync` is disabled. If this value is specified without units, it is taken as microseconds. The default `commit_delay` is zero (no delay). Only superusers can change this setting.

In PostgreSQL releases prior to 9.3, `commit_delay` behaved differently and was much less effective: it affected only commits, rather than all WAL flushes, and waited for the entire configured delay even if the WAL flush was completed sooner. Beginning in PostgreSQL 9.3, the first process that becomes ready to flush waits for the configured interval, while subsequent processes wait only until the leader completes the flush operation.

`commit_siblings` (`integer`)

Minimum number of concurrent open transactions to require before performing the `commit_delay` delay. A larger value makes it more probable that at least one other transaction will become ready to commit during the delay interval. The default is five transactions.

`wal_sender_check_crc` (`boolean`)

When this parameter is `on`, during replication the WAL sender process checks the CRC value of each record before sending it to a replica, and memory for a second copy of WAL buffers is allocated. The default value is `off`. This parameter can only be set at server start.

`wal_sender_panic_on_crc_error` (`boolean`)

When this parameter is `on`, Postgres Pro raises a PANIC-level error if a corrupted WAL record could not be restored from WAL buffers. The default value is `off` for raising a FATAL-level error. This parameter can only be set at server start.

19.5.2. Checkpoints

`checkpoint_timeout` (`integer`)

Maximum time between automatic WAL checkpoints. If this value is specified without units, it is taken as seconds. The valid range is between 30 seconds and one day. The default is five minutes (`5min`). Increasing this parameter can increase the amount of time needed for crash recovery. This parameter can only be set in the `postgresql.conf` file or on the server command line.

checkpoint_completion_target (floating point)

Specifies the target of checkpoint completion, as a fraction of total time between checkpoints. The default is 0.9, which spreads the checkpoint across almost all of the available interval, providing fairly consistent I/O load while also leaving some time for checkpoint completion overhead. Reducing this parameter is not recommended because it causes the checkpoint to complete faster. This results in a higher rate of I/O during the checkpoint followed by a period of less I/O between the checkpoint completion and the next scheduled checkpoint. This parameter can only be set in the postgresql.conf file or on the server command line.

checkpoint_flush_after (integer)

Whenever more than this amount of data has been written while performing a checkpoint, attempt to force the OS to issue these writes to the underlying storage. Doing so will limit the amount of dirty data in the kernel's page cache, reducing the likelihood of stalls when an fsync is issued at the end of the checkpoint, or when the OS writes data back in larger batches in the background. Often that will result in greatly reduced transaction latency, but there also are some cases, especially with workloads that are bigger than shared_buffers, but smaller than the OS's page cache, where performance might degrade. This setting may have no effect on some platforms. If this value is specified without units, it is taken as blocks, that is BLCKSZ bytes, typically 8kB. The valid range is between 0, which disables forced writeback, and 2MB. The default is 256kB on Linux, 0 elsewhere. (If BLCKSZ is not 8kB, the default and maximum values scale proportionally to it.) This parameter can only be set in the postgresql.conf file or on the server command line.

checkpoint_warning (integer)

Write a message to the server log if checkpoints caused by the filling of WAL segment files happen closer together than this amount of time (which suggests that max_wal_size ought to be raised). If this value is specified without units, it is taken as seconds. The default is 30 seconds (30s). Zero disables the warning. No warnings will be generated if checkpoint_timeout is less than checkpoint_warning. This parameter can only be set in the postgresql.conf file or on the server command line.

max_wal_size (integer)

Maximum size to let the WAL grow during automatic checkpoints. This is a soft limit; WAL size can exceed max_wal_size under special circumstances, such as heavy load, a failing archive_command, or a high wal_keep_size setting. If this value is specified without units, it is taken as megabytes. The default is 1 GB. Increasing this parameter can increase the amount of time needed for crash recovery. This parameter can only be set in the postgresql.conf file or on the server command line.

min_wal_size (integer)

As long as WAL disk usage stays below this setting, old WAL files are always recycled for future use at a checkpoint, rather than removed. This can be used to ensure that enough WAL space is reserved to handle spikes in WAL usage, for example when running large batch jobs. If this value is specified without units, it is taken as megabytes. The default is 80 MB. This parameter can only be set in the postgresql.conf file or on the server command line.

19.5.3. Archiving

archive_mode (enum)

When archive_mode is enabled, completed WAL segments are sent to archive storage by setting archive_command. In addition to off, to disable, there are two modes: on, and always. During normal operation, there is no difference between the two modes, but when set to always the WAL archiver is enabled also during archive recovery or standby mode. In always mode, all files restored from the archive or streamed with streaming replication will be archived (again). See Section 26.2.9 for details.

archive_mode and archive_command are separate variables so that archive_command can be changed without leaving archiving mode. This parameter can only be set at server start. archive_mode cannot be enabled when wal_level is set to minimal.

archive_command (

last valid restart point. That is the earliest file that must be kept to allow a restore to be restartable, so this information can be used to truncate the archive to just the minimum required to support restarting from the current restore. `%r` is typically only used by warm-standby configurations (see Section 26.2). Write `%%` to embed an actual `%` character.

It is important for the command to return a zero exit status only if it succeeds. The command *will* be asked for file names that are not present in the archive; it must return nonzero when so asked. Examples:

```
restore_command = 'cp /mnt/server/archivedir/%f "%p"'
restore_command = 'copy "C:\\server\\archivedir\\%f" "%p"'  # Windows
```

An exception is that if the command was terminated by a signal (other than SIGTERM, which is used as part of a database server shutdown) or an error by the shell (such as command not found), then recovery will abort and the server will not start up.

`archive_cleanup_command` (`string`)

This optional parameter specifies a shell command that will be executed at every restartpoint. The purpose of `archive_cleanup_command` is to provide a mechanism for cleaning up old archived WAL files that are no longer needed by the standby server. Any `%r` is replaced by the name of the file containing the last valid restart point. That is the earliest file that must be *kept* to allow a restore to be restartable, and so all files earlier than `%r` may be safely removed. This information can be used to truncate the archive to just the minimum required to support restart from the current restore. The pg_archivecleanup module is often used in `archive_cleanup_command` for single-standby configurations, for example:

```
archive_cleanup_command = 'pg_archivecleanup /mnt/server/archivedir %r'
```

Note however that if multiple standby servers are restoring from the same archive directory, you will need to ensure that you do not delete WAL files until they are no longer needed by any of the servers. `archive_cleanup_command` would typically be used in a warm-standby configuration (see Section 26.2). Write `%%` to embed an actual `%` character in the command.

If the command returns a nonzero exit status then a warning log message will be written. An exception is that if the command was terminated by a signal or an error by the shell (such as command not found), a fatal error will be raised.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`recovery_end_command` (`string`)

This parameter specifies a shell command that will be executed once only at the end of recovery. This parameter is optional. The purpose of the `recovery_end_command` is to provide a mechanism for cleanup following replication or recovery. Any `%r` is replaced by the name of the file containing the last valid restart point, like in archive_cleanup_command.

If the command returns a nonzero exit status then a warning log message will be written and the database will proceed to start up anyway. An exception is that if the command was terminated by a signal or an error by the shell (such as command not found), the database will not proceed with startup.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.5.5. Recovery Target

By default, recovery will recover to the end of the WAL log. The following parameters can be used to specify an earlier stopping point. At most one of `recovery_target`, `recovery_target_lsn`, `recovery_target_name`, `recovery_target_time`, or `recovery_target_xid` can be used; if more than one of these is specified in the configuration file, an error will be raised. These parameters can only be set at server start.

`recovery_target = 'immediate'`

This parameter specifies that recovery should end as soon as a consistent state is reached, i.e., as early as possible. When restoring from an online backup, this means the point where taking the backup ended.

Technically, this is a string parameter, but `'immediate'` is currently the only allowed value.

`recovery_target_name` (`string`)

This parameter specifies the named restore point (created with `pg_create_restore_point()`) to which recovery will proceed.

`recovery_target_time` (`timestamp`)

This parameter specifies the time stamp up to which recovery will proceed. The precise stopping point is also influenced by recovery_target_inclusive.

The value of this parameter is a time stamp in the same format accepted by the `timestamp with time zone` data type, except that you cannot use a time zone abbreviation (unless the timezone_abbreviations variable has been set earlier in the configuration file). Preferred style is to use a numeric offset from UTC, or you can write a full time zone name, e.g., `Europe/Helsinki` not `EEST`.

`recovery_target_xid` (`string`)

This parameter specifies the transaction ID up to which recovery will proceed. Keep in mind that while transaction IDs are assigned sequentially at transaction start, transactions can complete in a different numeric order. The transactions that will be recovered are those that committed before (and optionally including) the specified one. The precise stopping point is also influenced by recovery_target_inclusive.

`recovery_target_lsn` (`pg_lsn`)

This parameter specifies the LSN of the write-ahead log location up to which recovery will proceed. The precise stopping point is also influenced by recovery_target_inclusive. This parameter is parsed using the system data type `pg_lsn`.

The following options further specify the recovery target, and affect what happens when the target is reached:

`recovery_target_inclusive` (`boolean`)

Specifies whether to stop just after the specified recovery target (`on`), or just before the recovery target (`off`). Applies when recovery_target_lsn, recovery_target_time, or recovery_target_xid is specified. This setting controls whether transactions having exactly the target WAL location (LSN), commit time, or transaction ID, respectively, will be included in the recovery. Default is `on`.

`recovery_target_timeline` (`string`)

Specifies recovering into a particular timeline. The value can be a numeric timeline ID or a special value. The value `current` recovers along the same timeline that was current when the base backup was taken. The value `latest` recovers to the latest timeline found in the archive, which is useful in a standby server. `latest` is the default.

You usually only need to set this parameter in complex re-recovery situations, where you need to return to a state that itself was reached after a point-in-time recovery. See Section 25.3.5 for discussion.

`recovery_target_action` (`enum`)

Specifies what action the server should take once the recovery target is reached. The default is `pause`, which means recovery will be paused. `promote` means the recovery process will finish and the server will start to accept connections. Finally `shutdown` will stop the server after reaching the recovery target.

The intended use of the `pause` setting is to allow queries to be executed against the database to check if this recovery target is the most desirable point for recovery. The paused state can be resumed by using `pg_wal_replay_resume()` (see Table 9.89), which then causes recovery to end. If this recovery target is not the desired stopping point, then shut down the server, change the recovery target settings to a later target and restart to continue recovery.

The `shutdown` setting is useful to have the instance ready at the exact replay point desired. The instance will still be able to replay more WAL records (and in fact will have to replay WAL records since the last checkpoint next time it is started).

Note that because `recovery.signal` will not be removed when `recovery_target_action` is set to `shutdown`, any subsequent start will end with immediate shutdown unless the configuration is changed or the `recovery.signal` file is removed manually.

This setting has no effect if no recovery target is set. If hot_standby is not enabled, a setting of `pause` will act the same as `shutdown`. If the recovery target is reached while a promotion is ongoing, a setting of `pause` will act the same as `promote`.

In any case, if a recovery target is configured but the archive recovery ends before the target is reached, the server will shut down with a fatal error.

19.6. Replication

These settings control the behavior of the built-in *streaming replication* feature (see Section 26.2.5). Servers will be either a primary or a standby server. Primaries can send data, while standbys are always receivers of replicated data. When cascading replication (see Section 26.2.7) is used, standby servers can also be senders, as well as receivers. Parameters are mainly for sending and standby servers, though some parameters have meaning only on the primary server. Settings may vary across the cluster without problems if that is required.

19.6.1. Sending Servers

These parameters can be set on any server that is to send replication data to one or more standby servers. The primary is always a sending server, so these parameters must always be set on the primary. The role and meaning of these parameters does not change after a standby becomes the primary.

`max_wal_senders` (`integer`)

Specifies the maximum number of concurrent connections from standby servers or streaming base backup clients (i.e., the maximum number of simultaneously running WAL sender processes). The default is `10`. The value `0` means replication is disabled. Abrupt disconnection of a streaming client might leave an orphaned connection slot behind until a timeout is reached, so this parameter should be set slightly higher than the maximum number of expected clients so disconnected clients can immediately reconnect. This parameter can only be set at server start. Also, `wal_level` must be set to `replica` or higher to allow connections from standby servers.

When running a standby server, you must set this parameter to the same or higher value than on the primary server. Otherwise, queries will not be allowed in the standby server.

`max_replication_slots` (`integer`)

Specifies the maximum number of replication slots (see Section 26.2.6) that the server can support. The default is 10. This parameter can only be set at server start. Setting it to a lower value than the number of currently existing replication slots will prevent the server from starting. Also, `wal_level` must be set to `replica` or higher to allow replication slots to be used.

On the subscriber side, specifies how many replication origins (see Chapter 52) can be tracked simultaneously, effectively limiting how many logical replication subscriptions can be created on the server. Setting it to a lower value than the current number of tracked replication origins (reflected in pg_replication_origin_status, not pg_replication_origin) will prevent the server from starting.

`wal_keep_size` (`integer`)

Specifies the minimum size of past log file segments kept in the `pg_wal` directory, in case a standby server needs to fetch them for streaming replication. If a standby server connected to the sending server falls behind by more than `wal_keep_size` megabytes, the sending server might remove a WAL segment still needed by the standby, in which case the replication connection will be terminated. Downstream connections will also eventually fail as a result. (However, the standby server can recover by fetching the segment from archive, if WAL archiving is in use.)

This sets only the minimum size of segments retained in `pg_wal`; the system might need to retain more segments for WAL archival or to recover from a checkpoint. If `wal_keep_size` is zero (the default), the system doesn't keep any extra segments for standby purposes, so the number of old WAL segments available to standby servers is a function of the location of the previous checkpoint and status of WAL archiving. If this value is specified without units, it is taken as megabytes. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`max_slot_wal_keep_size` (`integer`)

Specify the maximum size of WAL files that replication slots are allowed to retain in the `pg_wal` directory at checkpoint time. If `max_slot_wal_keep_size` is -1 (the default), replication slots may retain an unlimited amount of WAL files. Otherwise, if restart_lsn of a replication slot falls behind the current LSN by more than the given size, the standby using the slot may no longer be able to continue replication due to removal of required WAL files. You can see the WAL availability of replication slots in pg_replication_slots. If this value is specified without units, it is taken as megabytes. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`wal_sender_timeout` (`integer`)

Terminate replication connections that are inactive for longer than this amount of time. This is useful for the sending server to detect a standby crash or network outage. If this value is specified without units, it is taken as milliseconds. The default value is 60 seconds. A value of zero disables the timeout mechanism.

With a cluster distributed across multiple geographic locations, using different values per location brings more flexibility in the cluster management. A smaller value is useful for faster failure detection with a standby having a low-latency network connection, and a larger value helps in judging better the health of a standby if located on a remote location, with a high-latency network connection.

`track_commit_timestamp` (`boolean`)

Record commit time of transactions. This parameter can only be set in `postgresql.conf` file or on the server command line. The default value is `off`.

`page_repair` (`boolean`)

Enable page repair via streaming replication from standby in case of data corruption. This parameter can only be set in `postgresql.conf` file or on the server command line. The default value is `off`.

19.6.2. Primary Server

These parameters can be set on the primary server that is to send replication data to one or more standby servers. Note that in addition to these parameters, wal_level must be set appropriately on the primary server, and optionally WAL archiving can be enabled as well (see Section 19.5.3). The values of these parameters on standby servers are irrelevant, although you may wish to set them there in preparation for the possibility of a standby becoming the primary.

`synchronous_standby_names` (`string`)

Specifies a list of standby servers that can support *synchronous replication*, as described in Section 26.2.8. There will be one or more active synchronous standbys; transactions waiting for commit will be allowed to proceed after these standby servers confirm receipt of their data. The synchronous standbys will be those whose names appear in this list, and that are both currently connected and

streaming data in real-time (as shown by a state of `streaming` in the `pg_stat_replication` view). Specifying more than one synchronous standby can allow for very high availability and protection against data loss.

The name of a standby server for this purpose is the `application_name` setting of the standby, as set in the standby's connection information. In case of a physical replication standby, this should be set in the `primary_conninfo` setting; the default is the setting of cluster_name if set, else `walreceiver`. For logical replication, this can be set in the connection information of the subscription, and it defaults to the subscription name. For other replication stream consumers, consult their documentation.

This parameter specifies a list of standby servers using either of the following syntaxes:

```
[FIRST] num_sync [MIN num_sync_min] ( standby_name [, ...] )
ANY num_sync [MIN num_sync_min] ( standby_name [, ...] )
standby_name [, ...]
```

where *`num_sync`* is the number of synchronous standbys that transactions need to wait for replies from, *`num_sync_min`* is the minimum number of synchronous standbys that must be connected to the primary server for it to continue running, and *`standby_name`* is the name of a standby server. `FIRST` and `ANY` specify the method to choose synchronous standbys from the listed servers. `MIN` allows to avoid the primary server blocking if some of the standbys are temporarily unavailable.

The keyword `FIRST`, coupled with *`num_sync`*, specifies a priority-based synchronous replication and makes transaction commits wait until their WAL records are replicated to *`num_sync`* synchronous standbys chosen based on their priorities. For example, a setting of `FIRST 3 (s1, s2, s3, s4)` will cause each commit to wait for replies from three higher-priority standbys chosen from standby servers `s1`, `s2`, `s3` and `s4`. The standbys whose names appear earlier in the list are given higher priority and will be considered as synchronous. Other standby servers appearing later in this list represent potential synchronous standbys. If any of the current synchronous standbys disconnects for whatever reason, it will be replaced immediately with the next-highest-priority standby. The keyword `FIRST` is optional.

The keyword `ANY`, coupled with *`num_sync`*, specifies a quorum-based synchronous replication and makes transaction commits wait until their WAL records are replicated to *at least* *`num_sync`* listed standbys. For example, a setting of `ANY 3 (s1, s2, s3, s4)` will cause each commit to proceed as soon as at least any three standbys of `s1`, `s2`, `s3` and `s4` reply.

`FIRST` and `ANY` are case-insensitive. If these keywords are used as the name of a standby server, its *`standby_name`* must be double-quoted.

The optional `MIN` *`num_sync_min`* setting relaxes the standby requirements specified by `FIRST` and `ANY`. If the primary loses connection to one or more synchronous standbys, it continues running while at least *`num_sync_min`* standby servers are available. Once the connection is restored, the behavior of the primary server depends on the synchronous_standby_gap setting.

The third syntax was used before PostgreSQL version 9.6 and is still supported. It's the same as the first syntax with `FIRST` and *`num_sync`* equal to 1. For example, `FIRST 1 (s1, s2)` and `s1, s2` have the same meaning: either `s1` or `s2` is chosen as a synchronous standby.

The special entry `*` matches any standby name.

There is no mechanism to enforce uniqueness of standby names. In case of duplicates one of the matching standbys will be considered as higher priority, though exactly which one is indeterminate.

> **Note**
>
> Each *`standby_name`* should have the form of a valid SQL identifier, unless it is `*`. You can use double-quoting if necessary. But note that *`standby_name`*s are compared to standby application names case-insensitively, whether double-quoted or not.

If no synchronous standby names are specified here, then synchronous replication is not enabled and transaction commits will not wait for replication. This is the default configuration. Even when synchronous replication is enabled, individual transactions can be configured not to wait for replication by setting the synchronous_commit parameter to `local` or `off`.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`synchronous_standby_gap` (`integer`)

Specifies the WAL data gap between the primary server and its synchronous standbys, in kilobytes. Setting this parameter to a positive value allows to minimize the primary server downtime when using synchronous replication. If a standby lags behind the primary for more than the specified gap, the primary server continues running while the standby tries to catch up. Once the standby reaches the specified gap, the primary is blocked to complete standby synchronization. See Section 26.2.8.1 for details.

The default value is 0, which means that the primary is always blocked while a synchronous standby replays WAL data.

`vacuum_defer_cleanup_age` (`integer 64`)

Specifies the number of transactions by which `VACUUM` and HOT updates will defer cleanup of dead row versions. The default is zero transactions, meaning that dead row versions can be removed as soon as possible, that is, as soon as they are no longer visible to any open transaction. You may wish to set this to a non-zero value on a primary server that is supporting hot standby servers, as described in Section 26.4. This allows more time for queries on the standby to complete without incurring conflicts due to early cleanup of rows. However, since the value is measured in terms of number of write transactions occurring on the primary server, it is difficult to predict just how much additional grace time will be made available to standby queries. This parameter can only be set in the `postgresql.conf` file or on the server command line.

You should also consider setting `hot_standby_feedback` on standby server(s) as an alternative to using this parameter.

This does not prevent cleanup of dead rows which have reached the age specified by `old_snapshot_threshold`.

19.6.3. Standby Servers

These settings control the behavior of a standby server that is to receive replication data. Their values on the primary server are irrelevant.

`primary_conninfo` (`string`)

Specifies a connection string to be used for the standby server to connect with a sending server. This string is in the format described in Section 36.1.1. If any option is unspecified in this string, then the corresponding environment variable (see Section 36.15) is checked. If the environment variable is not set either, then defaults are used.

The connection string should specify the host name (or address) of the sending server, as well as the port number if it is not the same as the standby server's default. Also specify a user name corresponding to a suitably-privileged role on the sending server (see Section 26.2.5.1). A password needs to be provided too, if the sender demands password authentication. It can be provided in the `primary_conninfo` string, or in a separate `~/.pgpass` file on the standby server (use `replication` as the database name). Do not specify a database name in the `primary_conninfo` string.

This parameter can only be set in the `postgresql.conf` file or on the server command line. If this parameter is changed while the WAL receiver process is running, that process is signaled to shut down and expected to restart with the new setting (except if `primary_conninfo` is an empty string). This setting has no effect if the server is not in standby mode.

`primary_slot_name` (`string`)

Optionally specifies an existing replication slot to be used when connecting to the sending server via streaming replication to control resource removal on the upstream node (see Section 26.2.6). This parameter can only be set in the `postgresql.conf` file or on the server command line. If this parameter is changed while the WAL receiver process is running, that process is signaled to shut down and expected to restart with the new setting. This setting has no effect if `primary_conninfo` is not set or the server is not in standby mode.

`promote_trigger_file` (`string`)

Specifies a trigger file whose presence ends recovery in the standby. Even if this value is not set, you can still promote the standby using `pg_ctl promote` or calling `pg_promote()`. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`hot_standby` (`boolean`)

Specifies whether or not you can connect and run queries during recovery, as described in Section 26.4. The default value is `on`. This parameter can only be set at server start. It only has effect during archive recovery or in standby mode.

`max_standby_archive_delay` (`integer`)

When Hot Standby is active, this parameter determines how long the standby server should wait before canceling standby queries that conflict with about-to-be-applied WAL entries, as described in Section 26.4.2. `max_standby_archive_delay` applies when WAL data is being read from WAL archive (and is therefore not current). If this value is specified without units, it is taken as milliseconds. The default is 30 seconds. A value of -1 allows the standby to wait forever for conflicting queries to complete. This parameter can only be set in the `postgresql.conf` file or on the server command line.

Note that `max_standby_archive_delay` is not the same as the maximum length of time a query can run before cancellation; rather it is the maximum total time allowed to apply any one WAL segment's data. Thus, if one query has resulted in significant delay earlier in the WAL segment, subsequent conflicting queries will have much less grace time.

`max_standby_streaming_delay` (`integer`)

When Hot Standby is active, this parameter determines how long the standby server should wait before canceling standby queries that conflict with about-to-be-applied WAL entries, as described in Section 26.4.2. `max_standby_streaming_delay` applies when WAL data is being received via streaming replication. If this value is specified without units, it is taken as milliseconds. The default is 30 seconds. A value of -1 allows the standby to wait forever for conflicting queries to complete. This parameter can only be set in the `postgresql.conf` file or on the server command line.

Note that `max_standby_streaming_delay` is not the same as the maximum length of time a query can run before cancellation; rather it is the maximum total time allowed to apply WAL data once it has been received from the primary server. Thus, if one query has resulted in significant delay, subsequent conflicting queries will have much less grace time until the standby server has caught up again.

`wal_receiver_create_temp_slot` (`boolean`)

Specifies whether the WAL receiver process should create a temporary replication slot on the remote instance when no permanent replication slot to use has been configured (using primary_slot_name). The default is off. This parameter can only be set in the `postgresql.conf` file or on the server command line. If this parameter is changed while the WAL receiver process is running, that process is signaled to shut down and expected to restart with the new setting.

`wal_receiver_status_interval` (`integer`)

Specifies the minimum frequency for the WAL receiver process on the standby to send information about replication progress to the primary or upstream standby, where it can be seen using the `pg_stat_replication` view. The standby will report the last write-ahead log location it has written, the

last position it has flushed to disk, and the last position it has applied. This parameter's value is the maximum amount of time between reports. Updates are sent each time the write or flush positions change, or as often as specified by this parameter if set to a non-zero value. There are additional cases where updates are sent while ignoring this parameter; for example, when processing of the existing WAL completes or when `synchronous_commit` is set to `remote_apply`. Thus, the apply position may lag slightly behind the true position. If this value is specified without units, it is taken as seconds. The default value is 10 seconds. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`hot_standby_feedback` (`boolean`)

Specifies whether or not a hot standby will send feedback to the primary or upstream standby about queries currently executing on the standby. This parameter can be used to eliminate query cancels caused by cleanup records, but can cause database bloat on the primary for some workloads. Feedback messages will not be sent more frequently than once per `wal_receiver_status_interval`. The default value is `off`. This parameter can only be set in the `postgresql.conf` file or on the server command line.

If cascaded replication is in use the feedback is passed upstream until it eventually reaches the primary. Standbys make no other use of feedback they receive other than to pass upstream.

This setting does not override the behavior of `old_snapshot_threshold` on the primary; a snapshot on the standby which exceeds the primary's age threshold can become invalid, resulting in cancellation of transactions on the standby. This is because `old_snapshot_threshold` is intended to provide an absolute limit on the time which dead rows can contribute to bloat, which would otherwise be violated because of the configuration of a standby.

`wal_receiver_timeout` (`integer`)

Terminate replication connections that are inactive for longer than this amount of time. This is useful for the receiving standby server to detect a primary node crash or network outage. If this value is specified without units, it is taken as milliseconds. The default value is 60 seconds. A value of zero disables the timeout mechanism. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`wal_retrieve_retry_interval` (`integer`)

Specifies how long the standby server should wait when WAL data is not available from any sources (streaming replication, local `pg_wal` or WAL archive) before trying again to retrieve WAL data. If this value is specified without units, it is taken as milliseconds. The default value is 5 seconds. This parameter can only be set in the `postgresql.conf` file or on the server command line.

This parameter is useful in configurations where a node in recovery needs to control the amount of time to wait for new WAL data to be available. For example, in archive recovery, it is possible to make the recovery more responsive in the detection of a new WAL log file by reducing the value of this parameter. On a system with low WAL activity, increasing it reduces the amount of requests necessary to access WAL archives, something useful for example in cloud environments where the amount of times an infrastructure is accessed is taken into account.

`recovery_min_apply_delay` (`integer`)

By default, a standby server restores WAL records from the sending server as soon as possible. It may be useful to have a time-delayed copy of the data, offering opportunities to correct data loss errors. This parameter allows you to delay recovery by a specified amount of time. For example, if you set this parameter to `5min`, the standby will replay each transaction commit only when the system time on the standby is at least five minutes past the commit time reported by the primary. If this value is specified without units, it is taken as milliseconds. The default is zero, adding no delay.

It is possible that the replication delay between servers exceeds the value of this parameter, in which case no delay is added. Note that the delay is calculated between the WAL time stamp as written on primary and the current time on the standby. Delays in transfer because of network lag or cascading

replication configurations may reduce the actual wait time significantly. If the system clocks on primary and standby are not synchronized, this may lead to recovery applying records earlier than expected; but that is not a major issue because useful settings of this parameter are much larger than typical time deviations between servers.

The delay occurs only on WAL records for transaction commits. Other records are replayed as quickly as possible, which is not a problem because MVCC visibility rules ensure their effects are not visible until the corresponding commit record is applied.

The delay occurs once the database in recovery has reached a consistent state, until the standby is promoted or triggered. After that the standby will end recovery without further waiting.

This parameter is intended for use with streaming replication deployments; however, if the parameter is specified it will be honored in all cases except crash recovery. `hot_standby_feedback` will be delayed by use of this feature which could lead to bloat on the primary; use both together with care.

> **Warning**
>
> Synchronous replication is affected by this setting when `synchronous_commit` is set to `remote_apply`; every `COMMIT` will need to wait to be applied.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.6.4. Subscribers

These settings control the behavior of a logical replication subscriber. Their values on the publisher are irrelevant.

Note that `wal_receiver_timeout`, `wal_receiver_status_interval` and `wal_retrieve_retry_interval` configuration parameters affect the logical replication workers as well.

`max_logical_replication_workers` (`int`)

Specifies maximum number of logical replication workers. This includes both apply workers and table synchronization workers.

Logical replication workers are taken from the pool defined by `max_worker_processes`.

The default value is 4. This parameter can only be set at server start.

`max_sync_workers_per_subscription` (`integer`)

Maximum number of synchronization workers per subscription. This parameter controls the amount of parallelism of the initial data copy during the subscription initialization or when new tables are added.

Currently, there can be only one synchronization worker per table.

The synchronization workers are taken from the pool defined by `max_logical_replication_workers`.

The default value is 2. This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.7. Query Planning

19.7.1. Planner Method Configuration

These configuration parameters provide a crude method of influencing the query plans chosen by the query optimizer. If the default plan chosen by the optimizer for a particular query is not optimal, a

temporary solution is to use one of these configuration parameters to force the optimizer to choose a different plan. Better ways to improve the quality of the plans chosen by the optimizer include adjusting the planner cost constants (see Section 19.7.2), running `ANALYZE` manually, increasing the value of the default_statistics_target configuration parameter, and increasing the amount of statistics collected for specific columns using `ALTER TABLE SET STATISTICS`.

`enable_async_append` (`boolean`)

Enables or disables the query planner's use of async-aware append plan types. The default is `on`.

`enable_bitmapscan` (`boolean`)

Enables or disables the query planner's use of bitmap-scan plan types. The default is `on`.

`enable_gathermerge` (`boolean`)

Enables or disables the query planner's use of gather merge plan types. The default is `on`.

`enable_hashagg` (`boolean`)

Enables or disables the query planner's use of hashed aggregation plan types. The default is `on`.

`enable_alternative_sorting_cost_model` (`boolean`)

Enables or disables the query planner's use of alternative model for estimating the cost of tuple sorting. If this parameter is disabled, the query planner will use the standard model. The default is `on`.

`enable_hashjoin` (`boolean`)

Enables or disables the query planner's use of hash-join plan types. The default is `on`.

`enable_incremental_sort` (`boolean`)

Enables or disables the query planner's use of incremental sort steps. The default is `on`.

`enable_indexscan` (`boolean`)

Enables or disables the query planner's use of index-scan and index-only-scan plan types. The default is `on`. Also see enable_indexonlyscan.

`enable_indexonlyscan` (`boolean`)

Enables or disables the query planner's use of index-only-scan plan types (see Section 11.9). The default is `on`. The enable_indexscan setting must also be enabled to have the query planner consider index-only-scans.

`enable_material` (`boolean`)

Enables or disables the query planner's use of materialization. It is impossible to suppress materialization entirely, but turning this variable off prevents the planner from inserting materialize nodes except in cases where it is required for correctness. The default is `on`.

`enable_memoize` (`boolean`)

Enables or disables the query planner's use of memoize plans for caching results from parameterized scans inside nested-loop joins. This plan type allows scans to the underlying plans to be skipped when the results for the current parameters are already in the cache. Less commonly looked up results may be evicted from the cache when more space is required for new entries. The default is `on`.

`enable_mergejoin` (`boolean`)

Enables or disables the query planner's use of merge-join plan types. The default is `on`.

`enable_nestloop` (`boolean`)

Enables or disables the query planner's use of nested-loop join plans. It is impossible to suppress nested-loop joins entirely, but turning this variable off discourages the planner from using one if there are other methods available. The default is `on`.

`enable_parallel_append` (`boolean`)

Enables or disables the query planner's use of parallel-aware append plan types. The default is `on`.

`enable_parallel_hash` (`boolean`)

Enables or disables the query planner's use of hash-join plan types with parallel hash. Has no effect if hash-join plans are not also enabled. The default is `on`.

`enable_partition_pruning` (`boolean`)

Enables or disables the query planner's ability to eliminate a partitioned table's partitions from query plans. This also controls the planner's ability to generate query plans which allow the query executor to remove (ignore) partitions during query execution. The default is `on`. See Section 5.11.4 for details.

`enable_partitionwise_join` (`boolean`)

Enables or disables the query planner's use of partitionwise join, which allows a join between partitioned tables to be performed by joining the matching partitions. Partitionwise join currently applies only when the join conditions include all the partition keys, which must be of the same data type and have one-to-one matching sets of child partitions. With this setting enabled, the number of nodes whose memory usage is restricted by `work_mem` appearing in the final plan can increase linearly according to the number of partitions being scanned. This can result in a large increase in overall memory consumption during the execution of the query. Query planning also becomes significantly more expensive in terms of memory and CPU. The default value is `off`.

`enable_partitionwise_aggregate` (`boolean`)

Enables or disables the query planner's use of partitionwise grouping or aggregation, which allows grouping or aggregation on partitioned tables to be performed separately for each partition. If the `GROUP BY` clause does not include the partition keys, only partial aggregation can be performed on a per-partition basis, and finalization must be performed later. With this setting enabled, the number of nodes whose memory usage is restricted by `work_mem` appearing in the final plan can increase linearly according to the number of partitions being scanned. This can result in a large increase in overall memory consumption during the execution of the query. Query planning also becomes significantly more expensive in terms of memory and CPU. The default value is `off`.

`enable_self_join_removal` (`boolean`)

Enables or disables removal of self joins from query plans. Removing self joins based on unique column can significantly speed up queries without affecting the results.

Default: `on`

`enable_compound_index_stats` (`boolean`)

Enables or disables use of compound indexes statistics for selectivity estimation.

Default: `on`

`enable_seqscan` (`boolean`)

Enables or disables the query planner's use of sequential scan plan types. It is impossible to suppress sequential scans entirely, but turning this variable off discourages the planner from using one if there are other methods available. The default is `on`.

`enable_sort` (`boolean`)

Enables or disables the query planner's use of explicit sort steps. It is impossible to suppress explicit sorts entirely, but turning this variable off discourages the planner from using one if there are other methods available. The default is `on`.

`enable_tidscan` (`boolean`)

Enables or disables the query planner's use of TID scan plan types. The default is `on`.

`self_join_search_limit` (`integer`)

Specifies the maximum size of a list of links from a query to the same table where self joins will be looked for. Such a list is created to analyze a possibility of self join removal. To find a self join, interrelationships of all the elements in this list with all the other ones must by analyzed. The limitation on the list size aims to reduce the quickly growing complexity of this process. The default is `32`.

19.7.2. Planner Cost Constants

The *cost* variables described in this section are measured on an arbitrary scale. Only their relative values matter, hence scaling them all up or down by the same factor will result in no change in the planner's choices. By default, these cost variables are based on the cost of sequential page fetches; that is, `seq_page_cost` is conventionally set to `1.0` and the other cost variables are set with reference to that. But you can use a different scale if you prefer, such as actual execution times in milliseconds on a particular machine.

> **Note**
>
> Unfortunately, there is no well-defined method for determining ideal values for the cost variables. They are best treated as averages over the entire mix of queries that a particular installation will receive. This means that changing them on the basis of just a few experiments is very risky.

`seq_page_cost` (`floating point`)

Sets the planner's estimate of the cost of a disk page fetch that is part of a series of sequential fetches. The default is 1.0. This value can be overridden for tables and indexes in a particular tablespace by setting the tablespace parameter of the same name (see ALTER TABLESPACE).

`random_page_cost` (`floating point`)

Sets the planner's estimate of the cost of a non-sequentially-fetched disk page. The default is 4.0. This value can be overridden for tables and indexes in a particular tablespace by setting the tablespace parameter of the same name (see ALTER TABLESPACE).

Reducing this value relative to `seq_page_cost` will cause the system to prefer index scans; raising it will make index scans look relatively more expensive. You can raise or lower both values together to change the importance of disk I/O costs relative to CPU costs, which are described by the following parameters.

Random access to mechanical disk storage is normally much more expensive than four times sequential access. However, a lower default is used (4.0) because the majority of random accesses to disk, such as indexed reads, are assumed to be in cache. The default value can be thought of as modeling random access as 40 times slower than sequential, while expecting 90% of random reads to be cached.

If you believe a 90% cache rate is an incorrect assumption for your workload, you can increase random_page_cost to better reflect the true cost of random storage reads. Correspondingly, if your data is likely to be completely in cache, such as when the database is smaller than the total server memory, decreasing random_page_cost can be appropriate. Storage that has a low random read cost relative to sequential, e.g., solid-state drives, might also be better modeled with a lower value for random_page_cost, e.g., `1.1`.

> **Tip**
>
> Although the system will let you set `random_page_cost` to less than `seq_page_cost`, it is not physically sensible to do so. However, setting them equal makes sense if the database is entirely cached in RAM, since in that case there is no penalty for touching pages out of sequence. Also, in a heavily-cached database you should lower both values relative to the CPU parameters, since the cost of fetching a page already in RAM is much smaller than it would normally be.

`cpu_tuple_cost` (`floating point`)

Sets the planner's estimate of the cost of processing each row during a query. The default is 0.01.

`cpu_index_tuple_cost` (`floating point`)

Sets the planner's estimate of the cost of processing each index entry during an index scan. The default is 0.005.

`cpu_operator_cost` (`floating point`)

Sets the planner's estimate of the cost of processing each operator or function executed during a query. The default is 0.0025.

`parallel_setup_cost` (`floating point`)

Sets the planner's estimate of the cost of launching parallel worker processes. The default is 1000.

`parallel_tuple_cost` (`floating point`)

Sets the planner's estimate of the cost of transferring one tuple from a parallel worker process to another process. The default is 0.1.

`min_parallel_table_scan_size` (`integer`)

Sets the minimum amount of table data that must be scanned in order for a parallel scan to be considered. For a parallel sequential scan, the amount of table data scanned is always equal to the size of the table, but when indexes are used the amount of table data scanned will normally be less. If this value is specified without units, it is taken as blocks, that is `BLCKSZ` bytes, typically 8kB. The default is 8 megabytes (`8MB`).

`min_parallel_index_scan_size` (`integer`)

Sets the minimum amount of index data that must be scanned in order for a parallel scan to be considered. Note that a parallel index scan typically won't touch the entire index; it is the number of pages which the planner believes will actually be touched by the scan which is relevant. This parameter is also used to decide whether a particular index can participate in a parallel vacuum. See VACUUM. If this value is specified without units, it is taken as blocks, that is `BLCKSZ` bytes, typically 8kB. The default is 512 kilobytes (`512kB`).

`effective_cache_size` (`integer`)

Sets the planner's assumption about the effective size of the disk cache that is available to a single query. This is factored into estimates of the cost of using an index; a higher value makes it more likely index scans will be used, a lower value makes it more likely sequential scans will be used. When setting this parameter you should consider both Postgres Pro's shared buffers and the portion of the kernel's disk cache that will be used for Postgres Pro data files, though some data might exist in both places. Also, take into account the expected number of concurrent queries on different tables, since they will have to share the available space. This parameter has no effect on the size of shared memory allocated by Postgres Pro, nor does it reserve kernel disk cache; it is used only for estimation purposes. The system also does not assume data remains in the disk cache between queries. If this value is specified without units, it is taken as blocks, that is `BLCKSZ` bytes, typically 8kB. The default is 4 gigabytes (`4GB`). (If `BLCKSZ` is not 8kB, the default value scales proportionally to it.)

`jit_above_cost` (`floating point`)

Sets the query cost above which JIT compilation is activated, if enabled (see Chapter 31). Performing JIT costs planning time but can accelerate query execution. Setting this to `-1` disables JIT compilation. The default is `100000`.

`jit_inline_above_cost` (`floating point`)

Sets the query cost above which JIT compilation attempts to inline functions and operators. Inlining adds planning time, but can improve execution speed. It is not meaningful to set this to less than `jit_above_cost`. Setting this to `-1` disables inlining. The default is `500000`.

`jit_optimize_above_cost` (`floating point`)

Sets the query cost above which JIT compilation applies expensive optimizations. Such optimization adds planning time, but can improve execution speed. It is not meaningful to set this to less than `jit_above_cost`, and it is unlikely to be beneficial to set it to more than `jit_inline_above_cost`. Setting this to `-1` disables expensive optimizations. The default is `500000`.

`generic_plan_fuzz_factor` (`double`)

Sets the plan cost calculation coefficient of the planner, which increases the probability that the generic or custom plan will be selected more often. By default, the value is set to `1`, which means that the generic plan is preferred over the custom plan. The higher the value, the more likely it is that the custom plan will be selected automatically. If plan_cache_mode is set to `force_generic_plan`, the planner will always opt for the generic plan, regardless of the value of this configuration parameter.

19.7.3. Genetic Query Optimizer

The genetic query optimizer (GEQO) is an algorithm that does query planning using heuristic searching. This reduces planning time for complex queries (those joining many relations), at the cost of producing plans that are sometimes inferior to those found by the normal exhaustive-search algorithm. For more information see Chapter 60.

`geqo` (`boolean`)

Enables or disables genetic query optimization. This is on by default. It is usually best not to turn it off in production; the `geqo_threshold` variable provides more granular control of GEQO.

`geqo_threshold` (`integer`)

Use genetic query optimization to plan queries with at least this many `FROM` items involved. (Note that a `FULL OUTER JOIN` construct counts as only one `FROM` item.) The default is 12. For simpler queries it is usually best to use the regular, exhaustive-search planner, but for queries with many tables the exhaustive search takes too long, often longer than the penalty of executing a suboptimal plan. Thus, a threshold on the size of the query is a convenient way to manage use of GEQO.

`geqo_effort` (`integer`)

Controls the trade-off between planning time and query plan quality in GEQO. This variable must be an integer in the range from 1 to 10. The default value is five. Larger values increase the time spent doing query planning, but also increase the likelihood that an efficient query plan will be chosen.

`geqo_effort` doesn't actually do anything directly; it is only used to compute the default values for the other variables that influence GEQO behavior (described below). If you prefer, you can set the other parameters by hand instead.

`geqo_pool_size` (`integer`)

Controls the pool size used by GEQO, that is the number of individuals in the genetic population. It must be at least two, and useful values are typically 100 to 1000. If it is set to zero (the default setting) then a suitable value is chosen based on `geqo_effort` and the number of tables in the query.

`geqo_generations` (`integer`)

Controls the number of generations used by GEQO, that is the number of iterations of the algorithm. It must be at least one, and useful values are in the same range as the pool size. If it is set to zero (the default setting) then a suitable value is chosen based on `geqo_pool_size`.

`geqo_selection_bias` (`floating point`)

Controls the selection bias used by GEQO. The selection bias is the selective pressure within the population. Values can be from 1.50 to 2.00; the latter is the default.

`geqo_seed` (`floating point`)

Controls the initial value of the random number generator used by GEQO to select random paths through the join order search space. The value can range from zero (the default) to one. Varying the

value changes the set of join paths explored, and may result in a better or worse best path being found.

19.7.4. Other Planner Options

`autoprepare_for_protocol` (`enum`)

Sets the protocol used for submitting queries that could be autoprepared. The allowed values are `simple`, `extended`, and `all` (both simple and extended query protocols can be used).

`autoprepare_for_protocol` takes effect only if autoprepare_threshold is set.

`autoprepare_limit` (`integer`)

Specifies the maximal number of statements that can be autoprepared on a backend. If this parameter is set to zero, there is no limit. Note that an infinite number of prepared queries can slow down query execution and cause backend memory overflow. The default value is 100.

`autoprepare_limit` takes effect only if autoprepare_threshold is set.

`autoprepare_memory_limit` (`integer`)

Limits the amount of memory that can be allocated for autoprepared statements on a backend. If this parameter is set to zero (the default), there is no memory limit. Setting this parameter to a non-zero value can cause a slowdown since calculating memory used by prepared statements adds some overhead. To avoid performance penalty, you can limit the number of autoprepared statements using the autoprepare_limit parameter.

`autoprepare_memory_limit` takes effect only if autoprepare_threshold is set.

`autoprepare_threshold` (`integer`)

Specifies the minimal number of times a statement should be executed before it is autoprepared. If set to zero (the default), disables the autoprepare mode. See Section 14.6 for more information.

`default_statistics_target` (`integer`)

Sets the default statistics target for table columns without a column-specific target set via `ALTER TABLE SET STATISTICS`. Larger values increase the time needed to do `ANALYZE`, but might improve the quality of the planner's estimates. The default is 100. For more information on the use of statistics by the Postgres Pro query planner, refer to Section 14.2.

`constraint_exclusion` (`enum`)

Controls the query planner's use of table constraints to optimize queries. The allowed values of `constraint_exclusion` are `on` (examine constraints for all tables), `off` (never examine constraints), and `partition` (examine constraints only for inheritance child tables and `UNION ALL` subqueries). `partition` is the default setting. It is often used with traditional inheritance trees to improve performance.

When this parameter allows it for a particular table, the planner compares query conditions with the table's `CHECK` constraints, and omits scanning tables for which the conditions contradict the constraints. For example:

```
CREATE TABLE parent(key integer, ...);
CREATE TABLE child1000(check (key between 1000 and 1999)) INHERITS(parent);
CREATE TABLE child2000(check (key between 2000 and 2999)) INHERITS(parent);
...
SELECT * FROM parent WHERE key = 2400;
```

With constraint exclusion enabled, this `SELECT` will not scan `child1000` at all, improving performance.

Currently, constraint exclusion is enabled by default only for cases that are often used to implement table partitioning via inheritance trees. Turning it on for all tables imposes extra planning overhead

that is quite noticeable on simple queries, and most often will yield no benefit for simple queries. If you have no tables that are partitioned using traditional inheritance, you might prefer to turn it off entirely. (Note that the equivalent feature for partitioned tables is controlled by a separate parameter, enable_partition_pruning.)

Refer to Section 5.11.5 for more information on using constraint exclusion to implement partitioning.

`cursor_tuple_fraction` (`floating point`)

Sets the planner's estimate of the fraction of a cursor's rows that will be retrieved. The default is 0.1. Smaller values of this setting bias the planner towards using “fast start” plans for cursors, which will retrieve the first few rows quickly while perhaps taking a long time to fetch all rows. Larger values put more emphasis on the total estimated time. At the maximum setting of 1.0, cursors are planned exactly like regular queries, considering only the total estimated time and not how soon the first rows might be delivered.

`from_collapse_limit` (`integer`)

The planner will merge sub-queries into upper queries if the resulting `FROM` list would have no more than this many items. Smaller values reduce planning time but might yield inferior query plans. The default is eight. For more information see Section 14.3.

Setting this value to geqo_threshold or more may trigger use of the GEQO planner, resulting in non-optimal plans. See Section 19.7.3.

`jit` (`boolean`)

Determines whether JIT compilation may be used by Postgres Pro, if available (see Chapter 31). The default is `on`.

`join_collapse_limit` (`integer`)

The planner will rewrite explicit `JOIN` constructs (except `FULL JOIN`s) into lists of `FROM` items whenever a list of no more than this many items would result. Smaller values reduce planning time but might yield inferior query plans.

By default, this variable is set the same as `from_collapse_limit`, which is appropriate for most uses. Setting it to 1 prevents any reordering of explicit `JOIN`s. Thus, the explicit join order specified in the query will be the actual order in which the relations are joined. Because the query planner does not always choose the optimal join order, advanced users can elect to temporarily set this variable to 1, and then specify the join order they desire explicitly. For more information see Section 14.3.

Setting this value to geqo_threshold or more may trigger use of the GEQO planner, resulting in non-optimal plans. See Section 19.7.3.

`plan_cache_mode` (`enum`)

Prepared statements (either explicitly prepared or implicitly generated, for example by PL/pgSQL) can be executed using custom or generic plans. Custom plans are made afresh for each execution using its specific set of parameter values, while generic plans do not rely on the parameter values and can be re-used across executions. Thus, use of a generic plan saves planning time, but if the ideal plan depends strongly on the parameter values then a generic plan may be inefficient. The choice between these options is normally made automatically, but it can be overridden with `plan_cache_mode`. The allowed values are `auto` (the default), `force_custom_plan` and `force_generic_plan`. This setting is considered when a cached plan is to be executed, not when it is prepared. For more information see PREPARE.

`enable_appendorpath` (`boolean`)

Enables the `Append` plan for `OR` clauses. This parameter adds one more strategy for the optimizer: the `Append` plan for expressions containing `OR` clauses. It is useful for applications with auto-generated queries.

`seq_scan_startup_cost_first_row` (`boolean`)

Adds an average cost of getting the first tuple to the startup cost of sequential scan plans. With this option enabled, index scans get higher priority over sequential scans. If this option is off (the default), the startup cost includes only preliminary work before starting the scan.

19.8. Error Reporting and Logging

19.8.1. Where to Log

`log_destination` (`string`)

Postgres Pro supports several methods for logging server messages, including stderr, csvlog and syslog. On Windows, eventlog is also supported. Set this parameter to a list of desired log destinations separated by commas. The default is to log to stderr only. This parameter can only be set in the `postgresql.conf` file or on the server command line.

If csvlog is included in `log_destination`, log entries are output in "comma separated value" (CSV) format, which is convenient for loading logs into programs. See Section 19.8.4 for details. logging_collector must be enabled to generate CSV-format log output.

When either stderr or csvlog are included, the file `current_logfiles` is created to record the location of the log file(s) currently in use by the logging collector and the associated logging destination. This provides a convenient way to find the logs currently in use by the instance. Here is an example of this file's content:

```
stderr log/postgresql.log
csvlog log/postgresql.csv
```

`current_logfiles` is recreated when a new log file is created as an effect of rotation, and when `log_destination` is reloaded. It is removed when neither stderr nor csvlog are included in `log_destination`, and when the logging collector is disabled.

> **Note**
>
> On most Unix systems, you will need to alter the configuration of your system's syslog daemon in order to make use of the syslog option for `log_destination`. Postgres Pro can log to syslog facilities `LOCAL0` through `LOCAL7` (see syslog_facility), but the default syslog configuration on most platforms will discard all such messages. You will need to add something like:
>
> ```
> local0.*    /var/log/postgresql
> ```
>
> to the syslog daemon's configuration file to make it work.
>
> On Windows, when you use the `eventlog` option for `log_destination`, you should register an event source and its library with the operating system so that the Windows Event Viewer can display event log messages cleanly. See Section 18.12 for details.

`logging_collector` (`boolean`)

This parameter enables the *logging collector*, which is a background process that captures log messages sent to stderr and redirects them into log files. This approach is often more useful than logging to syslog, since some types of messages might not appear in syslog output. (One common example is dynamic-linker failure messages; another is error messages produced by scripts such as `archive_command`.) This parameter can only be set at server start.

> **Note**
>
> It is possible to log to stderr without using the logging collector; the log messages will just go to wherever the server's stderr is directed. However, that method is only suitable for low log

volumes, since it provides no convenient way to rotate log files. Also, on some platforms not using the logging collector can result in lost or garbled log output, because multiple processes writing concurrently to the same log file can overwrite each other's output.

Note

The logging collector is designed to never lose messages. This means that in case of extremely high load, server processes could be blocked while trying to send additional log messages when the collector has fallen behind. In contrast, syslog prefers to drop messages if it cannot write them, which means it may fail to log some messages in such cases but it will not block the rest of the system.

`log_directory` (`string`)

When `logging_collector` is enabled, this parameter determines the directory in which log files will be created. It can be specified as an absolute path, or relative to the cluster data directory. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is `log`.

`log_filename` (`string`)

When `logging_collector` is enabled, this parameter sets the file names of the created log files. The value is treated as a `strftime` pattern, so `%`-escapes can be used to specify time-varying file names. (Note that if there are any time-zone-dependent `%`-escapes, the computation is done in the zone specified by log_timezone.) The supported `%`-escapes are similar to those listed in the Open Group's *strftime* specification. Note that the system's `strftime` is not used directly, so platform-specific (nonstandard) extensions do not work. The default is `postgresql-%Y-%m-%d_%H%M%S.log`.

If you specify a file name without escapes, you should plan to use a log rotation utility to avoid eventually filling the entire disk. In releases prior to 8.4, if no `%` escapes were present, PostgreSQL would append the epoch of the new log file's creation time, but this is no longer the case.

If CSV-format output is enabled in `log_destination`, `.csv` will be appended to the timestamped log file name to create the file name for CSV-format output. (If `log_filename` ends in `.log`, the suffix is replaced instead.)

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`log_file_mode` (`integer`)

On Unix systems this parameter sets the permissions for log files when `logging_collector` is enabled. (On Microsoft Windows this parameter is ignored.) The parameter value is expected to be a numeric mode specified in the format accepted by the `chmod` and `umask` system calls. (To use the customary octal format the number must start with a `0` (zero).)

The default permissions are `0600`, meaning only the server owner can read or write the log files. The other commonly useful setting is `0640`, allowing members of the owner's group to read the files. Note however that to make use of such a setting, you'll need to alter log_directory to store the files somewhere outside the cluster data directory. In any case, it's unwise to make the log files world-readable, since they might contain sensitive data.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`log_rotation_age` (`integer`)

When `logging_collector` is enabled, this parameter determines the maximum amount of time to use an individual log file, after which a new log file will be created. If this value is specified without

units, it is taken as minutes. The default is 24 hours. Set to zero to disable time-based creation of new log files. This parameter can only be set in the postgresql.conf file or on the server command line.

log_rotation_size (integer)

When logging_collector is enabled, this parameter determines the maximum size of an individual log file. After this amount of data has been emitted into a log file, a new log file will be created. If this value is specified without units, it is taken as kilobytes. The default is 10 megabytes. Set to zero to disable size-based creation of new log files. This parameter can only be set in the postgresql.conf file or on the server command line.

log_truncate_on_rotation (boolean)

When logging_collector is enabled, this parameter will cause Postgres Pro to truncate (overwrite), rather than append to, any existing log file of the same name. However, truncation will occur only when a new file is being opened due to time-based rotation, not during server startup or size-based rotation. When off, pre-existing files will be appended to in all cases. For example, using this setting in combination with a log_filename like postgresql-%H.log would result in generating twenty-four hourly log files and then cyclically overwriting them. This parameter can only be set in the postgresql.conf file or on the server command line.

Example: To keep 7 days of logs, one log file per day named server_log.Mon, server_log.Tue, etc, and automatically overwrite last week's log with this week's log, set log_filename to server_log.%a, log_truncate_on_rotation to on, and log_rotation_age to 1440.

Example: To keep 24 hours of logs, one log file per hour, but also rotate sooner if the log file size exceeds 1GB, set log_filename to server_log.%H%M, log_truncate_on_rotation to on, log_rotation_age to 60, and log_rotation_size to 1000000. Including %M in log_filename allows any size-driven rotations that might occur to select a file name different from the hour's initial file name.

syslog_facility (enum)

When logging to syslog is enabled, this parameter determines the syslog “facility” to be used. You can choose from LOCAL0, LOCAL1, LOCAL2, LOCAL3, LOCAL4, LOCAL5, LOCAL6, LOCAL7; the default is LOCAL0. See also the documentation of your system's syslog daemon. This parameter can only be set in the postgresql.conf file or on the server command line.

syslog_ident (string)

When logging to syslog is enabled, this parameter determines the program name used to identify Postgres Pro messages in syslog logs. The default is postgres. This parameter can only be set in the postgresql.conf file or on the server command line.

syslog_sequence_numbers (boolean)

When logging to syslog and this is on (the default), then each message will be prefixed by an increasing sequence number (such as [2]). This circumvents the “--- last message repeated N times ---” suppression that many syslog implementations perform by default. In more modern syslog implementations, repeated message suppression can be configured (for example, $RepeatedMsgReduction in rsyslog), so this might not be necessary. Also, you could turn this off if you actually want to suppress repeated messages.

This parameter can only be set in the postgresql.conf file or on the server command line.

syslog_split_messages (boolean)

When logging to syslog is enabled, this parameter determines how messages are delivered to syslog. When on (the default), messages are split by lines, and long lines are split so that they will fit into 1024 bytes, which is a typical size limit for traditional syslog implementations. When off, Postgres Pro server log messages are delivered to the syslog service as is, and it is up to the syslog service to cope with the potentially bulky messages.

If syslog is ultimately logging to a text file, then the effect will be the same either way, and it is best to leave the setting on, since most syslog implementations either cannot handle large messages or would need to be specially configured to handle them. But if syslog is ultimately writing into some other medium, it might be necessary or more useful to keep messages logically together.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`event_source` (`string`)

When logging to event log is enabled, this parameter determines the program name used to identify Postgres Pro messages in the log. The default is `Postgres Pro`. This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.8.2. When to Log

`log_min_messages` (`enum`)

Controls which message levels are written to the server log. Valid values are `DEBUG5`, `DEBUG4`, `DEBUG3`, `DEBUG2`, `DEBUG1`, `INFO`, `NOTICE`, `WARNING`, `ERROR`, `LOG`, `FATAL`, and `PANIC`. Each level includes all the levels that follow it. The later the level, the fewer messages are sent to the log. The default is `WARNING`. Note that `LOG` has a different rank here than in client_min_messages. Only superusers can change this setting.

`log_min_error_statement` (`enum`)

Controls which SQL statements that cause an error condition are recorded in the server log. The current SQL statement is included in the log entry for any message of the specified severity or higher. Valid values are `DEBUG5`, `DEBUG4`, `DEBUG3`, `DEBUG2`, `DEBUG1`, `INFO`, `NOTICE`, `WARNING`, `ERROR`, `LOG`, `FATAL`, and `PANIC`. The default is `ERROR`, which means statements causing errors, log messages, fatal errors, or panics will be logged. To effectively turn off logging of failing statements, set this parameter to `PANIC`. Only superusers can change this setting.

`log_min_duration_statement` (`integer`)

Causes the duration of each completed statement to be logged if the statement ran for at least the specified amount of time. For example, if you set it to `250ms` then all SQL statements that run 250ms or longer will be logged. Enabling this parameter can be helpful in tracking down unoptimized queries in your applications. If this value is specified without units, it is taken as milliseconds. Setting this to zero prints all statement durations. `-1` (the default) disables logging statement durations. Only superusers can change this setting.

This overrides log_min_duration_sample, meaning that queries with duration exceeding this setting are not subject to sampling and are always logged.

For clients using extended query protocol, durations of the Parse, Bind, and Execute steps are logged independently.

> **Note**
>
> When using this option together with log_statement, the text of statements that are logged because of `log_statement` will not be repeated in the duration log message. If you are not using syslog, it is recommended that you log the PID or session ID using log_line_prefix so that you can link the statement message to the later duration message using the process ID or session ID.

`log_min_duration_sample` (`integer`)

Allows sampling the duration of completed statements that ran for at least the specified amount of time. This produces the same kind of log entries as log_min_duration_statement, but only for a

subset of the executed statements, with sample rate controlled by log_statement_sample_rate. For example, if you set it to 100ms then all SQL statements that run 100ms or longer will be considered for sampling. Enabling this parameter can be helpful when the traffic is too high to log all queries. If this value is specified without units, it is taken as milliseconds. Setting this to zero samples all statement durations. -1 (the default) disables sampling statement durations. Only superusers can change this setting.

This setting has lower priority than log_min_duration_statement, meaning that statements with durations exceeding log_min_duration_statement are not subject to sampling and are always logged.

Other notes for log_min_duration_statement apply also to this setting.

log_statement_sample_rate (floating point)

Determines the fraction of statements with duration exceeding log_min_duration_sample that will be logged. Sampling is stochastic, for example 0.5 means there is statistically one chance in two that any given statement will be logged. The default is 1.0, meaning to log all sampled statements. Setting this to zero disables sampled statement-duration logging, the same as setting log_min_duration_sample to -1. Only superusers can change this setting.

log_transaction_sample_rate (floating point)

Sets the fraction of transactions whose statements are all logged, in addition to statements logged for other reasons. It applies to each new transaction regardless of its statements' durations. Sampling is stochastic, for example 0.1 means there is statistically one chance in ten that any given transaction will be logged. log_transaction_sample_rate can be helpful to construct a sample of transactions. The default is 0, meaning not to log statements from any additional transactions. Setting this to 1 logs all statements of all transactions. Only superusers can change this setting.

> **Note**
>
> Like all statement-logging options, this option can add significant overhead.

Table 19.3 explains the message severity levels used by Postgres Pro. If logging output is sent to syslog or Windows' eventlog, the severity levels are translated as shown in the table.

Table 19.3. Message Severity Levels

Severity	Usage	syslog	eventlog
DEBUG1 .. DEBUG5	Provides successively-more-detailed information for use by developers.	DEBUG	INFORMATION
INFO	Provides information implicitly requested by the user, e.g., output from VACUUM VERBOSE.	INFO	INFORMATION
NOTICE	Provides information that might be helpful to users, e.g., notice of truncation of long identifiers.	NOTICE	INFORMATION
WARNING	Provides warnings of likely problems, e.g., COMMIT outside a transaction block.	NOTICE	WARNING
ERROR	Reports an error that caused the current command to abort.	WARNING	ERROR
LOG	Reports information of interest to administrators, e.g., checkpoint activity.	INFO	INFORMATION
FATAL	Reports an error that caused the current session to abort.	ERR	ERROR

Severity	Usage	syslog	eventlog
PANIC	Reports an error that caused all database sessions to abort.	CRIT	ERROR

19.8.3. What to Log

> **Note**
>
> What you choose to log can have security implications; see Section 24.3.

`application_name` (`string`)

The `application_name` can be any string of less than `NAMEDATALEN` characters (64 characters in a standard build). It is typically set by an application upon connection to the server. The name will be displayed in the `pg_stat_activity` view and included in CSV log entries. It can also be included in regular log entries via the log_line_prefix parameter. Only printable ASCII characters may be used in the `application_name` value. Other characters will be replaced with question marks (`?`).

`debug_print_parse` (`boolean`)
`debug_print_rewritten` (`boolean`)
`debug_print_plan` (`boolean`)

These parameters enable various debugging output to be emitted. When set, they print the resulting parse tree, the query rewriter output, or the execution plan for each executed query. These messages are emitted at `LOG` message level, so by default they will appear in the server log but will not be sent to the client. You can change that by adjusting client_min_messages and/or log_min_messages. These parameters are off by default.

`debug_pretty_print` (`boolean`)

When set, `debug_pretty_print` indents the messages produced by `debug_print_parse`, `debug_print_rewritten`, or `debug_print_plan`. This results in more readable but much longer output than the “compact” format used when it is off. It is on by default.

`log_autovacuum_min_duration` (`integer`)

Causes each action executed by autovacuum to be logged if it ran for at least the specified amount of time. Setting this to zero logs all autovacuum actions. `-1` (the default) disables logging autovacuum actions. If this value is specified without units, it is taken as milliseconds. For example, if you set this to `250ms` then all automatic vacuums and analyzes that run 250ms or longer will be logged. In addition, when this parameter is set to any value other than `-1`, a message will be logged if an autovacuum action is skipped due to a conflicting lock or a concurrently dropped relation. Enabling this parameter can be helpful in tracking autovacuum activity. This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`log_checkpoints` (`boolean`)

Causes checkpoints and restartpoints to be logged in the server log. Some statistics are included in the log messages, including the number of buffers written and the time spent writing them. This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is off.

`log_connections` (`boolean`)

Causes each attempted connection to the server to be logged, as well as successful completion of both client authentication (if necessary) and authorization. Only superusers can change this parameter at session start, and it cannot be changed at all within a session. The default is `off`.

> **Note**
>
> Some client programs, like psql, attempt to connect twice while determining if a password is required, so duplicate “connection received” messages do not necessarily indicate a problem.

`log_disconnections` (`boolean`)

Causes session terminations to be logged. The log output provides information similar to `log_connections`, plus the duration of the session. Only superusers can change this parameter at session start, and it cannot be changed at all within a session. The default is `off`.

`log_duration` (`boolean`)

Causes the duration of every completed statement to be logged. The default is `off`. Only superusers can change this setting.

For clients using extended query protocol, durations of the Parse, Bind, and Execute steps are logged independently.

> **Note**
>
> The difference between enabling `log_duration` and setting log_min_duration_statement to zero is that exceeding `log_min_duration_statement` forces the text of the query to be logged, but this option doesn't. Thus, if `log_duration` is `on` and `log_min_duration_statement` has a positive value, all durations are logged but the query text is included only for statements exceeding the threshold. This behavior can be useful for gathering statistics in high-load installations.

`log_error_verbosity` (`enum`)

Controls the amount of detail written in the server log for each message that is logged. Valid values are `TERSE`, `DEFAULT`, and `VERBOSE`, each adding more fields to displayed messages. `TERSE` excludes the logging of `DETAIL`, `HINT`, `QUERY`, and `CONTEXT` error information. `VERBOSE` output includes the `SQLSTATE` error code (see also Appendix A) and the source code file name, function name, and line number that generated the error. Only superusers can change this setting.

`log_hostname` (`boolean`)

By default, connection log messages only show the IP address of the connecting host. Turning this parameter on causes logging of the host name as well. Note that depending on your host name resolution setup this might impose a non-negligible performance penalty. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`log_line_prefix` (`string`)

This is a `printf`-style string that is output at the beginning of each log line. `%` characters begin “escape sequences” that are replaced with status information as outlined below. Unrecognized escapes are ignored. Other characters are copied straight to the log line. Some escapes are only recognized by session processes, and will be treated as empty by background processes such as the main server process. Status information may be aligned either left or right by specifying a numeric literal after the % and before the option. A negative value will cause the status information to be padded on the right with spaces to give it a minimum width, whereas a positive value will pad on the left. Padding can be useful to aid human readability in log files.

This parameter can only be set in the `postgresql.conf` file or on the server command line. The default is `'%m [%p] '` which logs a time stamp and the process ID.

Escape	Effect	Session only
`%a`	Application name	yes

Escape	Effect	Session only
%u	User name	yes
%d	Database name	yes
%r	Remote host name or IP address, and remote port	yes
%h	Remote host name or IP address	yes
%b	Backend type	no
%p	Process ID	no
%P	Process ID of the parallel group leader, if this process is a parallel query worker	no
%t	Time stamp without milliseconds	no
%m	Time stamp with milliseconds	no
%n	Time stamp with milliseconds (as a Unix epoch)	no
%i	Command tag: type of session's current command	yes
%e	SQLSTATE error code	no
%c	Session ID: see below	no
%l	Number of the log line for each session or process, starting at 1	no
%s	Process start time stamp	no
%v	Virtual transaction ID (backendID/localXID)	no
%x	Transaction ID (0 if none is assigned)	no
%q	Produces no output, but tells non-session processes to stop at this point in the string; ignored by session processes	no
%Q	Query identifier of the current query. Query identifiers are not computed by default, so this field will be zero unless compute_query_id parameter is enabled or a third-party module that computes query identifiers is configured.	yes
%%	Literal %	no

The backend type corresponds to the column backend_type in the view pg_stat_activity, but additional types can appear in the log that don't show in that view.

The %c escape prints a quasi-unique session identifier, consisting of two 4-byte hexadecimal numbers (without leading zeros) separated by a dot. The numbers are the process start time and the process ID, so %c can also be used as a space saving way of printing those items. For example, to generate the session identifier from pg_stat_activity, use this query:

```
SELECT to_hex(trunc(EXTRACT(EPOCH FROM backend_start))::integer) || '.' ||
```

```
        to_hex(pid)
FROM pg_stat_activity;
```

> **Tip**
>
> If you set a nonempty value for `log_line_prefix`, you should usually make its last character be a space, to provide visual separation from the rest of the log line. A punctuation character can be used too.

> **Tip**
>
> Syslog produces its own time stamp and process ID information, so you probably do not want to include those escapes if you are logging to syslog.

> **Tip**
>
> The `%q` escape is useful when including information that is only available in session (backend) context like user or database name. For example:
>
> ```
> log_line_prefix = '%m [%p] %q%u@%d/%a '
> ```

> **Note**
>
> The `%Q` escape always reports a zero identifier for lines output by log_statement because `log_statement` generates output before an identifier can be calculated, including invalid statements for which an identifier cannot be calculated.

`log_lock_waits` (`boolean`)

Controls whether a log message is produced when a session waits longer than deadlock_timeout to acquire a lock. This is useful in determining if lock waits are causing poor performance. The default is `off`. Only superusers can change this setting.

`log_recovery_conflict_waits` (`boolean`)

Controls whether a log message is produced when the startup process waits longer than `deadlock_timeout` for recovery conflicts. This is useful in determining if recovery conflicts prevent the recovery from applying WAL.

The default is `off`. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`log_parameter_max_length` (`integer`)

If greater than zero, each bind parameter value logged with a non-error statement-logging message is trimmed to this many bytes. Zero disables logging of bind parameters for non-error statement logs. `-1` (the default) allows bind parameters to be logged in full. If this value is specified without units, it is taken as bytes. Only superusers can change this setting.

This setting only affects log messages printed as a result of log_statement, log_duration, and related settings. Non-zero values of this setting add some overhead, particularly if parameters are sent in binary form, since then conversion to text is required.

`log_parameter_max_length_on_error` (`integer`)

If greater than zero, each bind parameter value reported in error messages is trimmed to this many bytes. Zero (the default) disables including bind parameters in error messages. `-1` allows bind parameters to be printed in full. If this value is specified without units, it is taken as bytes.

Non-zero values of this setting add overhead, as Postgres Pro will need to store textual representations of parameter values in memory at the start of each statement, whether or not an error eventually occurs. The overhead is greater when bind parameters are sent in binary form than when they are sent as text, since the former case requires data conversion while the latter only requires copying the string.

`log_statement` (`enum`)

Controls which SQL statements are logged. Valid values are `none` (off), `ddl`, `mod`, and `all` (all statements). `ddl` logs all data definition statements, such as `CREATE`, `ALTER`, and `DROP` statements. `mod` logs all `ddl` statements, plus data-modifying statements such as `INSERT`, `UPDATE`, `DELETE`, `TRUNCATE`, and `COPY FROM`. `PREPARE`, `EXECUTE`, and `EXPLAIN ANALYZE` statements are also logged if their contained command is of an appropriate type. For clients using extended query protocol, logging occurs when an Execute message is received, and values of the Bind parameters are included (with any embedded single-quote marks doubled).

The default is `none`. Only superusers can change this setting.

> **Note**
>
> Statements that contain simple syntax errors are not logged even by the `log_statement = all` setting, because the log message is emitted only after basic parsing has been done to determine the statement type. In the case of extended query protocol, this setting likewise does not log statements that fail before the Execute phase (i.e., during parse analysis or planning). Set `log_min_error_statement` to `ERROR` (or lower) to log such statements.
>
> Logged statements might reveal sensitive data and even contain plaintext passwords.

`log_next_xid_assign_threshold` (`integer 64`)

If logging is enabled by this setting, a log entry is emitted when during WAL replay the next XID is greater than the current XID by the specified value. A value of zero disables such logging, the default value is 100000000. Only superusers can change this setting.

`log_replication_commands` (`boolean`)

Causes each replication command to be logged in the server log. See Section 55.4 for more information about replication command. The default value is `off`. Only superusers can change this setting.

`log_temp_files` (`integer`)

Controls logging of temporary file names and sizes. Temporary files can be created for sorts, hashes, and temporary query results. If enabled by this setting, a log entry is emitted for each temporary file when it is deleted. A value of zero logs all temporary file information, while positive values log only files whose size is greater than or equal to the specified amount of data. If this value is specified without units, it is taken as kilobytes. The default setting is -1, which disables such logging. Only superusers can change this setting.

`log_timezone` (`string`)

Sets the time zone used for timestamps written in the server log. Unlike TimeZone, this value is cluster-wide, so that all sessions will report timestamps consistently. The built-in default is `GMT`, but that is typically overridden in `postgresql.conf`; initdb will install a setting there corresponding to

its system environment. See Section 8.5.3 for more information. This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.8.4. Using CSV-Format Log Output

Including `csvlog` in the `log_destination` list provides a convenient way to import log files into a database table. This option emits log lines in comma-separated-values (CSV) format, with these columns: time stamp with milliseconds, user name, database name, process ID, client host:port number, session ID, per-session line number, command tag, session start time, virtual transaction ID, regular transaction ID, error severity, SQLSTATE code, error message, error message detail, hint, internal query that led to the error (if any), character count of the error position therein, error context, user query that led to the error (if any and enabled by `log_min_error_statement`), character count of the error position therein, location of the error in the Postgres Pro source code (if `log_error_verbosity` is set to `verbose`), application name, backend type, process ID of parallel group leader, and query id. Here is a sample table definition for storing CSV-format log output:

```
CREATE TABLE postgres_log
(
  log_time timestamp(3) with time zone,
  user_name text,
  database_name text,
  process_id integer,
  connection_from text,
  session_id text,
  session_line_num bigint,
  command_tag text,
  session_start_time timestamp with time zone,
  virtual_transaction_id text,
  transaction_id bigint,
  error_severity text,
  sql_state_code text,
  message text,
  detail text,
  hint text,
  internal_query text,
  internal_query_pos integer,
  context text,
  query text,
  query_pos integer,
  location text,
  application_name text,
  backend_type text,
  leader_pid integer,
  query_id bigint,
  PRIMARY KEY (session_id, session_line_num)
);
```

To import a log file into this table, use the `COPY FROM` command:

```
COPY postgres_log FROM '/full/path/to/logfile.csv' WITH csv;
```

It is also possible to access the file as a foreign table, using the supplied file_fdw module.

There are a few things you need to do to simplify importing CSV log files:

1. Set `log_filename` and `log_rotation_age` to provide a consistent, predictable naming scheme for your log files. This lets you predict what the file name will be and know when an individual log file is complete and therefore ready to be imported.
2. Set `log_rotation_size` to 0 to disable size-based log rotation, as it makes the log file name difficult to predict.

3. Set log_truncate_on_rotation to on so that old log data isn't mixed with the new in the same file.
4. The table definition above includes a primary key specification. This is useful to protect against accidentally importing the same information twice. The COPY command commits all of the data it imports at one time, so any error will cause the entire import to fail. If you import a partial log file and later import the file again when it is complete, the primary key violation will cause the import to fail. Wait until the log is complete and closed before importing. This procedure will also protect against accidentally importing a partial line that hasn't been completely written, which would also cause COPY to fail.

19.8.5. Process Title

These settings control how process titles of server processes are modified. Process titles are typically viewed using programs like ps or, on Windows, Process Explorer. See Section 27.1 for details.

cluster_name (string)

Sets a name that identifies this database cluster (instance) for various purposes. The cluster name appears in the process title for all server processes in this cluster. Moreover, it is the default application name for a standby connection (see synchronous_standby_names).

The name can be any string of less than NAMEDATALEN characters (64 characters in a standard build). Only printable ASCII characters may be used in the cluster_name value. Other characters will be replaced with question marks (?). No name is shown if this parameter is set to the empty string '' (which is the default). This parameter can only be set at server start.

update_process_title (boolean)

Enables updating of the process title every time a new SQL command is received by the server. This setting defaults to on on most platforms, but it defaults to off on Windows due to that platform's larger overhead for updating the process title. Only superusers can change this setting.

19.9. Run-time Statistics

19.9.1. Query and Index Statistics Collector

These parameters control server-wide statistics collection features. When statistics collection is enabled, the data that is produced can be accessed via the pg_stat and pg_statio family of system views. Refer to Chapter 27 for more information.

track_activities (boolean)

Enables the collection of information on the currently executing command of each session, along with its identifier and the time when that command began execution. This parameter is on by default. Note that even when enabled, this information is not visible to all users, only to superusers, roles with privileges of the pg_read_all_stats role and the user owning the sessions being reported on (including sessions belonging to a role they have the privileges of), so it should not represent a security risk. Only superusers can change this setting.

track_activity_query_size (integer)

Specifies the amount of memory reserved to store the text of the currently executing command for each active session, for the pg_stat_activity.query field. If this value is specified without units, it is taken as bytes. The default value is 1024 bytes. This parameter can only be set at server start.

track_counts (boolean)

Enables collection of statistics on database activity. This parameter is on by default, because the autovacuum daemon needs the collected information. Only superusers can change this setting.

track_io_timing (boolean)

Enables timing of database I/O calls. This parameter is off by default, as it will repeatedly query the operating system for the current time, which may cause significant overhead on some platforms.

You can use the pg_test_timing tool to measure the overhead of timing on your system. I/O timing information is displayed in pg_stat_database, in the output of EXPLAIN when the BUFFERS option is used, by autovacuum for auto-vacuums and auto-analyzes, when log_autovacuum_min_duration is set and by pg_stat_statements. Only superusers can change this setting.

track_wal_io_timing (boolean)

Enables timing of WAL I/O calls. This parameter is off by default, as it will repeatedly query the operating system for the current time, which may cause significant overhead on some platforms. You can use the pg_test_timing tool to measure the overhead of timing on your system. I/O timing information is displayed in pg_stat_wal. Only superusers can change this setting.

track_functions (enum)

Enables tracking of function call counts and time used. Specify pl to track only procedural-language functions, all to also track SQL and C language functions. The default is none, which disables function statistics tracking. Only superusers can change this setting.

> **Note**
>
> SQL-language functions that are simple enough to be "inlined" into the calling query will not be tracked, regardless of this setting.

stats_temp_directory (string)

Sets the directory to store temporary statistics data in. This can be a path relative to the data directory or an absolute path. The default is pg_stat_tmp. Pointing this at a RAM-based file system will decrease physical I/O requirements and can lead to improved performance. This parameter can only be set in the postgresql.conf file or on the server command line.

19.9.2. Statistics Monitoring

compute_query_id (enum)

Enables in-core computation of a query identifier. Query identifiers can be displayed in the pg_stat_activity view, using EXPLAIN, or emitted in the log if configured via the log_line_prefix parameter. The pg_stat_statements extension also requires a query identifier to be computed. Note that an external module can alternatively be used if the in-core query identifier computation method is not acceptable. In this case, in-core computation must be always disabled. Valid values are off (always disabled), on (always enabled), auto, which lets modules such as pg_stat_statements automatically enable it, and regress which has the same effect as auto, except that the query identifier is not shown in the EXPLAIN output in order to facilitate automated regression testing. The default is auto.

> **Note**
>
> To ensure that only one query identifier is calculated and displayed, extensions that calculate query identifiers should throw an error if a query identifier has already been computed.

log_statement_stats (boolean)
log_parser_stats (boolean)
log_planner_stats (boolean)
log_executor_stats (boolean)

For each query, output performance statistics of the respective module to the server log. This is a crude profiling instrument, similar to the Unix getrusage() operating system facility. log_statement_stats reports total statement statistics, while the others report per-module statistics. log_statement_stats cannot be enabled together with any of the per-module options. All of these options are disabled by default. Only superusers can change these settings.

19.10. Automatic Vacuuming

These settings control the behavior of the *autovacuum* feature. Refer to Section 24.1.6 for more information. Note that many of these settings can be overridden on a per-table basis; see Storage Parameters.

`autovacuum` (`boolean`)

Controls whether the server should run the autovacuum launcher daemon. This is on by default; however, track_counts must also be enabled for autovacuum to work. This parameter can only be set in the `postgresql.conf` file or on the server command line; however, autovacuuming can be disabled for individual tables by changing table storage parameters.

Note that even when this parameter is disabled, the system will launch autovacuum processes if necessary to shrink `pg_xact` and `pg_multixact`. See Section 24.1.5 for more information.

`autovacuum_max_workers` (`integer`)

Specifies the maximum number of autovacuum processes (other than the autovacuum launcher) that may be running at any one time. The default is three. This parameter can only be set at server start.

`autovacuum_naptime` (`integer`)

Specifies the minimum delay between autovacuum runs on any given database. In each round the daemon examines the database and issues `VACUUM` and `ANALYZE` commands as needed for tables in that database. If this value is specified without units, it is taken as seconds. The default is one minute (`1min`). This parameter can only be set in the `postgresql.conf` file or on the server command line.

`autovacuum_vacuum_threshold` (`integer`)

Specifies the minimum number of updated or deleted tuples needed to trigger a `VACUUM` in any one table. The default is 50 tuples. This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`autovacuum_vacuum_insert_threshold` (`integer`)

Specifies the number of inserted tuples needed to trigger a `VACUUM` in any one table. The default is 1000 tuples. If -1 is specified, autovacuum will not trigger a `VACUUM` operation on any tables based on the number of inserts. This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`autovacuum_analyze_threshold` (`integer`)

Specifies the minimum number of inserted, updated or deleted tuples needed to trigger an `ANALYZE` in any one table. The default is 50 tuples. This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`autovacuum_vacuum_scale_factor` (`floating point`)

Specifies a fraction of the table size to add to `autovacuum_vacuum_threshold` when deciding whether to trigger a `VACUUM`. The default is 0.2 (20% of table size). This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`autovacuum_vacuum_insert_scale_factor` (`floating point`)

Specifies a fraction of the table size to add to `autovacuum_vacuum_insert_threshold` when deciding whether to trigger a `VACUUM`. The default is 0.2 (20% of table size). This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`autovacuum_analyze_scale_factor` (`floating point`)

Specifies a fraction of the table size to add to `autovacuum_analyze_threshold` when deciding whether to trigger an `ANALYZE`. The default is 0.1 (10% of table size). This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`autovacuum_freeze_max_age` (`integer 64`)

Specifies the maximum age (in transactions) that a table's `pg_class.relfrozenxid` field can attain before a `VACUUM` operation is forced to shrink `pg_xact`. Note that the system will launch autovacuum processes for this purpose even when autovacuum is otherwise disabled. The default is 10 billion.

Vacuum also allows removal of old files from the `pg_xact` subdirectory. This parameter can only be set at server start, but the setting can be reduced for individual tables by changing table storage parameters. For more information see Section 24.1.5.

`autovacuum_multixact_freeze_max_age` (`integer 64`)

Specifies the maximum age (in multixacts) that a table's `pg_class.relminmxid` field can attain before a `VACUUM` operation is forced to shrink `pg_multixact`. Note that the system will launch autovacuum processes for this purpose even when autovacuum is otherwise disabled. The default is 20 billion.

This parameter can only be set at server start, but the setting can be reduced for individual tables by changing table storage parameters. For more information see Section 24.1.5.1.

`autovacuum_vacuum_cost_delay` (`floating point`)

Specifies the cost delay value that will be used in automatic `VACUUM` operations. If -1 is specified, the regular vacuum_cost_delay value will be used. If this value is specified without units, it is taken as milliseconds. The default value is 2 milliseconds. This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

`autovacuum_vacuum_cost_limit` (`integer`)

Specifies the cost limit value that will be used in automatic `VACUUM` operations. If -1 is specified (which is the default), the regular vacuum_cost_limit value will be used. Note that the value is distributed proportionally among the running autovacuum workers, if there is more than one, so that the sum of the limits for each worker does not exceed the value of this variable. This parameter can only be set in the `postgresql.conf` file or on the server command line; but the setting can be overridden for individual tables by changing table storage parameters.

19.11. Client Connection Defaults

19.11.1. Statement Behavior

`client_min_messages` (`enum`)

Controls which message levels are sent to the client. Valid values are `DEBUG5`, `DEBUG4`, `DEBUG3`, `DEBUG2`, `DEBUG1`, `LOG`, `NOTICE`, `WARNING`, and `ERROR`. Each level includes all the levels that follow it. The later the level, the fewer messages are sent. The default is `NOTICE`. Note that `LOG` has a different rank here than in log_min_messages.

`INFO` level messages are always sent to the client.

`search_path` (`string`)

This variable specifies the order in which schemas are searched when an object (table, data type, function, etc.) is referenced by a simple name with no schema specified. When there are objects of identical names in different schemas, the one found first in the search path is used. An object that

is not in any of the schemas in the search path can only be referenced by specifying its containing schema with a qualified (dotted) name.

The value for search_path must be a comma-separated list of schema names. Any name that is not an existing schema, or is a schema for which the user does not have USAGE permission, is silently ignored.

If one of the list items is the special name $user, then the schema having the name returned by CURRENT_USER is substituted, if there is such a schema and the user has USAGE permission for it. (If not, $user is ignored.)

The system catalog schema, pg_catalog, is always searched, whether it is mentioned in the path or not. If it is mentioned in the path then it will be searched in the specified order. If pg_catalog is not in the path then it will be searched *before* searching any of the path items.

Likewise, the current session's temporary-table schema, pg_temp_*nnn*, is always searched if it exists. It can be explicitly listed in the path by using the alias pg_temp. If it is not listed in the path then it is searched first (even before pg_catalog). However, the temporary schema is only searched for relation (table, view, sequence, etc) and data type names. It is never searched for function or operator names.

When objects are created without specifying a particular target schema, they will be placed in the first valid schema named in search_path. An error is reported if the search path is empty.

The default value for this parameter is "$user", public. This setting supports shared use of a database (where no users have private schemas, and all share use of public), private per-user schemas, and combinations of these. Other effects can be obtained by altering the default search path setting, either globally or per-user.

For more information on schema handling, see Section 5.9. In particular, the default configuration is suitable only when the database has a single user or a few mutually-trusting users.

The current effective value of the search path can be examined via the SQL function current_schemas (see Section 9.26). This is not quite the same as examining the value of search_path, since current_schemas shows how the items appearing in search_path were resolved.

row_security (boolean)

This variable controls whether to raise an error in lieu of applying a row security policy. When set to on, policies apply normally. When set to off, queries fail which would otherwise apply at least one policy. The default is on. Change to off where limited row visibility could cause incorrect results; for example, pg_dump makes that change by default. This variable has no effect on roles which bypass every row security policy, to wit, superusers and roles with the BYPASSRLS attribute.

For more information on row security policies, see CREATE POLICY.

default_table_access_method (string)

This parameter specifies the default table access method to use when creating tables or materialized views if the CREATE command does not explicitly specify an access method, or when SELECT ... INTO is used, which does not allow specifying a table access method. The default is heap.

default_tablespace (string)

This variable specifies the default tablespace in which to create objects (tables and indexes) when a CREATE command does not explicitly specify a tablespace.

The value is either the name of a tablespace, or an empty string to specify using the default tablespace of the current database. If the value does not match the name of any existing tablespace, Postgres Pro will automatically use the default tablespace of the current database. If a nondefault tablespace is specified, the user must have CREATE privilege for it, or creation attempts will fail.

This variable is not used for temporary tables; for them, temp_tablespaces is consulted instead.

This variable is also not used when creating databases. By default, a new database inherits its tablespace setting from the template database it is copied from.

If this parameter is set to a value other than the empty string when a partitioned table is created, the partitioned table's tablespace will be set to that value, which will be used as the default tablespace for partitions created in the future, even if `default_tablespace` has changed since then.

For more information on tablespaces, see Section 22.6.

`default_toast_compression` (`enum`)

This variable sets the default TOAST compression method for values of compressible columns. (This can be overridden for individual columns by setting the `COMPRESSION` column option in `CREATE TABLE` or `ALTER TABLE`.) The supported compression methods are `pglz` and (if Postgres Pro was compiled with `--with-lz4`) `lz4`. The default is `lz4`.

`temp_tablespaces` (`string`)

This variable specifies tablespaces in which to create temporary objects (temp tables and indexes on temp tables) when a `CREATE` command does not explicitly specify a tablespace. Temporary files for purposes such as sorting large data sets are also created in these tablespaces.

The value is a list of names of tablespaces. When there is more than one name in the list, Postgres Pro chooses a random member of the list each time a temporary object is to be created; except that within a transaction, successively created temporary objects are placed in successive tablespaces from the list. If the selected element of the list is an empty string, Postgres Pro will automatically use the default tablespace of the current database instead.

When `temp_tablespaces` is set interactively, specifying a nonexistent tablespace is an error, as is specifying a tablespace for which the user does not have `CREATE` privilege. However, when using a previously set value, nonexistent tablespaces are ignored, as are tablespaces for which the user lacks `CREATE` privilege. In particular, this rule applies when using a value set in `postgresql.conf`.

The default value is an empty string, which results in all temporary objects being created in the default tablespace of the current database.

See also default_tablespace.

`check_function_bodies` (`boolean`)

This parameter is normally on. When set to `off`, it disables validation of the routine body string during CREATE FUNCTION and CREATE PROCEDURE. Disabling validation avoids side effects of the validation process, in particular preventing false positives due to problems such as forward references. Set this parameter to `off` before loading functions on behalf of other users; pg_dump does so automatically.

`default_transaction_isolation` (`enum`)

Each SQL transaction has an isolation level, which can be either “read uncommitted”, “read committed”, “repeatable read”, or “serializable”. This parameter controls the default isolation level of each new transaction. The default is “read committed”.

Consult Chapter 13 and SET TRANSACTION for more information.

`default_transaction_read_only` (`boolean`)

A read-only SQL transaction cannot alter non-temporary tables. This parameter controls the default read-only status of each new transaction. The default is `off` (read/write).

Consult SET TRANSACTION for more information.

`default_transaction_deferrable` (`boolean`)

When running at the `serializable` isolation level, a deferrable read-only SQL transaction may be delayed before it is allowed to proceed. However, once it begins executing it does not incur any of the overhead required to ensure serializability; so serialization code will have no reason to force it to abort because of concurrent updates, making this option suitable for long-running read-only transactions.

This parameter controls the default deferrable status of each new transaction. It currently has no effect on read-write transactions or those operating at isolation levels lower than `serializable`. The default is `off`.

Consult SET TRANSACTION for more information.

`transaction_isolation` (`enum`)

This parameter reflects the current transaction's isolation level. At the beginning of each transaction, it is set to the current value of default_transaction_isolation. Any subsequent attempt to change it is equivalent to a SET TRANSACTION command.

`transaction_read_only` (`boolean`)

This parameter reflects the current transaction's read-only status. At the beginning of each transaction, it is set to the current value of default_transaction_read_only. Any subsequent attempt to change it is equivalent to a SET TRANSACTION command.

`transaction_deferrable` (`boolean`)

This parameter reflects the current transaction's deferrability status. At the beginning of each transaction, it is set to the current value of default_transaction_deferrable. Any subsequent attempt to change it is equivalent to a SET TRANSACTION command.

`session_replication_role` (`enum`)

Controls firing of replication-related triggers and rules for the current session. Setting this variable requires superuser privilege and results in discarding any previously cached query plans. Possible values are `origin` (the default), `replica` and `local`.

The intended use of this setting is that logical replication systems set it to `replica` when they are applying replicated changes. The effect of that will be that triggers and rules (that have not been altered from their default configuration) will not fire on the replica. See the `ALTER TABLE` clauses `ENABLE TRIGGER` and `ENABLE RULE` for more information.

Postgres Pro treats the settings `origin` and `local` the same internally. Third-party replication systems may use these two values for their internal purposes, for example using `local` to designate a session whose changes should not be replicated.

Since foreign keys are implemented as triggers, setting this parameter to `replica` also disables all foreign key checks, which can leave data in an inconsistent state if improperly used.

`statement_timeout` (`integer`)

Abort any statement that takes more than the specified amount of time. If `log_min_error_statement` is set to `ERROR` or lower, the statement that timed out will also be logged. If this value is specified without units, it is taken as milliseconds. A value of zero (the default) disables the timeout.

The timeout is measured from the time a command arrives at the server until it is completed by the server. If multiple SQL statements appear in a single simple-Query message, the timeout is applied to each statement separately. (PostgreSQL versions before 13 usually treated the timeout as applying to the whole query string.) In extended query protocol, the timeout starts running when any query-related message (Parse, Bind, Execute, Describe) arrives, and it is canceled by completion of an Execute or Sync message.

Setting statement_timeout in postgresql.conf is not recommended because it would affect all sessions.

lock_timeout (integer)

Abort any statement that waits longer than the specified amount of time while attempting to acquire a lock on a table, index, row, or other database object. The time limit applies separately to each lock acquisition attempt. The limit applies both to explicit locking requests (such as LOCK TABLE, or SELECT FOR UPDATE without NOWAIT) and to implicitly-acquired locks. If this value is specified without units, it is taken as milliseconds. A value of zero (the default) disables the timeout.

Unlike statement_timeout, this timeout can only occur while waiting for locks. Note that if statement_timeout is nonzero, it is rather pointless to set lock_timeout to the same or larger value, since the statement timeout would always trigger first. If log_min_error_statement is set to ERROR or lower, the statement that timed out will be logged.

Setting lock_timeout in postgresql.conf is not recommended because it would affect all sessions.

idle_in_transaction_session_timeout (integer)

Terminate any session that has been idle (that is, waiting for a client query) within an open transaction for longer than the specified amount of time. If this value is specified without units, it is taken as milliseconds. A value of zero (the default) disables the timeout.

This option can be used to ensure that idle sessions do not hold locks for an unreasonable amount of time. Even when no significant locks are held, an open transaction prevents vacuuming away recently-dead tuples that may be visible only to this transaction; so remaining idle for a long time can contribute to table bloat. See Section 24.1 for more details.

idle_session_timeout (integer)

Terminate any session that has been idle (that is, waiting for a client query), but not within an open transaction, for longer than the specified amount of time. If this value is specified without units, it is taken as milliseconds. A value of zero (the default) disables the timeout.

Unlike the case with an open transaction, an idle session without a transaction imposes no large costs on the server, so there is less need to enable this timeout than idle_in_transaction_session_timeout.

Be wary of enforcing this timeout on connections made through connection-pooling software or other middleware, as such a layer may not react well to unexpected connection closure. It may be helpful to enable this timeout only for interactive sessions, perhaps by applying it only to particular users.

vacuum_freeze_table_age (integer 64)

VACUUM performs an aggressive scan if the table's pg_class.relfrozenxid field has reached the age specified by this setting. An aggressive scan differs from a regular VACUUM in that it visits every page that might contain unfrozen XIDs or MXIDs, not just those that might contain dead tuples. The default is 150 million transactions. Although users can set this value anywhere from zero to 2^63 - 1, VACUUM will silently limit the effective value to 95% of autovacuum_freeze_max_age, so that a periodic manual VACUUM has a chance to run before an autovacuum to shrink pg_xact and pg_multixact is launched for the table. This value is also used as a “soft” limit for advancing datfrozenxid, helping to prevent pg_multixact bloat without immediately triggering autovacuum, which would require an exclusive database lock. For more information see Section 24.1.5.

vacuum_freeze_min_age (integer 64)

Specifies the cutoff age (in transactions) that VACUUM should use to decide whether to freeze row versions while scanning a table. The default is 50 million transactions. Although users can set this value anywhere from zero to 2^63 - 1, VACUUM will silently limit the effective value to half the value of autovacuum_freeze_max_age, so that there is not an unreasonably short time between forced autovacuums. For more information see Section 24.1.5.

vacuum_failsafe_age (integer)

Specifies the maximum age (in transactions) that a table's pg_class.relfrozenxid field can attain before VACUUM takes extraordinary measures to avoid system-wide transaction ID wraparound failure. This is VACUUM's strategy of last resort. The failsafe typically triggers when an autovacuum to prevent transaction ID wraparound has already been running for some time, though it's possible for the failsafe to trigger during any VACUUM.

When the failsafe is triggered, any cost-based delay that is in effect will no longer be applied, and further non-essential maintenance tasks (such as index vacuuming) are bypassed.

The default is 1.6 billion transactions. Although users can set this value anywhere from zero to 2.1 billion, VACUUM will silently adjust the effective value to no less than 105% of autovacuum_freeze_max_age.

vacuum_multixact_freeze_table_age (integer 64)

VACUUM performs an aggressive scan if the table's pg_class.relminmxid field has reached the age specified by this setting. An aggressive scan differs from a regular VACUUM in that it visits every page that might contain unfrozen XIDs or MXIDs, not just those that might contain dead tuples. The default is 150 million multixacts. Although users can set this value anywhere from zero to 2^63 - 1, VACUUM will silently limit the effective value to 95% of autovacuum_multixact_freeze_max_age, so that a periodic manual VACUUM has a chance to run before an autovacuum to shrink pg_xact and pg_multixact is launched for the table. This value is also used as a “soft” limit for advancing datminmxid, helping to prevent pg_multixact bloat without immediately triggering autovacuum, which would require an exclusive database lock. For more information see Section 24.1.5.

vacuum_multixact_freeze_min_age (integer 64)

Specifies the cutoff age (in multixacts) that VACUUM should use to decide whether to replace multixact IDs with a newer transaction ID or multixact ID while scanning a table. The default is 5 million multixacts. Although users can set this value anywhere from zero to 2^63 - 1, VACUUM will silently limit the effective value to half the value of autovacuum_multixact_freeze_max_age, so that there is not an unreasonably short time between forced autovacuums. For more information see Section 24.1.5.1.

vacuum_multixact_failsafe_age (integer)

Specifies the maximum age (in multixacts) that a table's pg_class.relminmxid field can attain before VACUUM takes extraordinary measures to avoid system-wide multixact ID wraparound failure. This is VACUUM's strategy of last resort. The failsafe typically triggers when an autovacuum to prevent transaction ID wraparound has already been running for some time, though it's possible for the failsafe to trigger during any VACUUM.

When the failsafe is triggered, any cost-based delay that is in effect will no longer be applied, and further non-essential maintenance tasks (such as index vacuuming) are bypassed.

The default is 1.6 billion multixacts. Although users can set this value anywhere from zero to 2.1 billion, VACUUM will silently adjust the effective value to no less than 105% of autovacuum_multixact_freeze_max_age.

bytea_output (enum)

Sets the output format for values of type bytea. Valid values are hex (the default) and escape (the traditional Postgres Pro format). See Section 8.4 for more information. The bytea type always accepts both formats on input, regardless of this setting.

xmlbinary (enum)

Sets how binary values are to be encoded in XML. This applies for example when bytea values are converted to XML by the functions xmlelement or xmlforest. Possible values are base64 and hex, which are both defined in the XML Schema standard. The default is base64. For further information about XML-related functions, see Section 9.15.

The actual choice here is mostly a matter of taste, constrained only by possible restrictions in client applications. Both methods support all possible values, although the hex encoding will be somewhat larger than the base64 encoding.

`xmloption` (`enum`)

Sets whether `DOCUMENT` or `CONTENT` is implicit when converting between XML and character string values. See Section 8.13 for a description of this. Valid values are `DOCUMENT` and `CONTENT`. The default is `CONTENT`.

According to the SQL standard, the command to set this option is

```
SET XML OPTION { DOCUMENT | CONTENT };
```

This syntax is also available in Postgres Pro.

`gin_pending_list_limit` (`integer`)

Sets the maximum size of a GIN index's pending list, which is used when `fastupdate` is enabled. If the list grows larger than this maximum size, it is cleaned up by moving the entries in it to the index's main GIN data structure in bulk. If this value is specified without units, it is taken as kilobytes. The default is four megabytes (`4MB`). This setting can be overridden for individual GIN indexes by changing index storage parameters. See Section 67.4.1 and Section 67.5 for more information.

`ignore_event_trigger` (`enum`)

Allows to temporarily disable event triggers from executing in order to troubleshoot and repair faulty event triggers. Valid values are `none`, `login`, and `all`.

`restrict_nonsystem_relation_kind` (`string`)

Set relation kinds for which access to non-system relations is prohibited. The value takes the form of a comma-separated list of relation kinds. Currently, the supported relation kinds are `view` and `foreign-table`.

19.11.2. Locale and Formatting

`DateStyle` (`string`)

Sets the display format for date and time values, as well as the rules for interpreting ambiguous date input values. For historical reasons, this variable contains two independent components: the output format specification (`ISO`, `Postgres`, `SQL`, or `German`) and the input/output specification for year/month/day ordering (`DMY`, `MDY`, or `YMD`). These can be set separately or together. The keywords `Euro` and `European` are synonyms for `DMY`; the keywords `US`, `NonEuro`, and `NonEuropean` are synonyms for `MDY`. See Section 8.5 for more information. The built-in default is `ISO, MDY`, but initdb will initialize the configuration file with a setting that corresponds to the behavior of the chosen `lc_time` locale.

`IntervalStyle` (`enum`)

Sets the display format for interval values. The value `sql_standard` will produce output matching SQL standard interval literals. The value `postgres` (which is the default) will produce output matching PostgreSQL releases prior to 8.4 when the DateStyle parameter was set to `ISO`. The value `postgres_verbose` will produce output matching PostgreSQL releases prior to 8.4 when the `DateStyle` parameter was set to non-`ISO` output. The value `iso_8601` will produce output matching the time interval “format with designators” defined in section 4.4.3.2 of ISO 8601.

The `IntervalStyle` parameter also affects the interpretation of ambiguous interval input. See Section 8.5.4 for more information.

`TimeZone` (`string`)

Sets the time zone for displaying and interpreting time stamps. The built-in default is `GMT`, but that is typically overridden in `postgresql.conf`; initdb will install a setting there corresponding to its system environment. See Section 8.5.3 for more information.

`timezone_abbreviations` (`string`)

Sets the collection of time zone abbreviations that will be accepted by the server for datetime input. The default is `'Default'`, which is a collection that works in most of the world; there are also `'Australia'` and `'India'`, and other collections can be defined for a particular installation. See Section B.4 for more information.

`extra_float_digits` (`integer`)

This parameter adjusts the number of digits used for textual output of floating-point values, including `float4`, `float8`, and geometric data types.

If the value is 1 (the default) or above, float values are output in shortest-precise format; see Section 8.1.3. The actual number of digits generated depends only on the value being output, not on the value of this parameter. At most 17 digits are required for `float8` values, and 9 for `float4` values. This format is both fast and precise, preserving the original binary float value exactly when correctly read. For historical compatibility, values up to 3 are permitted.

If the value is zero or negative, then the output is rounded to a given decimal precision. The precision used is the standard number of digits for the type (`FLT_DIG` or `DBL_DIG` as appropriate) reduced according to the value of this parameter. (For example, specifying -1 will cause `float4` values to be output rounded to 5 significant digits, and `float8` values rounded to 14 digits.) This format is slower and does not preserve all the bits of the binary float value, but may be more human-readable.

> **Note**
>
> The meaning of this parameter, and its default value, changed in Postgres Pro 12; see Section 8.1.3 for further discussion.

`client_encoding` (`string`)

Sets the client-side encoding (character set). The default is to use the database encoding. The character sets supported by the Postgres Pro server are described in Section 23.3.1.

`lc_messages` (`string`)

Sets the language in which messages are displayed. Acceptable values are system-dependent; see Section 23.1 for more information. If this variable is set to the empty string (which is the default) then the value is inherited from the execution environment of the server in a system-dependent way.

On some systems, this locale category does not exist. Setting this variable will still work, but there will be no effect. Also, there is a chance that no translated messages for the desired language exist. In that case you will continue to see the English messages.

Only superusers can change this setting, because it affects the messages sent to the server log as well as to the client, and an improper value might obscure the readability of the server logs.

`lc_monetary` (`string`)

Sets the locale to use for formatting monetary amounts, for example with the `to_char` family of functions. Acceptable values are system-dependent; see Section 23.1 for more information. If this variable is set to the empty string (which is the default) then the value is inherited from the execution environment of the server in a system-dependent way.

`lc_numeric` (`string`)

Sets the locale to use for formatting numbers, for example with the `to_char` family of functions. Acceptable values are system-dependent; see Section 23.1 for more information. If this variable is set to the empty string (which is the default) then the value is inherited from the execution environment of the server in a system-dependent way.

`lc_time` (`string`)

Sets the locale to use for formatting dates and times, for example with the `to_char` family of functions. Acceptable values are system-dependent; see Section 23.1 for more information. If this variable is set to the empty string (which is the default) then the value is inherited from the execution environment of the server in a system-dependent way.

`default_text_search_config` (`string`)

Selects the text search configuration that is used by those variants of the text search functions that do not have an explicit argument specifying the configuration. See Chapter 12 for further information. The built-in default is `pg_catalog.simple`, but initdb will initialize the configuration file with a setting that corresponds to the chosen `lc_ctype` locale, if a configuration matching that locale can be identified.

19.11.3. Shared Library Preloading

Several settings are available for preloading shared libraries into the server, in order to load additional functionality or achieve performance benefits. For example, a setting of `'$libdir/mylib'` would cause `mylib.so` (or on some platforms, `mylib.sl`) to be preloaded from the installation's standard library directory. The differences between the settings are when they take effect and what privileges are required to change them.

Postgres Pro procedural language libraries can be preloaded in this way, typically by using the syntax `'$libdir/plXXX'` where `XXX` is `pgsql`, `perl`, `tcl`, or `python`.

Only shared libraries specifically intended to be used with Postgres Pro can be loaded this way. Every Postgres Pro-supported library has a “magic block” that is checked to guarantee compatibility. For this reason, non-Postgres Pro libraries cannot be loaded in this way. You might be able to use operating-system facilities such as `LD_PRELOAD` for that.

In general, refer to the documentation of a specific module for the recommended way to load that module.

`local_preload_libraries` (`string`)

This variable specifies one or more shared libraries that are to be preloaded at connection start. It contains a comma-separated list of library names, where each name is interpreted as for the `LOAD` command. Whitespace between entries is ignored; surround a library name with double quotes if you need to include whitespace or commas in the name. The parameter value only takes effect at the start of the connection. Subsequent changes have no effect. If a specified library is not found, the connection attempt will fail.

This option can be set by any user. Because of that, the libraries that can be loaded are restricted to those appearing in the `plugins` subdirectory of the installation's standard library directory. (It is the database administrator's responsibility to ensure that only “safe” libraries are installed there.) Entries in `local_preload_libraries` can specify this directory explicitly, for example `$libdir/plugins/mylib`, or just specify the library name — `mylib` would have the same effect as `$libdir/plugins/mylib`.

The intent of this feature is to allow unprivileged users to load debugging or performance-measurement libraries into specific sessions without requiring an explicit `LOAD` command. To that end, it would be typical to set this parameter using the `PGOPTIONS` environment variable on the client or by using `ALTER ROLE SET`.

However, unless a module is specifically designed to be used in this way by non-superusers, this is usually not the right setting to use. Look at session_preload_libraries instead.

`session_preload_libraries` (`string`)

This variable specifies one or more shared libraries that are to be preloaded at connection start. It contains a comma-separated list of library names, where each name is interpreted as for the `LOAD` command. Whitespace between entries is ignored; surround a library name with double quotes if

you need to include whitespace or commas in the name. The parameter value only takes effect at the start of the connection. Subsequent changes have no effect. If a specified library is not found, the connection attempt will fail. Only superusers can change this setting.

The intent of this feature is to allow debugging or performance-measurement libraries to be loaded into specific sessions without an explicit `LOAD` command being given. For example, auto_explain could be enabled for all sessions under a given user name by setting this parameter with `ALTER ROLE SET`. Also, this parameter can be changed without restarting the server (but changes only take effect when a new session is started), so it is easier to add new modules this way, even if they should apply to all sessions.

Unlike shared_preload_libraries, there is no large performance advantage to loading a library at session start rather than when it is first used. There is some advantage, however, when connection pooling is used.

`shared_preload_libraries` (`string`)

This variable specifies one or more shared libraries to be preloaded at server start. It contains a comma-separated list of library names, where each name is interpreted as for the `LOAD` command. Whitespace between entries is ignored; surround a library name with double quotes if you need to include whitespace or commas in the name. This parameter can only be set at server start. If a specified library is not found, the server will fail to start.

Some libraries need to perform certain operations that can only take place at postmaster start, such as allocating shared memory, reserving light-weight locks, or starting background workers. Those libraries must be loaded at server start through this parameter. See the documentation of each library for details.

Other libraries can also be preloaded. By preloading a shared library, the library startup time is avoided when the library is first used. However, the time to start each new server process might increase slightly, even if that process never uses the library. So this parameter is recommended only for libraries that will be used in most sessions. Also, changing this parameter requires a server restart, so this is not the right setting to use for short-term debugging tasks, say. Use session_preload_libraries for that instead.

> **Note**
>
> On Windows hosts, preloading a library at server start will not reduce the time required to start each new server process; each server process will re-load all preload libraries. However, `shared_preload_libraries` is still useful on Windows hosts for libraries that need to perform operations at postmaster start time.

`jit_provider` (`string`)

This variable is the name of the JIT provider library to be used (see Section 31.4.2). The default is `llvmjit`. This parameter can only be set at server start.

If set to a non-existent library, JIT will not be available, but no error will be raised. This allows JIT support to be installed separately from the main Postgres Pro package.

19.11.4. Other Defaults

`dynamic_library_path` (`string`)

If a dynamically loadable module needs to be opened and the file name specified in the `CREATE FUNCTION` or `LOAD` command does not have a directory component (i.e., the name does not contain a slash), the system will search this path for the required file.

The value for `dynamic_library_path` must be a list of absolute directory paths separated by colons (or semi-colons on Windows). If a list element starts with the special string `$libdir`, the compiled-in

Postgres Pro package library directory is substituted for `$libdir`; this is where the modules provided by the standard Postgres Pro distribution are installed. (Use `pg_config --pkglibdir` to find out the name of this directory.) For example:

```
dynamic_library_path = '/usr/local/lib/postgresql:/home/my_project/lib:$libdir'
```

or, in a Windows environment:

```
dynamic_library_path = 'C:\tools\postgresql;H:\my_project\lib;$libdir'
```

The default value for this parameter is `'$libdir'`. If the value is set to an empty string, the automatic path search is turned off.

This parameter can be changed at run time by superusers, but a setting done that way will only persist until the end of the client connection, so this method should be reserved for development purposes. The recommended way to set this parameter is in the `postgresql.conf` configuration file.

`gin_fuzzy_search_limit` (`integer`)

Soft upper limit of the size of the set returned by GIN index scans. For more information see Section 67.5.

19.12. Lock Management

`deadlock_timeout` (`integer`)

This is the amount of time to wait on a lock before checking to see if there is a deadlock condition. The check for deadlock is relatively expensive, so the server doesn't run it every time it waits for a lock. We optimistically assume that deadlocks are not common in production applications and just wait on the lock for a while before checking for a deadlock. Increasing this value reduces the amount of time wasted in needless deadlock checks, but slows down reporting of real deadlock errors. If this value is specified without units, it is taken as milliseconds. The default is one second (`1s`), which is probably about the smallest value you would want in practice. On a heavily loaded server you might want to raise it. Ideally the setting should exceed your typical transaction time, so as to improve the odds that a lock will be released before the waiter decides to check for deadlock. Only superusers can change this setting.

When log_lock_waits is set, this parameter also determines the amount of time to wait before a log message is issued about the lock wait. If you are trying to investigate locking delays you might want to set a shorter than normal `deadlock_timeout`.

`max_locks_per_transaction` (`integer`)

The shared lock table tracks locks on `max_locks_per_transaction` * (max_connections + max_prepared_transactions) objects (e.g., tables); hence, no more than this many distinct objects can be locked at any one time. This parameter controls the average number of object locks allocated for each transaction; individual transactions can lock more objects as long as the locks of all transactions fit in the lock table. This is *not* the number of rows that can be locked; that value is unlimited. The default, 64, has historically proven sufficient, but you might need to raise this value if you have queries that touch many different tables in a single transaction, e.g., query of a parent table with many children. This parameter can only be set at server start.

When running a standby server, you must set this parameter to the same or higher value than on the primary server. Otherwise, queries will not be allowed in the standby server.

`max_pred_locks_per_transaction` (`integer`)

The shared predicate lock table tracks locks on `max_pred_locks_per_transaction` * (max_connections + max_prepared_transactions) objects (e.g., tables); hence, no more than this many distinct objects can be locked at any one time. This parameter controls the average number of object locks allocated for each transaction; individual transactions can lock more objects as long as the locks of all transactions fit in the lock table. This is *not* the number of rows that can be locked; that value is

unlimited. The default, 64, has generally been sufficient in testing, but you might need to raise this value if you have clients that touch many different tables in a single serializable transaction. This parameter can only be set at server start.

`max_pred_locks_per_relation` (`integer`)

This controls how many pages or tuples of a single relation can be predicate-locked before the lock is promoted to covering the whole relation. Values greater than or equal to zero mean an absolute limit, while negative values mean max_pred_locks_per_transaction divided by the absolute value of this setting. The default is -2, which keeps the behavior from previous versions of Postgres Pro. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`max_pred_locks_per_page` (`integer`)

This controls how many rows on a single page can be predicate-locked before the lock is promoted to covering the whole page. The default is 2. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`lwlock_shared_limit` (`integer`)

Specifies the number of sequential shared LWLocks held before switching to the *fair mode*. In the fair mode, would-be shared lockers are added to the queue instead of acquiring the lock immediately, which allows to acquire an exclusive LWLock within reasonable time and thus avoid lock starvation. Setting this option to small values allows to acquire exclusive locks much faster, but can cause significant overhead. The larger the value, the lower the overhead and the speedup. As a rule of thumb, setting this option to 16 provides good speedup with minimal overhead. The default is 0 (the option is disabled). This parameter can only be set in the `postgresql.conf` file or on the server command line.

`log2_num_lock_partitions` (`integer`)

This controls how many partitions the shared lock tables are divided into. Number of partitions is calculated by raising 2 to the power of this parameter. The default value is 4, which corresponds to 16 partitions, and the maximum is 8. This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.13. Version and Platform Compatibility

19.13.1. Previous Postgres Pro Versions

`array_nulls` (`boolean`)

This controls whether the array input parser recognizes unquoted `NULL` as specifying a null array element. By default, this is `on`, allowing array values containing null values to be entered. However, PostgreSQL versions before 8.2 did not support null values in arrays, and therefore would treat `NULL` as specifying a normal array element with the string value “NULL”. For backward compatibility with applications that require the old behavior, this variable can be turned `off`.

Note that it is possible to create array values containing null values even when this variable is `off`.

`backslash_quote` (`enum`)

This controls whether a quote mark can be represented by `\'` in a string literal. The preferred, SQL-standard way to represent a quote mark is by doubling it (`''`) but Postgres Pro has historically also accepted `\'`. However, use of `\'` creates security risks because in some client character set encodings, there are multibyte characters in which the last byte is numerically equivalent to ASCII `\`. If client-side code does escaping incorrectly then an SQL-injection attack is possible. This risk can be prevented by making the server reject queries in which a quote mark appears to be escaped by a backslash. The allowed values of `backslash_quote` are `on` (allow `\'` always), `off` (reject always), and `safe_encoding` (allow only if client encoding does not allow ASCII `\` within a multibyte character). `safe_encoding` is the default setting.

Note that in a standard-conforming string literal, \ just means \ anyway. This parameter only affects the handling of non-standard-conforming literals, including escape string syntax (E'...').

escape_string_warning (boolean)

When on, a warning is issued if a backslash (\) appears in an ordinary string literal ('...' syntax) and standard_conforming_strings is off. The default is on.

Applications that wish to use backslash as escape should be modified to use escape string syntax (E'...'), because the default behavior of ordinary strings is now to treat backslash as an ordinary character, per SQL standard. This variable can be enabled to help locate code that needs to be changed.

lo_compat_privileges (boolean)

In PostgreSQL releases prior to 9.0, large objects did not have access privileges and were, therefore, always readable and writable by all users. Setting this variable to on disables the new privilege checks, for compatibility with prior releases. The default is off. Only superusers can change this setting.

Setting this variable does not disable all security checks related to large objects — only those for which the default behavior has changed in PostgreSQL 9.0.

partition_backend (string)

Defines the backend to use for partitioning with declarative syntax. Possible values are:

- internal — use Postgres Pro Enterprise core functionality for range and list partitioning. This value is incompatible with declarative syntax for hash partitioning.
- pg_pathman — use pg_pathman for range and hash partitioning. This value is incompatible with declarative syntax for list partitioning. You must have pg_pathman installed to use this value.

  Starting from Postgres Pro 12, using pg_pathman is not recommended.

Default: internal

quote_all_identifiers (boolean)

When the database generates SQL, force all identifiers to be quoted, even if they are not (currently) keywords. This will affect the output of EXPLAIN as well as the results of functions like pg_get_viewdef. See also the --quote-all-identifiers option of pg_dump and pg_dumpall.

nul_byte_replacement_on_import (string)

Replace NUL bytes '\0' with the specified decimal code of an ASCII character while loading data using the COPY FROM command. Such a replacement may be required when transferring data from another DBMS since Postgres Pro does not allow NUL bytes in data. The specified ASCII code must not coincide with the QUOTE and DELIMITER characters used by COPY FROM as it may cause unexpected results. The default value is '\0', so no replacement occurs.

enable_large_mem_buffers (boolean)

When set to true, allows to copy, dump and restore large bytea values exceeding 0.5 GB (up to 1 GB) and records with several text values exceeding 1 GB in total (up to 2 GB). The default value is false. Only superusers can change this setting and only in the current session using the SET command.

standard_conforming_strings (boolean)

This controls whether ordinary string literals ('...') treat backslashes literally, as specified in the SQL standard. Beginning in PostgreSQL 9.1, the default is on (prior releases defaulted to off). Applications can check this parameter to determine how string literals will be processed. The presence of this parameter can also be taken as an indication that the escape string syntax (E'...') is sup-

ported. Escape string syntax (Section 4.1.2.2) should be used if an application desires backslashes to be treated as escape characters.

`synchronize_seqscans` (`boolean`)

This allows sequential scans of large tables to synchronize with each other, so that concurrent scans read the same block at about the same time and hence share the I/O workload. When this is enabled, a scan might start in the middle of the table and then "wrap around" the end to cover all rows, so as to synchronize with the activity of scans already in progress. This can result in unpredictable changes in the row ordering returned by queries that have no `ORDER BY` clause. Setting this parameter to `off` ensures the pre-8.3 behavior in which a sequential scan always starts from the beginning of the table. The default is `on`.

19.13.2. Platform and Client Compatibility

`unicode_nul_character_replacement_in_jsonb` (`integer`)

Replace `'\u0000'` with the specified unicode character when calling a function processing JSONB since `jsonb*` functions do not accept `'\u0000'`. The replacing character is specified with the numeric value from 0 to 65535. Anyone can set the value of this configuration parameter anytime. The default value is `0`, so no replacement occurs.

`transform_null_equals` (`boolean`)

When on, expressions of the form *`expr`* `= NULL` (or `NULL =` *`expr`*) are treated as *`expr`* `IS NULL`, that is, they return true if *`expr`* evaluates to the null value, and false otherwise. The correct SQL-spec-compliant behavior of *`expr`* `= NULL` is to always return null (unknown). Therefore this parameter defaults to `off`.

However, filtered forms in Microsoft Access generate queries that appear to use *`expr`* `= NULL` to test for null values, so if you use that interface to access the database you might want to turn this option on. Since expressions of the form *`expr`* `= NULL` always return the null value (using the SQL standard interpretation), they are not very useful and do not appear often in normal applications so this option does little harm in practice. But new users are frequently confused about the semantics of expressions involving null values, so this option is off by default.

Note that this option only affects the exact form `= NULL`, not other comparison operators or other expressions that are computationally equivalent to some expression involving the equals operator (such as `IN`). Thus, this option is not a general fix for bad programming.

Refer to Section 9.2 for related information.

19.14. Memory Purge

Postgres Pro Enterprise provides memory purge configuration parameters that can automatically replace data with zero bytes before it is deleted. For details, see Section 32.1.

`wipe_file_on_delete` (`boolean`)

Replace a file with zero bytes before it is deleted.

Default: `on`

`wipe_heaptuple_on_delete` (`boolean`)

Replace a row version with zero bytes before it is deleted.

Default: `on`

`wipe_memctx_on_free` (`boolean`)

Clear random-access memory before it is freed. This parameter only controls the memory allocated as part of a particular context.

Default: `on`

`wipe_mem_on_free` (`boolean`)

Clear random-access memory before it is freed. This parameter controls the memory that does not belong to any context.

Default: `on`

`wipe_xlog_on_free` (`boolean`)

Replace WAL segments with zero bytes before they are deleted or overwritten.

Default: `on`

19.15. Data Compression

`cfs_gc` (`boolean`)

Enables/disables background garbage collection of compressed pages. Default: `on`

`cfs_gc_lock_file` (`char`)

Path to the lock file to be used to ensure running only one garbage collection worker at a time for several Postgres Pro servers when cfs_gc_workers = 1. This parameter can only be set at server start.

`cfs_gc_workers` (`integer`)

Number of CFS background garbage collection workers. This parameter can only be set at server start. The number of workers cannot exceed 100. Default: 1

`cfs_level` (`integer`)

CFS compression level: 0 — no compression, 1 — maximal speed. Other possible values depend on the specific compression algorithm used. For example, 9 for `zlib` or 19 for `zstd`. Default: 1

`cfs_gc_threshold` (`integer`)

Minimum percent of garbage blocks in the file required to start garbage collection. If you would like to manually defragment a relation with a smaller percent of garbage, you can temporarily set this parameter to a smaller value for your current session. Default: 30

`cfs_gc_period` (`integer`)

Time interval between CFS garbage collection iterations, in milliseconds. Default: 5 seconds

`cfs_compress_temp_relations` (`bool`)

When set to `true`, compresses temporary tables. For large temporary tables, this setting can save disk space and speed up execution as less data needs to be read. This parameter can only be set at server start. Default: `false`

`cfs_gc_delay` (`integer`)

Time interval for which garbage collection is paused after each file defragmentation, in milliseconds. Default: 0

`cfs_gc_respond_time` (`integer`)

Time interval that CFS waits for the lock to be released from a file processed by garbage collector before writing a warning to the log, in seconds. Default: 3600

`cfs_gc_time_bloom_query` (`integer`)

Reports the number of times the Bloom filter was queried for CFS files. This parameter is read-only.

`cfs_gc_time_bloom_passed` (`integer`)

Reports the number of elements that passed through the Bloom filter. This parameter is read-only.

`cfs_gc_time_bloom_false_positive` (`integer`)

Reports the number of false positives returned by the Bloom filter. This parameter is read-only.

`cfs_log_verbose` (`boolean`)

Controls the CFS log level of defragmentation messages. If set to `false`, the level is `INFO`. Defragmentation messages are written to the log file when `log_min_messages` has a level from `DEBUG5` to `INFO`.

If set to `true`, the level is set to `LOG`. Defragmentation messages are written to the log file when `log_min_messages` has a level from `DEBUG5` to `LOG`. In this case, they all have `LOG` as prefix, regardless of their level. See message levels for more information.

19.16. Error Handling

`exit_on_error` (`boolean`)

If on, any error will terminate the current session. By default, this is set to off, so that only FATAL errors will terminate the session.

`restart_after_crash` (`boolean`)

When set to on, which is the default, Postgres Pro will automatically reinitialize after a backend crash. Leaving this value set to on is normally the best way to maximize the availability of the database. However, in some circumstances, such as when Postgres Pro is being invoked by clusterware, it may be useful to disable the restart so that the clusterware can gain control and take any actions it deems appropriate.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`data_sync_retry` (`boolean`)

When set to off, which is the default, Postgres Pro will raise a PANIC-level error on failure to flush modified data files to the file system. This causes the database server to crash. This parameter can only be set at server start.

On some operating systems, the status of data in the kernel's page cache is unknown after a write-back failure. In some cases it might have been entirely forgotten, making it unsafe to retry; the second attempt may be reported as successful, when in fact the data has been lost. In these circumstances, the only way to avoid data loss is to recover from the WAL after any failure is reported, preferably after investigating the root cause of the failure and replacing any faulty hardware.

If set to on, Postgres Pro will instead report an error but continue to run so that the data flushing operation can be retried in a later checkpoint. Only set it to on after investigating the operating system's treatment of buffered data in case of write-back failure.

`recovery_init_sync_method` (`enum`)

When set to `fsync`, which is the default, Postgres Pro will recursively open and synchronize all files in the data directory before crash recovery begins. The search for files will follow symbolic links for the WAL directory and each configured tablespace (but not any other symbolic links). This is intended to make sure that all WAL and data files are durably stored on disk before replaying changes. This applies whenever starting a database cluster that did not shut down cleanly, including copies created with pg_basebackup.

On Linux, `syncfs` may be used instead, to ask the operating system to synchronize the whole file systems that contain the data directory, the WAL files and each tablespace (but not any other file systems that may be reachable through symbolic links). This may be a lot faster than the `fsync` setting, because it doesn't need to open each file one by one. On the other hand, it may be slower

if a file system is shared by other applications that modify a lot of files, since those files will also be written to disk. Furthermore, on versions of Linux before 5.8, I/O errors encountered while writing data to disk may not be reported to Postgres Pro, and relevant error messages may appear only in kernel logs.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`crash_info` (`boolean`)

When set to `on`, which is the default, Postgres Pro will write diagnostic information about a backend crash into a file.

This parameter can only be set at server start.

`crash_info_dump` (`text`)

Specifies a comma-separated list of character strings that contain data sources to provide data for a crash dump. Possible values of the strings are as follows:

- `queries` — query texts
- `memory_context` — memory context
- `system` — information on the OS
- `module` — information on modules loaded to the `postgres` process
- `cpuinfo` — information on the processor
- `virtual_memory` — information on virtual memory regions

The default value is `system,module,queries,memory_context`.

This parameter can only be set at server start.

`crash_info_location` (`string`)

Specifies the directory where information about a backend crash is to be stored. The value of `stderr` sends information about the crash to stderr. If this parameter is set to the empty string `''`, which is the default, the `$PGDATA/crash_info` directory is used. If you wish to keep the files elsewhere, create the target directory in advance and grant appropriate privileges.

This parameter can only be set at server start.

19.17. Preset Options

The following “parameters” are read-only. As such, they have been excluded from the sample `postgresql.conf` file. These options report various aspects of Postgres Pro behavior that might be of interest to certain applications, particularly administrative front-ends. Most of them are determined when Postgres Pro is compiled or when it is installed.

`block_size` (`integer`)

Reports the size of a disk block. It is determined by the value of `BLCKSZ` when building the server. The default value is 8192 bytes. The meaning of some configuration variables (such as shared_buffers) is influenced by `block_size`. See Section 19.4 for information.

`data_checksums` (`boolean`)

Reports whether data checksums are enabled for this cluster. See data checksums for more information.

`data_directory_mode` (`integer`)

On Unix systems this parameter reports the permissions the data directory (defined by data_directory) had at server startup. (On Microsoft Windows this parameter will always display `0700`.) See group access for more information.

`debug_assertions` (`boolean`)

Reports whether Postgres Pro has been built with assertions enabled. That is the case if the macro `USE_ASSERT_CHECKING` is defined when Postgres Pro is built (accomplished e.g., by the `configure` option `--enable-cassert`). By default Postgres Pro is built without assertions.

`integer_datetimes` (`boolean`)

Reports whether Postgres Pro was built with support for 64-bit-integer dates and times. As of Postgres Pro 10, this is always `on`.

`in_hot_standby` (`boolean`)

Reports whether the server is currently in hot standby mode. When this is `on`, all transactions are forced to be read-only. Within a session, this can change only if the server is promoted to be primary. See Section 26.4 for more information.

`lc_collate` (`string`)

Reports the locale in which sorting of textual data is done. See Section 23.1 for more information. This value is determined when a database is created.

`lc_collate_canonical` (`string`)

Reports the canonical name of the collation order locale. Unlike `lc_collate`, `lc_collate_canonical` does not contain the modifier of the collation provider.

`lc_ctype` (`string`)

Reports the locale that determines character classifications. See Section 23.1 for more information. This value is determined when a database is created. Ordinarily this will be the same as `lc_collate`, but for special applications it might be set differently.

`max_function_args` (`integer`)

Reports the maximum number of function arguments. It is determined by the value of `FUNC_MAX_ARGS` when building the server. The default value is 100 arguments.

`max_identifier_length` (`integer`)

Reports the maximum identifier length. It is determined as one less than the value of `NAMEDATALEN` when building the server. The default value of `NAMEDATALEN` is 64; therefore the default `max_identifier_length` is 63 bytes, which can be less than 63 characters when using multibyte encodings.

`max_index_keys` (`integer`)

Reports the maximum number of index keys. It is determined by the value of `INDEX_MAX_KEYS` when building the server. The default value is 32 keys.

`pgpro_build` (`string`)

Reports the commit ID of Postgres Pro source files.

`pgpro_edition` (`string`)

Reports the Postgres Pro edition as a string, i.e. `standard` or `enterprise`.

`pgpro_version` (`string`)

Reports the Postgres Pro server version as a string.

`segment_size` (`integer`)

Reports the number of blocks (pages) that can be stored within a file segment. It is determined by the value of `RELSEG_SIZE` when building the server. The maximum size of a segment file in bytes is equal to `segment_size` multiplied by `block_size`; by default this is 1GB.

`server_encoding` (`string`)

Reports the database encoding (character set). It is determined when the database is created. Ordinarily, clients need only be concerned with the value of client_encoding.

`server_version` (`string`)

Reports the version number of the server. It is determined by the value of `PG_VERSION` when building the server.

`server_version_num` (`integer`)

Reports the version number of the server as an integer. It is determined by the value of `PG_VERSION_NUM` when building the server.

`ssl_library` (`string`)

Reports the name of the SSL library that this Postgres Pro server was built with (even if SSL is not currently configured or in use on this instance), for example `OpenSSL`, or an empty string if none.

`wal_block_size` (`integer`)

Reports the size of a WAL disk block. It is determined by the value of `XLOG_BLCKSZ` when building the server. The default value is 8192 bytes.

`wal_segment_size` (`integer`)

Reports the size of write ahead log segments. The default value is 16MB. See Section 29.5 for more information.

19.18. Customized Options

This feature was designed to allow parameters not normally known to Postgres Pro to be added by add-on modules (such as procedural languages). This allows extension modules to be configured in the standard ways.

Custom options have two-part names: an extension name, then a dot, then the parameter name proper, much like qualified names in SQL. An example is `plpgsql.variable_conflict`.

Because custom options may need to be set in processes that have not loaded the relevant extension module, Postgres Pro will accept a setting for any two-part parameter name. Such variables are treated as placeholders and have no function until the module that defines them is loaded. When an extension module is loaded, it will add its variable definitions, convert any placeholder values according to those definitions, and issue warnings for any unrecognized placeholders that begin with its extension name.

19.19. Developer Options

The following parameters are intended for developer testing, and should never be used on a production database. However, some of them can be used to assist with the recovery of severely damaged databases. As such, they have been excluded from the sample `postgresql.conf` file. Note that many of these parameters require special source compilation flags to work at all.

`allow_in_place_tablespaces` (`boolean`)

Allows tablespaces to be created as directories inside `pg_tblspc`, when an empty location string is provided to the `CREATE TABLESPACE` command. This is intended to allow testing replication scenarios where primary and standby servers are running on the same machine. Such directories are likely to confuse backup tools that expect to find only symbolic links in that location. Only superusers can change this setting.

`allow_system_table_mods` (`boolean`)

Allows modification of the structure of system tables as well as certain other risky actions on system tables. This is otherwise not allowed even for superusers. Ill-advised use of this setting can cause

irretrievable data loss or seriously corrupt the database system. Only superusers can change this setting.

`backtrace_functions` (`string`)

This parameter contains a comma-separated list of C function names. If an error is raised and the name of the internal C function where the error happens matches a value in the list, then a backtrace is written to the server log together with the error message. This can be used to debug specific areas of the source code.

Backtrace support is not available on all platforms, and the quality of the backtraces depends on compilation options.

This parameter can only be set by superusers.

`debug_discard_caches` (`integer`)

When set to `1`, each system catalog cache entry is invalidated at the first possible opportunity, whether or not anything that would render it invalid really occurred. Caching of system catalogs is effectively disabled as a result, so the server will run extremely slowly. Higher values run the cache invalidation recursively, which is even slower and only useful for testing the caching logic itself. The default value of `0` selects normal catalog caching behavior.

This parameter can be very helpful when trying to trigger hard-to-reproduce bugs involving concurrent catalog changes, but it is otherwise rarely needed.

This parameter is supported when `DISCARD_CACHES_ENABLED` was defined at compile time (which happens automatically when using the configure option `--enable-cassert`). In production builds, its value will always be `0` and attempts to set it to another value will raise an error.

`force_parallel_mode` (`enum`)

Allows the use of parallel queries for testing purposes even in cases where no performance benefit is expected. The allowed values of `force_parallel_mode` are `off` (use parallel mode only when it is expected to improve performance), `on` (force parallel query for all queries for which it is thought to be safe), and `regress` (like `on`, but with additional behavior changes as explained below).

More specifically, setting this value to `on` will add a `Gather` node to the top of any query plan for which this appears to be safe, so that the query runs inside of a parallel worker. Even when a parallel worker is not available or cannot be used, operations such as starting a subtransaction that would be prohibited in a parallel query context will be prohibited unless the planner believes that this will cause the query to fail. If failures or unexpected results occur when this option is set, some functions used by the query may need to be marked `PARALLEL UNSAFE` (or, possibly, `PARALLEL RESTRICTED`).

Setting this value to `regress` has all of the same effects as setting it to `on` plus some additional effects that are intended to facilitate automated regression testing. Normally, messages from a parallel worker include a context line indicating that, but a setting of `regress` suppresses this line so that the output is the same as in non-parallel execution. Also, the `Gather` nodes added to plans by this setting are hidden in `EXPLAIN` output so that the output matches what would be obtained if this setting were turned `off`.

`ignore_system_indexes` (`boolean`)

Ignore system indexes when reading system tables (but still update the indexes when modifying the tables). This is useful when recovering from damaged system indexes. This parameter cannot be changed after session start.

`post_auth_delay` (`integer`)

The amount of time to delay when a new server process is started, after it conducts the authentication procedure. This is intended to give developers an opportunity to attach to the server process with a debugger. If this value is specified without units, it is taken as seconds. A value of zero (the default) disables the delay. This parameter cannot be changed after session start.

`pre_auth_delay` (`integer`)

The amount of time to delay just after a new server process is forked, before it conducts the authentication procedure. This is intended to give developers an opportunity to attach to the server process with a debugger to trace down misbehavior in authentication. If this value is specified without units, it is taken as seconds. A value of zero (the default) disables the delay. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`trace_notify` (`boolean`)

Generates a great amount of debugging output for the `LISTEN` and `NOTIFY` commands. client_min_messages or log_min_messages must be `DEBUG1` or lower to send this output to the client or server logs, respectively.

`trace_recovery_messages` (`enum`)

Enables logging of recovery-related debugging output that otherwise would not be logged. This parameter allows the user to override the normal setting of log_min_messages, but only for specific messages. This is intended for use in debugging Hot Standby. Valid values are `DEBUG5`, `DEBUG4`, `DEBUG3`, `DEBUG2`, `DEBUG1`, and `LOG`. The default, `LOG`, does not affect logging decisions at all. The other values cause recovery-related debug messages of that priority or higher to be logged as though they had `LOG` priority; for common settings of `log_min_messages` this results in unconditionally sending them to the server log. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`trace_sort` (`boolean`)

If on, emit information about resource usage during sort operations. This parameter is only available if the `TRACE_SORT` macro was defined when Postgres Pro was compiled. (However, `TRACE_SORT` is currently defined by default.)

`trace_locks` (`boolean`)

If on, emit information about lock usage. Information dumped includes the type of lock operation, the type of lock and the unique identifier of the object being locked or unlocked. Also included are bit masks for the lock types already granted on this object as well as for the lock types awaited on this object. For each lock type a count of the number of granted locks and waiting locks is also dumped as well as the totals. An example of the log file output is shown here:

```
LOG:  LockAcquire: new: lock(0xb7acd844) id(24688,24696,0,0,0,1)
      grantMask(0) req(0,0,0,0,0,0,0)=0 grant(0,0,0,0,0,0,0)=0
      wait(0) type(AccessShareLock)
LOG:  GrantLock: lock(0xb7acd844) id(24688,24696,0,0,0,1)
      grantMask(2) req(1,0,0,0,0,0,0)=1 grant(1,0,0,0,0,0,0)=1
      wait(0) type(AccessShareLock)
LOG:  UnGrantLock: updated: lock(0xb7acd844) id(24688,24696,0,0,0,1)
      grantMask(0) req(0,0,0,0,0,0,0)=0 grant(0,0,0,0,0,0,0)=0
      wait(0) type(AccessShareLock)
LOG:  CleanUpLock: deleting: lock(0xb7acd844) id(24688,24696,0,0,0,1)
      grantMask(0) req(0,0,0,0,0,0,0)=0 grant(0,0,0,0,0,0,0)=0
      wait(0) type(INVALID)
```

This parameter is only available if the `LOCK_DEBUG` macro was defined when Postgres Pro was compiled.

`trace_lwlocks` (`boolean`)

If on, emit information about lightweight lock usage. Lightweight locks are intended primarily to provide mutual exclusion of access to shared-memory data structures.

This parameter is only available if the `LOCK_DEBUG` macro was defined when Postgres Pro was compiled.

`trace_userlocks` (`boolean`)

If on, emit information about user lock usage. Output is the same as for `trace_locks`, only for advisory locks.

This parameter is only available if the `LOCK_DEBUG` macro was defined when Postgres Pro was compiled.

`trace_lock_oidmin` (`integer`)

If set, do not trace locks for tables below this OID (used to avoid output on system tables).

This parameter is only available if the `LOCK_DEBUG` macro was defined when Postgres Pro was compiled.

`trace_lock_table` (`integer`)

Unconditionally trace locks on this table (OID).

This parameter is only available if the `LOCK_DEBUG` macro was defined when Postgres Pro was compiled.

`debug_deadlocks` (`boolean`)

If set, dumps information about all current locks when a deadlock timeout occurs.

This parameter is only available if the `LOCK_DEBUG` macro was defined when Postgres Pro was compiled.

`log_btree_build_stats` (`boolean`)

If set, logs system resource usage statistics (memory and CPU) on various B-tree operations.

This parameter is only available if the `BTREE_BUILD_STATS` macro was defined when Postgres Pro was compiled.

`wal_consistency_checking` (`string`)

This parameter is intended to be used to check for bugs in the WAL redo routines. When enabled, full-page images of any buffers modified in conjunction with the WAL record are added to the record. If the record is subsequently replayed, the system will first apply each record and then test whether the buffers modified by the record match the stored images. In certain cases (such as hint bits), minor variations are acceptable, and will be ignored. Any unexpected differences will result in a fatal error, terminating recovery.

The default value of this setting is the empty string, which disables the feature. It can be set to `all` to check all records, or to a comma-separated list of resource managers to check only records originating from those resource managers. Currently, the supported resource managers are `heap`, `heap2`, `btree`, `hash`, `gin`, `gist`, `sequence`, `spgist`, `brin`, and `generic`. Only superusers can change this setting.

`wal_debug` (`boolean`)

If on, emit WAL-related debugging output. This parameter is only available if the `WAL_DEBUG` macro was defined when Postgres Pro was compiled.

`ignore_checksum_failure` (`boolean`)

Only has effect if data checksums are enabled.

Detection of a checksum failure during a read normally causes Postgres Pro to report an error, aborting the current transaction. Setting `ignore_checksum_failure` to on causes the system to ignore the failure (but still report a warning), and continue processing. This behavior may *cause crashes, propagate or hide corruption, or other serious problems*. However, it may allow you to get past the error and retrieve undamaged tuples that might still be present in the table if the block header is

still sane. If the header is corrupt an error will be reported even if this option is enabled. The default setting is `off`, and it can only be changed by a superuser.

`zero_damaged_pages` (`boolean`)

Detection of a damaged page header normally causes Postgres Pro to report an error, aborting the current transaction. Setting `zero_damaged_pages` to on causes the system to instead report a warning, zero out the damaged page in memory, and continue processing. This behavior *will destroy data*, namely all the rows on the damaged page. However, it does allow you to get past the error and retrieve rows from any undamaged pages that might be present in the table. It is useful for recovering data if corruption has occurred due to a hardware or software error. You should generally not set this on until you have given up hope of recovering data from the damaged pages of a table. Zeroed-out pages are not forced to disk so it is recommended to recreate the table or the index before turning this parameter off again. The default setting is `off`, and it can only be changed by a superuser.

`ignore_invalid_pages` (`boolean`)

If set to `off` (the default), detection of WAL records having references to invalid pages during recovery causes Postgres Pro to raise a PANIC-level error, aborting the recovery. Setting `ignore_invalid_pages` to `on` causes the system to ignore invalid page references in WAL records (but still report a warning), and continue the recovery. This behavior may *cause crashes, data loss, propagate or hide corruption, or other serious problems*. However, it may allow you to get past the PANIC-level error, to finish the recovery, and to cause the server to start up. The parameter can only be set at server start. It only has effect during recovery or in standby mode.

`jit_debugging_support` (`boolean`)

If LLVM has the required functionality, register generated functions with GDB. This makes debugging easier. The default setting is `off`. This parameter can only be set at server start.

`jit_dump_bitcode` (`boolean`)

Writes the generated LLVM IR out to the file system, inside data_directory. This is only useful for working on the internals of the JIT implementation. The default setting is `off`. This parameter can only be changed by a superuser.

`jit_expressions` (`boolean`)

Determines whether expressions are JIT compiled, when JIT compilation is activated (see Section 31.2). The default is `on`.

`jit_profiling_support` (`boolean`)

If LLVM has the required functionality, emit the data needed to allow perf to profile functions generated by JIT. This writes out files to `~/.debug/jit/`; the user is responsible for performing cleanup when desired. The default setting is `off`. This parameter can only be set at server start.

`jit_tuple_deforming` (`boolean`)

Determines whether tuple deforming is JIT compiled, when JIT compilation is activated (see Section 31.2). The default is `on`.

`remove_temp_files_after_crash` (`boolean`)

When set to `on`, which is the default, Postgres Pro will automatically remove temporary files after a backend crash. If disabled, the files will be retained and may be used for debugging, for example. Repeated crashes may however result in accumulation of useless files. This parameter can only be set in the `postgresql.conf` file or on the server command line.

19.20. Short Options

For convenience there are also single letter command-line option switches available for some parameters. They are described in Table 19.4. Some of these options exist for historical reasons, and their presence as a single-letter option does not necessarily indicate an endorsement to use the option heavily.

Table 19.4. Short Option Key

Short Option	Equivalent
-B *x*	shared_buffers = *x*
-d *x*	log_min_messages = DEBUG *x*
-e	datestyle = euro
-fb, -fh, -fi, -fm, -fn, -fo, -fs, -ft	enable_bitmapscan = off , enable_hashjoin = off , enable_indexscan = off, enable_mergejoin = off , enable_nestloop = off, enable_indexonlyscan = off , enable_seqscan = off , enable_tidscan = off
-F	fsync = off
-h *x*	listen_addresses = *x*
-i	listen_addresses = '*'
-k *x*	unix_socket_directories = *x*
-l	ssl = on
-N *x*	max_connections = *x*
-O	allow_system_table_mods = on
-p *x*	port = *x*
-P	ignore_system_indexes = on
-s	log_statement_stats = on
-S *x*	work_mem = *x*
-tpa, -tpl, -te	log_parser_stats = on , log_planner_stats = on , log_executor_stats = on
-W *x*	post_auth_delay = *x*

Chapter 20. Client Authentication

When a client application connects to the database server, it specifies which Postgres Pro database user name it wants to connect as, much the same way one logs into a Unix computer as a particular user. Within the SQL environment the active database user name determines access privileges to database objects — see Chapter 21 for more information. Therefore, it is essential to restrict which database users can connect.

> **Note**
>
> As explained in Chapter 21, Postgres Pro actually does privilege management in terms of “roles”. In this chapter, we consistently use *database user* to mean “role with the `LOGIN` privilege”.

Authentication is the process by which the database server establishes the identity of the client, and by extension determines whether the client application (or the user who runs the client application) is permitted to connect with the database user name that was requested.

Postgres Pro offers a number of different client authentication methods. The method used to authenticate a particular client connection can be selected on the basis of (client) host address, database, and user.

Postgres Pro database user names are logically separate from user names of the operating system in which the server runs. If all the users of a particular server also have accounts on the server's machine, it makes sense to assign database user names that match their operating system user names. However, a server that accepts remote connections might have many database users who have no local operating system account, and in such cases there need be no connection between database user names and OS user names.

20.1. The `pg_hba.conf` File

Client authentication is controlled by a configuration file, which traditionally is named `pg_hba.conf` and is stored in the database cluster's data directory. (HBA stands for host-based authentication.) A default `pg_hba.conf` file is installed when the data directory is initialized by `initdb`. It is possible to place the authentication configuration file elsewhere, however; see the hba_file configuration parameter.

The general format of the `pg_hba.conf` file is a set of records, one per line. Blank lines are ignored, as is any text after the `#` comment character. A record can be continued onto the next line by ending the line with a backslash. (Backslashes are not special except at the end of a line.) A record is made up of a number of fields which are separated by spaces and/or tabs. Fields can contain white space if the field value is double-quoted. Quoting one of the keywords in a database, user, or address field (e.g., `all` or `replication`) makes the word lose its special meaning, and just match a database, user, or host with that name. Backslash line continuation applies even within quoted text or comments.

Each record specifies a connection type, a client IP address range (if relevant for the connection type), a database name, a user name, and the authentication method to be used for connections matching these parameters. The first record with a matching connection type, client address, requested database, and user name is used to perform authentication. There is no “fall-through” or “backup”: if one record is chosen and the authentication fails, subsequent records are not considered. If no record matches, access is denied.

A record can have several formats:

```
local         database  user  auth-method [auth-options]
host          database  user  address     auth-method  [auth-options]
hostssl       database  user  address     auth-method  [auth-options]
hostnossl     database  user  address     auth-method  [auth-options]
hostgssenc    database  user  address     auth-method  [auth-options]
hostnogssenc  database  user  address     auth-method  [auth-options]
host          database  user  IP-address  IP-mask      auth-method  [auth-options]
```

```
hostssl       database  user  IP-address  IP-mask      auth-method  [auth-options]
hostnossl     database  user  IP-address  IP-mask      auth-method  [auth-options]
hostgssenc    database  user  IP-address  IP-mask      auth-method  [auth-options]
hostnogssenc  database  user  IP-address  IP-mask      auth-method  [auth-options]
```

The meaning of the fields is as follows:

`local`

This record matches connection attempts using Unix-domain sockets. Without a record of this type, Unix-domain socket connections are disallowed.

`host`

This record matches connection attempts made using TCP/IP. `host` records match SSL or non-SSL connection attempts as well as GSSAPI encrypted or non-GSSAPI encrypted connection attempts.

> **Note**
>
> Remote TCP/IP connections will not be possible unless the server is started with an appropriate value for the listen_addresses configuration parameter, since the default behavior is to listen for TCP/IP connections only on the local loopback address `localhost`.

`hostssl`

This record matches connection attempts made using TCP/IP, but only when the connection is made with SSL encryption.

To make use of this option the server must be built with SSL support. Furthermore, SSL must be enabled by setting the ssl configuration parameter (see Section 18.9 for more information). Otherwise, the `hostssl` record is ignored except for logging a warning that it cannot match any connections.

`hostnossl`

This record type has the opposite behavior of `hostssl`; it only matches connection attempts made over TCP/IP that do not use SSL.

`hostgssenc`

This record matches connection attempts made using TCP/IP, but only when the connection is made with GSSAPI encryption.

To make use of this option the server must be built with GSSAPI support. Otherwise, the `hostgssenc` record is ignored except for logging a warning that it cannot match any connections.

`hostnogssenc`

This record type has the opposite behavior of `hostgssenc`; it only matches connection attempts made over TCP/IP that do not use GSSAPI encryption.

`database`

Specifies which database name(s) this record matches. The value `all` specifies that it matches all databases. The value `sameuser` specifies that the record matches if the requested database has the same name as the requested user. The value `samerole` specifies that the requested user must be a member of the role with the same name as the requested database. (`samegroup` is an obsolete but still accepted spelling of `samerole`.) Superusers are not considered to be members of a role for the purposes of `samerole` unless they are explicitly members of the role, directly or indirectly, and not just by virtue of being a superuser. The value `replication` specifies that the record matches if a physical replication connection is requested, however, it doesn't match with logical replication connections. Note that physical replication connections do not specify any particular database whereas logical replication connections do specify it. Otherwise, this is the name of a specific Postgres Pro database. Multiple database names can be supplied by separating them with commas. A separate file containing database names can be specified by preceding the file name with `@`.

user

Specifies which database user name(s) this record matches. The value `all` specifies that it matches all users. Otherwise, this is either the name of a specific database user, or a group name preceded by `+`. (Recall that there is no real distinction between users and groups in Postgres Pro; a `+` mark really means “match any of the roles that are directly or indirectly members of this role”, while a name without a `+` mark matches only that specific role.) For this purpose, a superuser is only considered to be a member of a role if they are explicitly a member of the role, directly or indirectly, and not just by virtue of being a superuser. Multiple user names can be supplied by separating them with commas. A separate file containing user names can be specified by preceding the file name with `@`.

address

Specifies the client machine address(es) that this record matches. This field can contain either a host name, an IP address range, or one of the special key words mentioned below.

An IP address range is specified using standard numeric notation for the range's starting address, then a slash (`/`) and a CIDR mask length. The mask length indicates the number of high-order bits of the client IP address that must match. Bits to the right of this should be zero in the given IP address. There must not be any white space between the IP address, the `/`, and the CIDR mask length.

Typical examples of an IPv4 address range specified this way are `172.20.143.89/32` for a single host, or `172.20.143.0/24` for a small network, or `10.6.0.0/16` for a larger one. An IPv6 address range might look like `::1/128` for a single host (in this case the IPv6 loopback address) or `fe80::7a31:c1f-f:0000:0000/96` for a small network. `0.0.0.0/0` represents all IPv4 addresses, and `::0/0` represents all IPv6 addresses. To specify a single host, use a mask length of 32 for IPv4 or 128 for IPv6. In a network address, do not omit trailing zeroes.

An entry given in IPv4 format will match only IPv4 connections, and an entry given in IPv6 format will match only IPv6 connections, even if the represented address is in the IPv4-in-IPv6 range. Note that entries in IPv6 format will be rejected if the system's C library does not have support for IPv6 addresses.

You can also write `all` to match any IP address, `samehost` to match any of the server's own IP addresses, or `samenet` to match any address in any subnet that the server is directly connected to.

If a host name is specified (anything that is not an IP address range or a special key word is treated as a host name), that name is compared with the result of a reverse name resolution of the client's IP address (e.g., reverse DNS lookup, if DNS is used). Host name comparisons are case insensitive. If there is a match, then a forward name resolution (e.g., forward DNS lookup) is performed on the host name to check whether any of the addresses it resolves to are equal to the client's IP address. If both directions match, then the entry is considered to match. (The host name that is used in `pg_hba.conf` should be the one that address-to-name resolution of the client's IP address returns, otherwise the line won't be matched. Some host name databases allow associating an IP address with multiple host names, but the operating system will only return one host name when asked to resolve an IP address.)

A host name specification that starts with a dot (`.`) matches a suffix of the actual host name. So `.example.com` would match `foo.example.com` (but not just `example.com`).

When host names are specified in `pg_hba.conf`, you should make sure that name resolution is reasonably fast. It can be of advantage to set up a local name resolution cache such as `nscd`. Also, you may wish to enable the configuration parameter `log_hostname` to see the client's host name instead of the IP address in the log.

These fields do not apply to `local` records.

> **Note**
>
> Users sometimes wonder why host names are handled in this seemingly complicated way, with two name resolutions including a reverse lookup of the client's IP address. This complicates use of the feature in case the client's reverse DNS entry is not set up or yields some undesirable

host name. It is done primarily for efficiency: this way, a connection attempt requires at most two resolver lookups, one reverse and one forward. If there is a resolver problem with some address, it becomes only that client's problem. A hypothetical alternative implementation that only did forward lookups would have to resolve every host name mentioned in `pg_hba.conf` during every connection attempt. That could be quite slow if many names are listed. And if there is a resolver problem with one of the host names, it becomes everyone's problem.

Also, a reverse lookup is necessary to implement the suffix matching feature, because the actual client host name needs to be known in order to match it against the pattern.

Note that this behavior is consistent with other popular implementations of host name-based access control, such as the Apache HTTP Server and TCP Wrappers.

IP-address
IP-mask

These two fields can be used as an alternative to the *IP-address/mask-length* notation. Instead of specifying the mask length, the actual mask is specified in a separate column. For example, `255.0.0.0` represents an IPv4 CIDR mask length of 8, and `255.255.255.255` represents a CIDR mask length of 32.

These fields do not apply to `local` records.

auth-method

Specifies the authentication method to use when a connection matches this record. The possible choices are summarized here; details are in Section 20.3. All the options are lower case and treated case sensitively, so even acronyms like `ldap` must be specified as lower case.

`trust`

Allow the connection unconditionally. This method allows anyone that can connect to the Postgres Pro database server to login as any Postgres Pro user they wish, without the need for a password or any other authentication. See Section 20.4 for details.

`reject`

Reject the connection unconditionally. This is useful for "filtering out" certain hosts from a group, for example a `reject` line could block a specific host from connecting, while a later line allows the remaining hosts in a specific network to connect.

`scram-sha-256`

Perform SCRAM-SHA-256 authentication to verify the user's password. See Section 20.5 for details.

`md5`

Perform SCRAM-SHA-256 or MD5 authentication to verify the user's password. See Section 20.5 for details.

`password`

Require the client to supply an unencrypted password for authentication. Since the password is sent in clear text over the network, this should not be used on untrusted networks. See Section 20.5 for details.

`gss`

Use GSSAPI to authenticate the user. This is only available for TCP/IP connections. See Section 20.6 for details. It can be used in conjunction with GSSAPI encryption.

`sspi`

Use SSPI to authenticate the user. This is only available on Windows. See Section 20.7 for details.

`ident`

Obtain the operating system user name of the client by contacting the ident server on the client and check if it matches the requested database user name. Ident authentication can only be used on TCP/IP connections. When specified for local connections, peer authentication will be used instead. See Section 20.8 for details.

`peer`

Obtain the client's operating system user name from the operating system and check if it matches the requested database user name. This is only available for local connections. See Section 20.9 for details.

`ldap`

Authenticate using an LDAP server. See Section 20.10 for details.

`radius`

Authenticate using a RADIUS server. See Section 20.11 for details.

`cert`

Authenticate using SSL client certificates. See Section 20.12 for details.

`pam`

Authenticate using the Pluggable Authentication Modules (PAM) service provided by the operating system. See Section 20.13 for details.

`bsd`

Authenticate using the BSD Authentication service provided by the operating system. See Section 20.14 for details.

`auth-options`

After the *`auth-method`* field, there can be field(s) of the form *`name=value`* that specify options for the authentication method. Details about which options are available for which authentication methods appear below.

In addition to the method-specific options listed below, there is a method-independent authentication option `clientcert`, which can be specified in any `hostssl` record. This option can be set to `verify-ca` or `verify-full`. Both options require the client to present a valid (trusted) SSL certificate, while `verify-full` additionally enforces that the `cn` (Common Name) in the certificate matches the username or an applicable mapping. This behavior is similar to the `cert` authentication method (see Section 20.12) but enables pairing the verification of client certificates with any authentication method that supports `hostssl` entries.

On any record using client certificate authentication (i.e. one using the `cert` authentication method or one using the `clientcert` option), you can specify which part of the client certificate credentials to match using the `clientname` option. This option can have one of two values. If you specify `clientname=CN`, which is the default, the username is matched against the certificate's `Common Name (CN)`. If instead you specify `clientname=DN` the username is matched against the entire `Distinguished Name (DN)` of the certificate. This option is probably best used in conjunction with a username map. The comparison is done with the `DN` in *RFC 2253* format. To see the `DN` of a client certificate in this format, do

```
openssl x509 -in myclient.crt -noout -subject -nameopt RFC2253 | sed "s/^subject=//"
```

Care needs to be taken when using this option, especially when using regular expression matching against the `DN`.

Files included by `@` constructs are read as lists of names, which can be separated by either whitespace or commas. Comments are introduced by `#`, just as in `pg_hba.conf`, and nested `@` constructs are allowed. Unless the file name following `@` is an absolute path, it is taken to be relative to the directory containing the referencing file.

Since the pg_hba.conf records are examined sequentially for each connection attempt, the order of the records is significant. Typically, earlier records will have tight connection match parameters and weaker authentication methods, while later records will have looser match parameters and stronger authentication methods. For example, one might wish to use trust authentication for local TCP/IP connections but require a password for remote TCP/IP connections. In this case a record specifying trust authentication for connections from 127.0.0.1 would appear before a record specifying password authentication for a wider range of allowed client IP addresses.

The pg_hba.conf file is read on start-up and when the main server process receives a SIGHUP signal. If you edit the file on an active system, you will need to signal the postmaster (using pg_ctl reload, calling the SQL function pg_reload_conf(), or using kill -HUP) to make it re-read the file.

> **Note**
>
> The preceding statement is not true on Microsoft Windows: there, any changes in the pg_hba.conf file are immediately applied by subsequent new connections.

The system view pg_hba_file_rules can be helpful for pre-testing changes to the pg_hba.conf file, or for diagnosing problems if loading of the file did not have the desired effects. Rows in the view with non-null error fields indicate problems in the corresponding lines of the file.

> **Tip**
>
> To connect to a particular database, a user must not only pass the pg_hba.conf checks, but must have the CONNECT privilege for the database. If you wish to restrict which users can connect to which databases, it's usually easier to control this by granting/revoking CONNECT privilege than to put the rules in pg_hba.conf entries.

Some examples of pg_hba.conf entries are shown in Example 20.1. See the next section for details on the different authentication methods.

Example 20.1. Example pg_hba.conf Entries

```
# Allow any user on the local system to connect to any database with
# any database user name using Unix-domain sockets (the default for local
# connections).
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
local   all             all                                     trust

# The same using local loopback TCP/IP connections.
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    all             all             127.0.0.1/32            trust

# The same as the previous line, but using a separate netmask column
#
# TYPE  DATABASE        USER            IP-ADDRESS      IP-MASK             METHOD
host    all             all             127.0.0.1       255.255.255.255     trust

# The same over IPv6.
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    all             all             ::1/128                 trust

# The same using a host name (would typically cover both IPv4 and IPv6).
#
```

```
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    all             all             localhost               trust

# Allow any user from any host with IP address 192.168.93.x to connect
# to database "postgres" as the same user name that ident reports for
# the connection (typically the operating system user name).
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    postgres        all             192.168.93.0/24         ident

# Allow any user from host 192.168.12.10 to connect to database
# "postgres" if the user's password is correctly supplied.
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    postgres        all             192.168.12.10/32        scram-sha-256

# Allow any user from hosts in the example.com domain to connect to
# any database if the user's password is correctly supplied.
#
# Require SCRAM authentication for most users, but make an exception
# for user 'mike', who uses an older client that doesn't support SCRAM
# authentication.
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    all             mike            .example.com            md5
host    all             all             .example.com            scram-sha-256

# In the absence of preceding "host" lines, these three lines will
# reject all connections from 192.168.54.1 (since that entry will be
# matched first), but allow GSSAPI-encrypted connections from anywhere else
# on the Internet.  The zero mask causes no bits of the host IP address to
# be considered, so it matches any host.  Unencrypted GSSAPI connections
# (which "fall through" to the third line since "hostgssenc" only matches
# encrypted GSSAPI connections) are allowed, but only from 192.168.12.10.
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    all             all             192.168.54.1/32         reject
hostgssenc all          all             0.0.0.0/0               gss
host    all             all             192.168.12.10/32        gss

# Allow users from 192.168.x.x hosts to connect to any database, if
# they pass the ident check.  If, for example, ident says the user is
# "bryanh" and he requests to connect as Postgres Pro user "guest1", the
# connection is allowed if there is an entry in pg_ident.conf for map
# "omicron" that says "bryanh" is allowed to connect as "guest1".
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    all             all             192.168.0.0/16          ident map=omicron

# If these are the only three lines for local connections, they will
# allow local users to connect only to their own databases (databases
# with the same name as their database user name) except for administrators
# and members of role "support", who can connect to all databases.  The file
# $PGDATA/admins contains a list of names of administrators.  Passwords
# are required in all cases.
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
local   sameuser        all                                     md5
```

```
local   all             @admins                                 md5
local   all             +support                                md5

# The last two lines above can be combined into a single line:
local   all             @admins,+support                        md5

# The database column can also use lists and file names:
local   db1,db2,@demodbs  all                                   md5
```

20.2. User Name Maps

When using an external authentication system such as Ident or GSSAPI, the name of the operating system user that initiated the connection might not be the same as the database user (role) that is to be used. In this case, a user name map can be applied to map the operating system user name to a database user. To use user name mapping, specify `map=`*`map-name`* in the options field in `pg_hba.conf`. This option is supported for all authentication methods that receive external user names. Since different mappings might be needed for different connections, the name of the map to be used is specified in the *`map-name`* parameter in `pg_hba.conf` to indicate which map to use for each individual connection.

User name maps are defined in the ident map file, which by default is named `pg_ident.conf`and is stored in the cluster's data directory. (It is possible to place the map file elsewhere, however; see the ident_file configuration parameter.) The ident map file contains lines of the general form:

`map-name system-username database-username`

Comments, whitespace and line continuations are handled in the same way as in `pg_hba.conf`. The *`map-name`* is an arbitrary name that will be used to refer to this mapping in `pg_hba.conf`. The other two fields specify an operating system user name and a matching database user name. The same *`map-name`* can be used repeatedly to specify multiple user-mappings within a single map.

There is no restriction regarding how many database users a given operating system user can correspond to, nor vice versa. Thus, entries in a map should be thought of as meaning “this operating system user is allowed to connect as this database user”, rather than implying that they are equivalent. The connection will be allowed if there is any map entry that pairs the user name obtained from the external authentication system with the database user name that the user has requested to connect as.

If the *`system-username`* field starts with a slash (`/`), the remainder of the field is treated as a regular expression. (See Section 9.7.3.1 for details of Postgres Pro's regular expression syntax.) The regular expression can include a single capture, or parenthesized subexpression, which can then be referenced in the *`database-username`* field as `\1` (backslash-one). This allows the mapping of multiple user names in a single line, which is particularly useful for simple syntax substitutions. For example, these entries

```
mymap   /^(.*)@mydomain\.com$       \1
mymap   /^(.*)@otherdomain\.com$    guest
```

will remove the domain part for users with system user names that end with `@mydomain.com`, and allow any user whose system name ends with `@otherdomain.com` to log in as `guest`.

> **Tip**
>
> Keep in mind that by default, a regular expression can match just part of a string. It's usually wise to use `^` and `$`, as shown in the above example, to force the match to be to the entire system user name.

The `pg_ident.conf` file is read on start-up and when the main server process receives a SIGHUP signal. If you edit the file on an active system, you will need to signal the postmaster (using `pg_ctl reload`, calling the SQL function `pg_reload_conf()`, or using `kill -HUP`) to make it re-read the file.

A `pg_ident.conf` file that could be used in conjunction with the `pg_hba.conf` file in Example 20.1 is shown in Example 20.2. In this example, anyone logged in to a machine on the 192.168 network that

does not have the operating system user name `bryanh`, `ann`, or `robert` would not be granted access. Unix user `robert` would only be allowed access when he tries to connect as Postgres Pro user `bob`, not as `robert` or anyone else. `ann` would only be allowed to connect as `ann`. User `bryanh` would be allowed to connect as either `bryanh` or as `guest1`.

Example 20.2. An Example `pg_ident.conf` File

```
# MAPNAME       SYSTEM-USERNAME         PG-USERNAME

omicron         bryanh                  bryanh
omicron         ann                     ann
# bob has user name robert on these machines
omicron         robert                  bob
# bryanh can also connect as guest1
omicron         bryanh                  guest1
```

20.3. Authentication Methods

Postgres Pro provides various methods for authenticating users:

- Trust authentication, which simply trusts that users are who they say they are.
- Password authentication, which requires that users send a password.
- GSSAPI authentication, which relies on a GSSAPI-compatible security library. Typically this is used to access an authentication server such as a Kerberos or Microsoft Active Directory server.
- SSPI authentication, which uses a Windows-specific protocol similar to GSSAPI.
- Ident authentication, which relies on an "Identification Protocol" (*RFC 1413*) service on the client's machine. (On local Unix-socket connections, this is treated as peer authentication.)
- Peer authentication, which relies on operating system facilities to identify the process at the other end of a local connection. This is not supported for remote connections.
- LDAP authentication, which relies on an LDAP authentication server.
- RADIUS authentication, which relies on a RADIUS authentication server.
- Certificate authentication, which requires an SSL connection and authenticates users by checking the SSL certificate they send.
- PAM authentication, which relies on a PAM (Pluggable Authentication Modules) library.
- BSD authentication, which relies on the BSD Authentication framework (currently available only on OpenBSD).

Peer authentication is usually recommendable for local connections, though trust authentication might be sufficient in some circumstances. Password authentication is the easiest choice for remote connections. All the other options require some kind of external security infrastructure (usually an authentication server or a certificate authority for issuing SSL certificates), or are platform-specific.

The following sections describe each of these authentication methods in more detail.

20.4. Trust Authentication

When `trust` authentication is specified, Postgres Pro assumes that anyone who can connect to the server is authorized to access the database with whatever database user name they specify (even superuser names). Of course, restrictions made in the `database` and `user` columns still apply. This method should only be used when there is adequate operating-system-level protection on connections to the server.

`trust` authentication is appropriate and very convenient for local connections on a single-user workstation. It is usually *not* appropriate by itself on a multiuser machine. However, you might be able to use `trust` even on a multiuser machine, if you restrict access to the server's Unix-domain socket file using file-system permissions. To do this, set the `unix_socket_permissions` (and possibly `unix_sock-`

et_group) configuration parameters as described in Section 19.3. Or you could set the unix_socket_directories configuration parameter to place the socket file in a suitably restricted directory.

Setting file-system permissions only helps for Unix-socket connections. Local TCP/IP connections are not restricted by file-system permissions. Therefore, if you want to use file-system permissions for local security, remove the host ... 127.0.0.1 ... line from pg_hba.conf, or change it to a non-trust authentication method.

trust authentication is only suitable for TCP/IP connections if you trust every user on every machine that is allowed to connect to the server by the pg_hba.conf lines that specify trust. It is seldom reasonable to use trust for any TCP/IP connections other than those from localhost (127.0.0.1).

20.5. Password Authentication

There are several password-based authentication methods. These methods operate similarly but differ in how the users' passwords are stored on the server and how the password provided by a client is sent across the connection.

scram-sha-256

The method scram-sha-256 performs SCRAM-SHA-256 authentication, as described in *RFC 7677*. It is a challenge-response scheme that prevents password sniffing on untrusted connections and supports storing passwords on the server in a cryptographically hashed form that is thought to be secure.

This is the most secure of the currently provided methods, but it is not supported by older client libraries.

md5

The method md5 uses a custom less secure challenge-response mechanism. It prevents password sniffing and avoids storing passwords on the server in plain text but provides no protection if an attacker manages to steal the password hash from the server. Also, the MD5 hash algorithm is nowadays no longer considered secure against determined attacks.

The md5 method cannot be used with the db_user_namespace feature.

To ease transition from the md5 method to the newer SCRAM method, if md5 is specified as a method in pg_hba.conf but the user's password on the server is encrypted for SCRAM (see below), then SCRAM-based authentication will automatically be chosen instead.

password

The method password sends the password in clear-text and is therefore vulnerable to password "sniffing" attacks. It should always be avoided if possible. If the connection is protected by SSL encryption then password can be used safely, though. (Though SSL certificate authentication might be a better choice if one is depending on using SSL).

Postgres Pro database passwords are separate from operating system user passwords. The password for each database user is stored in the pg_authid system catalog. Passwords can be managed with the SQL commands CREATE ROLE and ALTER ROLE, e.g., **CREATE ROLE foo WITH LOGIN PASSWORD 'secret'**, or the psql command \password. If no password has been set up for a user, the stored password is null and password authentication will always fail for that user.

The availability of the different password-based authentication methods depends on how a user's password on the server is encrypted (or hashed, more accurately). This is controlled by the configuration parameter password_encryption at the time the password is set. If a password was encrypted using the scram-sha-256 setting, then it can be used for the authentication methods scram-sha-256 and password (but password transmission will be in plain text in the latter case). The authentication method specification md5 will automatically switch to using the scram-sha-256 method in this case, as explained above, so it will also work. If a password was encrypted using the md5 setting, then it can be used only

for the `md5` and `password` authentication method specifications (again, with the password transmitted in plain text in the latter case). (Previous Postgres Pro releases supported storing the password on the server in plain text. This is no longer possible.) To check the currently stored password hashes, see the system catalog `pg_authid`.

To upgrade an existing installation from `md5` to `scram-sha-256`, after having ensured that all client libraries in use are new enough to support SCRAM, set `password_encryption = 'scram-sha-256'` in `postgresql.conf`, make all users set new passwords, and change the authentication method specifications in `pg_hba.conf` to `scram-sha-256`.

20.6. GSSAPI Authentication

GSSAPI is an industry-standard protocol for secure authentication defined in *RFC 2743*. Postgres Pro supports GSSAPI for authentication, communications encryption, or both. GSSAPI provides automatic authentication (single sign-on) for systems that support it. The authentication itself is secure. If GSSAPI encryption or SSL encryption is used, the data sent along the database connection will be encrypted; otherwise, it will not.

GSSAPI support has to be enabled when Postgres Pro is built.

When GSSAPI uses Kerberos, it uses a standard service principal (authentication identity) name in the format *servicename*`/`*hostname*`@`*realm*. The principal name used by a particular installation is not encoded in the Postgres Pro server in any way; rather it is specified in the *keytab* file that the server reads to determine its identity. If multiple principals are listed in the keytab file, the server will accept any one of them. The server's realm name is the preferred realm specified in the Kerberos configuration file(s) accessible to the server.

When connecting, the client must know the principal name of the server it intends to connect to. The *servicename* part of the principal is ordinarily `postgres`, but another value can be selected via libpq's krbsrvname connection parameter. The *hostname* part is the fully qualified host name that libpq is told to connect to. The realm name is the preferred realm specified in the Kerberos configuration file(s) accessible to the client.

The client will also have a principal name for its own identity (and it must have a valid ticket for this principal). To use GSSAPI for authentication, the client principal must be associated with a Postgres Pro database user name. The `pg_ident.conf` configuration file can be used to map principals to user names; for example, `pgusername@realm` could be mapped to just `pgusername`. Alternatively, you can use the full `username@realm` principal as the role name in Postgres Pro without any mapping.

Postgres Pro also supports mapping client principals to user names by just stripping the realm from the principal. This method is supported for backwards compatibility and is strongly discouraged as it is then impossible to distinguish different users with the same user name but coming from different realms. To enable this, set `include_realm` to 0. For simple single-realm installations, doing that combined with setting the `krb_realm` parameter (which checks that the principal's realm matches exactly what is in the `krb_realm` parameter) is still secure; but this is a less capable approach compared to specifying an explicit mapping in `pg_ident.conf`.

The location of the server's keytab file is specified by the krb_server_keyfile configuration parameter. For security reasons, it is recommended to use a separate keytab just for the Postgres Pro server rather than allowing the server to read the system keytab file. Make sure that your server keytab file is readable (and preferably only readable, not writable) by the Postgres Pro server account. (See also Section 18.1.)

The keytab file is generated using the Kerberos software; see the Kerberos documentation for details. The following example shows doing this using the kadmin tool of MIT-compatible Kerberos 5 implementations:

```
kadmin% addprinc -randkey postgres/server.my.domain.org
kadmin% ktadd -k krb5.keytab postgres/server.my.domain.org
```

The following authentication options are supported for the GSSAPI authentication method:

include_realm

If set to 0, the realm name from the authenticated user principal is stripped off before being passed through the user name mapping (Section 20.2). This is discouraged and is primarily available for backwards compatibility, as it is not secure in multi-realm environments unless krb_realm is also used. It is recommended to leave include_realm set to the default (1) and to provide an explicit mapping in pg_ident.conf to convert principal names to Postgres Pro user names.

map

Allows mapping from client principals to database user names. See Section 20.2 for details. For a GSSAPI/Kerberos principal, such as username@EXAMPLE.COM (or, less commonly, username/hostbased@EXAMPLE.COM), the user name used for mapping is username@EXAMPLE.COM (or username/hostbased@EXAMPLE.COM, respectively), unless include_realm has been set to 0, in which case username (or username/hostbased) is what is seen as the system user name when mapping.

krb_realm

Sets the realm to match user principal names against. If this parameter is set, only users of that realm will be accepted. If it is not set, users of any realm can connect, subject to whatever user name mapping is done.

In addition to these settings, which can be different for different pg_hba.conf entries, there is the server-wide krb_caseins_users configuration parameter. If that is set to true, client principals are matched to user map entries case-insensitively. krb_realm, if set, is also matched case-insensitively.

20.7. SSPI Authentication

SSPI is a Windows technology for secure authentication with single sign-on. Postgres Pro will use SSPI in negotiate mode, which will use Kerberos when possible and automatically fall back to NTLM in other cases. SSPI and GSSAPI interoperate as clients and servers, e.g., an SSPI client can authenticate to an GSSAPI server. It is recommended to use SSPI on Windows clients and servers and GSSAPI on non-Windows platforms.

When using Kerberos authentication, SSPI works the same way GSSAPI does; see Section 20.6 for details.

The following configuration options are supported for SSPI:

include_realm

If set to 0, the realm name from the authenticated user principal is stripped off before being passed through the user name mapping (Section 20.2). This is discouraged and is primarily available for backwards compatibility, as it is not secure in multi-realm environments unless krb_realm is also used. It is recommended to leave include_realm set to the default (1) and to provide an explicit mapping in pg_ident.conf to convert principal names to Postgres Pro user names.

compat_realm

If set to 1, the domain's SAM-compatible name (also known as the NetBIOS name) is used for the include_realm option. This is the default. If set to 0, the true realm name from the Kerberos user principal name is used.

Do not disable this option unless your server runs under a domain account (this includes virtual service accounts on a domain member system) and all clients authenticating through SSPI are also using domain accounts, or authentication will fail.

upn_username

If this option is enabled along with compat_realm, the user name from the Kerberos UPN is used for authentication. If it is disabled (the default), the SAM-compatible user name is used. By default, these two names are identical for new user accounts.

Note that libpq uses the SAM-compatible name if no explicit user name is specified. If you use libpq or a driver based on it, you should leave this option disabled or explicitly specify user name in the connection string.

`map`

Allows for mapping between system and database user names. See Section 20.2 for details. For an SSPI/Kerberos principal, such as `username@EXAMPLE.COM` (or, less commonly, `username/hostbased@EXAMPLE.COM`), the user name used for mapping is `username@EXAMPLE.COM` (or `username/hostbased@EXAMPLE.COM`, respectively), unless `include_realm` has been set to 0, in which case `username` (or `username/hostbased`) is what is seen as the system user name when mapping.

`krb_realm`

Sets the realm to match user principal names against. If this parameter is set, only users of that realm will be accepted. If it is not set, users of any realm can connect, subject to whatever user name mapping is done.

20.8. Ident Authentication

The ident authentication method works by obtaining the client's operating system user name from an ident server and using it as the allowed database user name (with an optional user name mapping). This is only supported on TCP/IP connections.

> **Note**
>
> When ident is specified for a local (non-TCP/IP) connection, peer authentication (see Section 20.9) will be used instead.

The following configuration options are supported for ident:

`map`

Allows for mapping between system and database user names. See Section 20.2 for details.

The "Identification Protocol" is described in *RFC 1413*. Virtually every Unix-like operating system ships with an ident server that listens on TCP port 113 by default. The basic functionality of an ident server is to answer questions like "What user initiated the connection that goes out of your port *X* and connects to my port *Y*?". Since Postgres Pro knows both *X* and *Y* when a physical connection is established, it can interrogate the ident server on the host of the connecting client and can theoretically determine the operating system user for any given connection.

The drawback of this procedure is that it depends on the integrity of the client: if the client machine is untrusted or compromised, an attacker could run just about any program on port 113 and return any user name they choose. This authentication method is therefore only appropriate for closed networks where each client machine is under tight control and where the database and system administrators operate in close contact. In other words, you must trust the machine running the ident server. Heed the warning:

> The Identification Protocol is not intended as an authorization or access control protocol.
>
> —RFC 1413

Some ident servers have a nonstandard option that causes the returned user name to be encrypted, using a key that only the originating machine's administrator knows. This option *must not* be used when using the ident server with Postgres Pro, since Postgres Pro does not have any way to decrypt the returned string to determine the actual user name.

20.9. Peer Authentication

The peer authentication method works by obtaining the client's operating system user name from the kernel and using it as the allowed database user name (with optional user name mapping). This method is only supported on local connections.

The following configuration options are supported for peer:

`map`

Allows for mapping between system and database user names. See Section 20.2 for details.

Peer authentication is only available on operating systems providing the `getpeereid()` function, the `SO_PEERCRED` socket parameter, or similar mechanisms. Currently that includes Linux, most flavors of BSD including macOS, and Solaris.

20.10. LDAP Authentication

This authentication method operates similarly to `password` except that it uses LDAP as the password verification method. LDAP is used only to validate the user name/password pairs. Therefore the user must already exist in the database before LDAP can be used for authentication.

LDAP authentication can operate in two modes. In the first mode, which we will call the simple bind mode, the server will bind to the distinguished name constructed as *`prefix username suffix`*. Typically, the *`prefix`* parameter is used to specify `cn=`, or *`DOMAIN`*`\` in an Active Directory environment. *`suffix`* is used to specify the remaining part of the DN in a non-Active Directory environment.

In the second mode, which we will call the search+bind mode, the server first binds to the LDAP directory with a fixed user name and password, specified with *`ldapbinddn`* and *`ldapbindpasswd`*, and performs a search for the user trying to log in to the database. If no user and password is configured, an anonymous bind will be attempted to the directory. The search will be performed over the subtree at *`ldapbasedn`*, and will try to do an exact match of the attribute specified in *`ldapsearchattribute`*. Once the user has been found in this search, the server disconnects and re-binds to the directory as this user, using the password specified by the client, to verify that the login is correct. This mode is the same as that used by LDAP authentication schemes in other software, such as Apache `mod_authnz_ldap` and `pam_ldap`. This method allows for significantly more flexibility in where the user objects are located in the directory, but will cause two separate connections to the LDAP server to be made.

The following configuration options are used in both modes:

`ldapserver`

Names or IP addresses of LDAP servers to connect to. Multiple servers may be specified, separated by spaces.

`ldapport`

Port number on LDAP server to connect to. If no port is specified, the LDAP library's default port setting will be used.

`ldapscheme`

Set to `ldaps` to use LDAPS. This is a non-standard way of using LDAP over SSL, supported by some LDAP server implementations. See also the `ldaptls` option for an alternative.

`ldaptls`

Set to 1 to make the connection between Postgres Pro and the LDAP server use TLS encryption. This uses the `StartTLS` operation per *RFC 4513*. See also the `ldapscheme` option for an alternative.

Note that using `ldapscheme` or `ldaptls` only encrypts the traffic between the Postgres Pro server and the LDAP server. The connection between the Postgres Pro server and the Postgres Pro client will still be unencrypted unless SSL is used there as well.

The following options are used in simple bind mode only:

`ldapprefix`

String to prepend to the user name when forming the DN to bind as, when doing simple bind authentication.

`ldapsuffix`

String to append to the user name when forming the DN to bind as, when doing simple bind authentication.

The following options are used in search+bind mode only:

`ldapbasedn`

Root DN to begin the search for the user in, when doing search+bind authentication.

`ldapbinddn`

DN of user to bind to the directory with to perform the search when doing search+bind authentication.

`ldapbindpasswd`

Password for user to bind to the directory with to perform the search when doing search+bind authentication.

`ldapsearchattribute`

Attribute to match against the user name in the search when doing search+bind authentication. If no attribute is specified, the `uid` attribute will be used.

`ldapsearchfilter`

The search filter to use when doing search+bind authentication. Occurrences of `$username` will be replaced with the user name. This allows for more flexible search filters than `ldapsearchattribute`.

`ldapurl`

An *RFC 4516* LDAP URL. This is an alternative way to write some of the other LDAP options in a more compact and standard form. The format is

`ldap[s]://`*`host`*`[:`*`port`*`]/`*`basedn`*`[?[`*`attribute`*`][?[`*`scope`*`][?[`*`filter`*`]]]]`

`scope` must be one of `base`, `one`, `sub`, typically the last. (The default is `base`, which is normally not useful in this application.) *`attribute`* can nominate a single attribute, in which case it is used as a value for `ldapsearchattribute`. If *`attribute`* is empty then *`filter`* can be used as a value for `ldapsearchfilter`.

The URL scheme `ldaps` chooses the LDAPS method for making LDAP connections over SSL, equivalent to using `ldapscheme=ldaps`. To use encrypted LDAP connections using the `StartTLS` operation, use the normal URL scheme `ldap` and specify the `ldaptls` option in addition to `ldapurl`.

For non-anonymous binds, `ldapbinddn` and `ldapbindpasswd` must be specified as separate options.

LDAP URLs are currently only supported with OpenLDAP, not on Windows.

It is an error to mix configuration options for simple bind with options for search+bind.

When using search+bind mode, the search can be performed using a single attribute specified with `ldapsearchattribute`, or using a custom search filter specified with `ldapsearchfilter`. Specifying `ldapsearchattribute=foo` is equivalent to specifying `ldapsearchfilter="(foo=$username)"`. If neither option is specified the default is `ldapsearchattribute=uid`.

If Postgres Pro was compiled with OpenLDAP as the LDAP client library, the `ldapserver` setting may be omitted. In that case, a list of host names and ports is looked up via *RFC 2782* DNS SRV records. The name `_ldap._tcp.DOMAIN` is looked up, where `DOMAIN` is extracted from `ldapbasedn`.

Here is an example for a simple-bind LDAP configuration:

```
host ... ldap ldapserver=ldap.example.net ldapprefix="cn=" ldapsuffix=", dc=example,
 dc=net"
```

When a connection to the database server as database user `someuser` is requested, Postgres Pro will attempt to bind to the LDAP server using the DN `cn=someuser, dc=example, dc=net` and the password provided by the client. If that connection succeeds, the database access is granted.

Here is an example for a search+bind configuration:

```
host ... ldap ldapserver=ldap.example.net ldapbasedn="dc=example, dc=net"
 ldapsearchattribute=uid
```

When a connection to the database server as database user `someuser` is requested, Postgres Pro will attempt to bind anonymously (since `ldapbinddn` was not specified) to the LDAP server, perform a search for `(uid=someuser)` under the specified base DN. If an entry is found, it will then attempt to bind using that found information and the password supplied by the client. If that second connection succeeds, the database access is granted.

Here is the same search+bind configuration written as a URL:

```
host ... ldap ldapurl="ldap://ldap.example.net/dc=example,dc=net?uid?sub"
```

Some other software that supports authentication against LDAP uses the same URL format, so it will be easier to share the configuration.

Here is an example for a search+bind configuration that uses `ldapsearchfilter` instead of `ldapsearchattribute` to allow authentication by user ID or email address:

```
host ... ldap ldapserver=ldap.example.net ldapbasedn="dc=example, dc=net"
 ldapsearchfilter="(|(uid=$username)(mail=$username))"
```

Here is an example for a search+bind configuration that uses DNS SRV discovery to find the host name(s) and port(s) for the LDAP service for the domain name `example.net`:

```
host ... ldap ldapbasedn="dc=example,dc=net"
```

> **Tip**
>
> Since LDAP often uses commas and spaces to separate the different parts of a DN, it is often necessary to use double-quoted parameter values when configuring LDAP options, as shown in the examples.

20.10.1. Recommendations on Configuring Common LDAP Servers

The following requirements must be satisfied to configure LDAP authentication on a Postgres Pro server:

- An LDAP server must be accessible from the Postgres Pro server.
- The LDAP authentication method must be the first record in the `pg_hba.conf` configuration file on the Postgres Pro server.
- If LDAP authentication is configured with the `ldapbinddn` option, then the corresponding DN must already exist on the LDAP server.
- If LDAP authentication is configured with the `ldapsearchfilter` option to filter users by checking their group membership, then the corresponding group must already exist on the LDAP server.

While some LDAP servers (like FreeIPA) allow anonymous binding in the search+bind mode by default, others (like ALD Pro) do not. It is not recommended to allow anonymous binding on any LDAP server as it may result in security issues.

> **Note**
>
> Postgres Pro can authenticate users via ALD Pro `2.4.0` or higher.

Examples of configuration records listed below are compatible with FreeIPA and ALD Pro LDAP servers.

Here is an example of a simple-bind LDAP configuration:

```
host ... ldap ldapserver=ldap.example.net \
              ldapport=389 \
              ldapbasedn="cn=users,cn=accounts,dc=example,dc=net"
```

Here is an example of a search+bind LDAP configuration:

```
host ... ldap ldapserver=ldap.example.net \
              ldapport=389 \
              ldapbasedn="cn=users,cn=accounts,dc=example,dc=net" \
              ldapbinddn="uid=pgpro,cn=users,cn=accounts,dc=example,dc=net" \
              ldapbindpasswd="<pgpro password>" \
              ldapsearchattribute=uid
```

When a database connection is requested as user `someuser`, Postgres Pro will attempt to bind to the LDAP server as `pgpro` user, search for `(uid=someuser)` under the specified base DN. If a matching record is found, the database server will then attempt to bind using that found information and the password supplied by the client. If that second connection succeeds, the database access is granted.

Here is an example for a search+bind LDAP configuration that uses `ldapsearchfilter` to filter users who are members of the `pgpro_access` group:

```
host ... ldap ldapserver=ldap.example.net \
              ldapport=389 \
              ldapbasedn="cn=users,cn=accounts,dc=example,dc=net" \
              ldapbinddn="uid=pgpro,cn=users,cn=accounts,dc=example,dc=net" \
              ldapbindpasswd="<pgpro password>" \
              ldapsearchfilter="(&(objectClass=person)(uid=$username)
(memberOf=cn=pgpro_access,cn=groups,cn=accounts,dc=example,dc=net))"
```

When a database connection is requested as user `someuser`, Postgres Pro will attempt to bind to the LDAP server as `pgpro` user, search for `(uid=someuser)` under the specified base DN according to the specified search filter. In this example, a user must be a member of the `pgpro_access` group according to the filter. If a matching record is found, the database server will then attempt to bind using that found information and the password supplied by the client. If that second connection succeeds, the database access is granted.

20.11. RADIUS Authentication

This authentication method operates similarly to `password` except that it uses RADIUS as the password verification method. RADIUS is used only to validate the user name/password pairs. Therefore the user must already exist in the database before RADIUS can be used for authentication.

When using RADIUS authentication, an Access Request message will be sent to the configured RADIUS server. This request will be of type `Authenticate Only`, and include parameters for `user name`, `password` (encrypted) and `NAS Identifier`. The request will be encrypted using a secret shared with the server.

The RADIUS server will respond to this request with either `Access Accept` or `Access Reject`. There is no support for RADIUS accounting.

Multiple RADIUS servers can be specified, in which case they will be tried sequentially. If a negative response is received from a server, the authentication will fail. If no response is received, the next server in the list will be tried. To specify multiple servers, separate the server names with commas and surround the list with double quotes. If multiple servers are specified, the other RADIUS options can also be given as comma-separated lists, to provide individual values for each server. They can also be specified as a single value, in which case that value will apply to all servers.

The following configuration options are supported for RADIUS:

`radiusservers`

The DNS names or IP addresses of the RADIUS servers to connect to. This parameter is required.

`radiussecrets`

The shared secrets used when talking securely to the RADIUS servers. This must have exactly the same value on the Postgres Pro and RADIUS servers. It is recommended that this be a string of at least 16 characters. This parameter is required.

> **Note**
>
> The encryption vector used will only be cryptographically strong if Postgres Pro is built with support for OpenSSL. In other cases, the transmission to the RADIUS server should only be considered obfuscated, not secured, and external security measures should be applied if necessary.

`radiusports`

The port numbers to connect to on the RADIUS servers. If no port is specified, the default RADIUS port (`1812`) will be used.

`radiusidentifiers`

The strings to be used as `NAS Identifier` in the RADIUS requests. This parameter can be used, for example, to identify which database cluster the user is attempting to connect to, which can be useful for policy matching on the RADIUS server. If no identifier is specified, the default `postgresql` will be used.

If it is necessary to have a comma or whitespace in a RADIUS parameter value, that can be done by putting double quotes around the value, but it is tedious because two layers of double-quoting are now required. An example of putting whitespace into RADIUS secret strings is:

```
host ... radius radiusservers="server1,server2" radiussecrets="""secret one"",""secret
 two"""
```

20.12. Certificate Authentication

This authentication method uses SSL client certificates to perform authentication. It is therefore only available for SSL connections; see Section 18.9.2 for SSL configuration instructions. When using this authentication method, the server will require that the client provide a valid, trusted certificate. No password prompt will be sent to the client. The `cn` (Common Name) attribute of the certificate will be compared to the requested database user name, and if they match the login will be allowed. User name mapping can be used to allow `cn` to be different from the database user name.

The following configuration options are supported for SSL certificate authentication:

`map`

Allows for mapping between system and database user names. See Section 20.2 for details.

It is redundant to use the `clientcert` option with `cert` authentication because `cert` authentication is effectively `trust` authentication with `clientcert=verify-full`.

20.13. PAM Authentication

This authentication method operates similarly to `password` except that it uses PAM (Pluggable Authentication Modules) as the authentication mechanism. The default PAM service name is `postgresql`. PAM is used only to validate user name/password pairs and optionally the connected remote host name or IP address. Therefore the user must already exist in the database before PAM can be used for authentication. For more information about PAM, please read the *Linux-PAM Page*.

The following configuration options are supported for PAM:

`pamservice`

PAM service name.

`pam_use_hostname`

Determines whether the remote IP address or the host name is provided to PAM modules through the `PAM_RHOST` item. By default, the IP address is used. Set this option to 1 to use the resolved host name instead. Host name resolution can lead to login delays. (Most PAM configurations don't use this information, so it is only necessary to consider this setting if a PAM configuration was specifically created to make use of it.)

> **Note**
>
> If PAM is set up to read `/etc/shadow`, authentication will fail because the Postgres Pro server is started by a non-root user. However, this is not an issue when PAM is configured to use LDAP or other authentication methods.

20.14. BSD Authentication

This authentication method operates similarly to `password` except that it uses BSD Authentication to verify the password. BSD Authentication is used only to validate user name/password pairs. Therefore the user's role must already exist in the database before BSD Authentication can be used for authentication. The BSD Authentication framework is currently only available on OpenBSD.

BSD Authentication in Postgres Pro uses the `auth-postgresql` login type and authenticates with the `postgresql` login class if that's defined in `login.conf`. By default that login class does not exist, and Postgres Pro will use the default login class.

> **Note**
>
> To use BSD Authentication, the Postgres Pro user account (that is, the operating system user running the server) must first be added to the `auth` group. The `auth` group exists by default on OpenBSD systems.

20.15. Authentication Problems

Authentication failures and related problems generally manifest themselves through error messages like the following:

```
FATAL:  no pg_hba.conf entry for host "123.123.123.123", user "andym", database
 "testdb"
```

This is what you are most likely to get if you succeed in contacting the server, but it does not want to talk to you. As the message suggests, the server refused the connection request because it found no matching entry in its `pg_hba.conf` configuration file.

```
FATAL:  password authentication failed for user "andym"
```

Messages like this indicate that you contacted the server, and it is willing to talk to you, but not until you pass the authorization method specified in the `pg_hba.conf` file. Check the password you are providing, or check your Kerberos or ident software if the complaint mentions one of those authentication types.

```
FATAL:  user "andym" does not exist
```

The indicated database user name was not found.

```
FATAL:  database "testdb" does not exist
```

The database you are trying to connect to does not exist. Note that if you do not specify a database name, it defaults to the database user name, which might or might not be the right thing.

> **Tip**
>
> The server log might contain more information about an authentication failure than is reported to the client. If you are confused about the reason for a failure, check the server log.

Chapter 21. Database Roles

Postgres Pro manages database access permissions using the concept of *roles*. A role can be thought of as either a database user, or a group of database users, depending on how the role is set up. Roles can own database objects (for example, tables and functions) and can assign privileges on those objects to other roles to control who has access to which objects. Furthermore, it is possible to grant *membership* in a role to another role, thus allowing the member role to use privileges assigned to another role.

The concept of roles subsumes the concepts of “users” and “groups”. In PostgreSQL versions before 8.1, users and groups were distinct kinds of entities, but now there are only roles. Any role can act as a user, a group, or both.

This chapter describes how to create and manage roles. More information about the effects of role privileges on various database objects can be found in Section 5.7.

21.1. Database Roles

Database roles are conceptually completely separate from operating system users. In practice it might be convenient to maintain a correspondence, but this is not required. Database roles are global across a database cluster installation (and not per individual database). To create a role use the `CREATE ROLE` SQL command:

```
CREATE ROLE name;
```

name follows the rules for SQL identifiers: either unadorned without special characters, or double-quoted. (In practice, you will usually want to add additional options, such as `LOGIN`, to the command. More details appear below.) To remove an existing role, use the analogous `DROP ROLE` command:

```
DROP ROLE name;
```

For convenience, the programs createuser and dropuser are provided as wrappers around these SQL commands that can be called from the shell command line:

```
createuser name
dropuser name
```

To determine the set of existing roles, examine the `pg_roles` system catalog, for example

```
SELECT rolname FROM pg_roles;
```

The psql program's `\du` meta-command is also useful for listing the existing roles.

In order to bootstrap the database system, a freshly initialized system always contains one predefined role. This role is always a “superuser”, and by default (unless altered when running `initdb`) it will have the same name as the operating system user that initialized the database cluster. Customarily, this role will be named `postgres`. In order to create more roles you first have to connect as this initial role.

Every connection to the database server is made using the name of some particular role, and this role determines the initial access privileges for commands issued in that connection. The role name to use for a particular database connection is indicated by the client that is initiating the connection request in an application-specific fashion. For example, the `psql` program uses the `-U` command line option to indicate the role to connect as. Many applications assume the name of the current operating system user by default (including `createuser` and `psql`). Therefore it is often convenient to maintain a naming correspondence between roles and operating system users.

The set of database roles a given client connection can connect as is determined by the client authentication setup, as explained in Chapter 20. (Thus, a client is not limited to connect as the role matching its operating system user, just as a person's login name need not match his or her real name.) Since the role identity determines the set of privileges available to a connected client, it is important to carefully configure privileges when setting up a multiuser environment.

21.2. Role Attributes

A database role can have a number of attributes that define its privileges and interact with the client authentication system.

login privilege

Only roles that have the `LOGIN` attribute can be used as the initial role name for a database connection. A role with the `LOGIN` attribute can be considered the same as a “database user”. To create a role with login privilege, use either:

```
CREATE ROLE name LOGIN;
CREATE USER name;
```

(`CREATE USER` is equivalent to `CREATE ROLE` except that `CREATE USER` includes `LOGIN` by default, while `CREATE ROLE` does not.)

superuser status

A database superuser bypasses all permission checks, except the right to log in. This is a dangerous privilege and should not be used carelessly; it is best to do most of your work as a role that is not a superuser. To create a new database superuser, use `CREATE ROLE name SUPERUSER`. You must do this as a role that is already a superuser.

database creation

A role must be explicitly given permission to create databases (except for superusers, since those bypass all permission checks). To create such a role, use `CREATE ROLE name CREATEDB`.

role creation

A role must be explicitly given permission to create more roles (except for superusers, since those bypass all permission checks). To create such a role, use `CREATE ROLE name CREATEROLE`. A role with `CREATEROLE` privilege can alter and drop roles which have been granted to the `CREATEROLE` user with the `ADMIN` option. Such a grant occurs automatically when a `CREATEROLE` user that is not a superuser creates a new role, so that by default, a `CREATEROLE` user can alter and drop the roles which they have created. Altering a role includes most changes that can be made using `ALTER ROLE`, including, for example, changing passwords. It also includes modifications to a role that can be made using the `COMMENT` and `SECURITY LABEL` commands.

However, `CREATEROLE` does not convey the ability to create `SUPERUSER` roles, nor does it convey any power over `SUPERUSER` roles that already exist. Furthermore, `CREATEROLE` does not convey the power to create `REPLICATION` users, nor the ability to grant or revoke the `REPLICATION` privilege, nor the ability to modify the role properties of such users. However, it does allow `ALTER ROLE ... SET` and `ALTER ROLE ... RENAME` to be used on `REPLICATION` roles, as well as the use of `COMMENT ON ROLE`, `SECURITY LABEL ON ROLE`, and `DROP ROLE`. Finally, `CREATEROLE` does not confer the ability to grant or revoke the `BYPASSRLS` privilege.

initiating replication

A role must explicitly be given permission to initiate streaming replication (except for superusers, since those bypass all permission checks). A role used for streaming replication must have `LOGIN` permission as well. To create such a role, use `CREATE ROLE name REPLICATION LOGIN`.

password

A password is only significant if the client authentication method requires the user to supply a password when connecting to the database. The `password` and `md5` authentication methods make use of passwords. Database passwords are separate from operating system passwords. Specify a password upon role creation with `CREATE ROLE name PASSWORD 'string'`.

inheritance of privileges

A role is given permission to inherit the privileges of roles it is a member of, by default. However, to create a role without the permission, use `CREATE ROLE name NOINHERIT`.

bypassing row-level security

A role must be explicitly given permission to bypass every row-level security (RLS) policy (except for superusers, since those bypass all permission checks). To create such a role, use `CREATE ROLE name BYPASSRLS` as a superuser.

connection limit

Connection limit can specify how many concurrent connections a role can make. -1 (the default) means no limit. Specify connection limit upon role creation with `CREATE ROLE name CONNECTION LIMIT 'integer'`.

A role's attributes can be modified after creation with `ALTER ROLE`. See the reference pages for the CREATE ROLE and ALTER ROLE commands for details.

A role can also have role-specific defaults for many of the run-time configuration settings described in Chapter 19. For example, if for some reason you want to disable index scans (hint: not a good idea) anytime you connect, you can use:

```
ALTER ROLE myname SET enable_indexscan TO off;
```

This will save the setting (but not set it immediately). In subsequent connections by this role it will appear as though `SET enable_indexscan TO off` had been executed just before the session started. You can still alter this setting during the session; it will only be the default. To remove a role-specific default setting, use `ALTER ROLE rolename RESET varname`. Note that role-specific defaults attached to roles without `LOGIN` privilege are fairly useless, since they will never be invoked.

When a non-superuser creates a role using the `CREATEROLE` privilege, the created role is automatically granted back to the creating user, just as if the bootstrap superuser had executed the command `GRANT created_user TO creating_user WITH ADMIN OPTION`. Since a `CREATEROLE` user can only exercise special privileges with regard to an existing role if they have `ADMIN OPTION` on it, this grant is just sufficient to allow a `CREATEROLE` user to administer the roles they created.

21.3. Role Membership

It is frequently convenient to group users together to ease management of privileges: that way, privileges can be granted to, or revoked from, a group as a whole. In Postgres Pro this is done by creating a role that represents the group, and then granting *membership* in the group role to individual user roles.

To set up a group role, first create the role:

```
CREATE ROLE name;
```

Typically a role being used as a group would not have the `LOGIN` attribute, though you can set it if you wish.

Once the group role exists, you can add and remove members using the `GRANT` and `REVOKE` commands:

```
GRANT group_role TO role1, ... ;
REVOKE group_role FROM role1, ... ;
```

You can grant membership to other group roles, too (since there isn't really any distinction between group roles and non-group roles). The database will not let you set up circular membership loops. Also, it is not permitted to grant membership in a role to `PUBLIC`.

The members of a group role can use the privileges of the role in two ways. First, every member of a group can explicitly do `SET ROLE` to temporarily “become” the group role. In this state, the database session has access to the privileges of the group role rather than the original login role, and any database objects created are considered owned by the group role not the login role. Second, member roles that have the `INHERIT` attribute automatically have use of the privileges of roles of which they are members, including any privileges inherited by those roles. As an example, suppose we have done:

```
CREATE ROLE joe LOGIN INHERIT;
CREATE ROLE admin NOINHERIT;
```

```
CREATE ROLE wheel NOINHERIT;
GRANT admin TO joe;
GRANT wheel TO admin;
```

Immediately after connecting as role `joe`, a database session will have use of privileges granted directly to `joe` plus any privileges granted to `admin`, because `joe` "inherits" `admin`'s privileges. However, privileges granted to `wheel` are not available, because even though `joe` is indirectly a member of `wheel`, the membership is via `admin` which has the `NOINHERIT` attribute. After:

```
SET ROLE admin;
```

the session would have use of only those privileges granted to `admin`, and not those granted to `joe`. After:

```
SET ROLE wheel;
```

the session would have use of only those privileges granted to `wheel`, and not those granted to either `joe` or `admin`. The original privilege state can be restored with any of:

```
SET ROLE joe;
SET ROLE NONE;
RESET ROLE;
```

> **Note**
>
> The `SET ROLE` command always allows selecting any role that the original login role is directly or indirectly a member of. Thus, in the above example, it is not necessary to become `admin` before becoming `wheel`.

> **Note**
>
> In the SQL standard, there is a clear distinction between users and roles, and users do not automatically inherit privileges while roles do. This behavior can be obtained in Postgres Pro by giving roles being used as SQL roles the `INHERIT` attribute, while giving roles being used as SQL users the `NOINHERIT` attribute. However, Postgres Pro defaults to giving all roles the `INHERIT` attribute, for backward compatibility with pre-8.1 releases in which users always had use of permissions granted to groups they were members of.

The role attributes `LOGIN`, `SUPERUSER`, `CREATEDB`, and `CREATEROLE` can be thought of as special privileges, but they are never inherited as ordinary privileges on database objects are. You must actually `SET ROLE` to a specific role having one of these attributes in order to make use of the attribute. Continuing the above example, we might choose to grant `CREATEDB` and `CREATEROLE` to the `admin` role. Then a session connecting as role `joe` would not have these privileges immediately, only after doing `SET ROLE admin`.

To destroy a group role, use `DROP ROLE`:

```
DROP ROLE name;
```

Any memberships in the group role are automatically revoked (but the member roles are not otherwise affected).

21.4. Dropping Roles

Because roles can own database objects and can hold privileges to access other objects, dropping a role is often not just a matter of a quick `DROP ROLE`. Any objects owned by the role must first be dropped or reassigned to other owners; and any permissions granted to the role must be revoked.

Ownership of objects can be transferred one at a time using `ALTER` commands, for example:

```
ALTER TABLE bobs_table OWNER TO alice;
```

Alternatively, the REASSIGN OWNED command can be used to reassign ownership of all objects owned by the role-to-be-dropped to a single other role. Because REASSIGN OWNED cannot access objects in other databases, it is necessary to run it in each database that contains objects owned by the role. (Note that the first such REASSIGN OWNED will change the ownership of any shared-across-databases objects, that is databases or tablespaces, that are owned by the role-to-be-dropped.)

Once any valuable objects have been transferred to new owners, any remaining objects owned by the role-to-be-dropped can be dropped with the DROP OWNED command. Again, this command cannot access objects in other databases, so it is necessary to run it in each database that contains objects owned by the role. Also, DROP OWNED will not drop entire databases or tablespaces, so it is necessary to do that manually if the role owns any databases or tablespaces that have not been transferred to new owners.

DROP OWNED also takes care of removing any privileges granted to the target role for objects that do not belong to it. Because REASSIGN OWNED does not touch such objects, it's typically necessary to run both REASSIGN OWNED and DROP OWNED (in that order!) to fully remove the dependencies of a role to be dropped.

In short then, the most general recipe for removing a role that has been used to own objects is:

```
REASSIGN OWNED BY doomed_role TO successor_role;
DROP OWNED BY doomed_role;
-- repeat the above commands in each database of the cluster
DROP ROLE doomed_role;
```

When not all owned objects are to be transferred to the same successor owner, it's best to handle the exceptions manually and then perform the above steps to mop up.

If DROP ROLE is attempted while dependent objects still remain, it will issue messages identifying which objects need to be reassigned or dropped.

21.5. Predefined Roles

Postgres Pro provides a set of predefined roles that provide access to certain, commonly needed, privileged capabilities and information. Administrators (including roles that have the CREATEROLE privilege) can GRANT these roles to users and/or other roles in their environment, providing those users with access to the specified capabilities and information.

The predefined roles are described in Table 21.1. Note that the specific permissions for each of the roles may change in the future as additional capabilities are added. Administrators should monitor the release notes for changes.

Table 21.1. Predefined Roles

Role	Allowed Access
pg_read_all_data	Read all data (tables, views, sequences), as if having SELECT rights on those objects, and USAGE rights on all schemas, even without having it explicitly. This role does not have the role attribute BYPASSRLS set. If RLS is being used, an administrator may wish to set BYPASSRLS on roles which this role is GRANTed to.
pg_write_all_data	Write all data (tables, views, sequences), as if having INSERT, UPDATE, and DELETE rights on those objects, and USAGE rights on all schemas, even without having it explicitly. This role does not have the role attribute BYPASSRLS set. If RLS is being used, an administrator may wish to set BYPASSRLS on roles which this role is GRANTed to.
pg_read_all_settings	Read all configuration variables, even those normally visible only to superusers.
pg_read_all_stats	Read all pg_stat_* views and use various statistics related extensions, even those normally visible only to superusers.

Role	Allowed Access
pg_stat_scan_tables	Execute monitoring functions that may take ACCESS SHARE locks on tables, potentially for a long time.
pg_monitor	Read/execute various monitoring views and functions. This role is a member of pg_read_all_settings, pg_read_all_stats and pg_stat_scan_tables.
pg_database_owner	None. Membership consists, implicitly, of the current database owner.
pg_signal_backend	Signal another backend to cancel a query or terminate its session.
pg_read_server_files	Allow reading files from any location the database can access on the server with COPY and other file-access functions.
pg_write_server_files	Allow writing to files in any location the database can access on the server with COPY and other file-access functions.
pg_execute_server_program	Allow executing programs on the database server as the user the database runs as with COPY and other functions which allow executing a server-side program.

The pg_monitor, pg_read_all_settings, pg_read_all_stats and pg_stat_scan_tables roles are intended to allow administrators to easily configure a role for the purpose of monitoring the database server. They grant a set of common privileges allowing the role to read various useful configuration settings, statistics and other system information normally restricted to superusers.

The pg_database_owner role has one implicit, situation-dependent member, namely the owner of the current database. The role conveys no rights at first. Like any role, it can own objects or receive grants of access privileges. Consequently, once pg_database_owner has rights within a template database, each owner of a database instantiated from that template will exercise those rights. pg_database_owner cannot be a member of any role, and it cannot have non-implicit members.

The pg_signal_backend role is intended to allow administrators to enable trusted, but non-superuser, roles to send signals to other backends. Currently this role enables sending of signals for canceling a query on another backend or terminating its session. A user granted this role cannot however send signals to a backend owned by a superuser. See Section 9.27.2.

The pg_read_server_files, pg_write_server_files and pg_execute_server_program roles are intended to allow administrators to have trusted, but non-superuser, roles which are able to access files and run programs on the database server as the user the database runs as. As these roles are able to access any file on the server file system, they bypass all database-level permission checks when accessing files directly and they could be used to gain superuser-level access, therefore great care should be taken when granting these roles to users.

Care should be taken when granting these roles to ensure they are only used where needed and with the understanding that these roles grant access to privileged information.

Administrators can grant access to these roles to users using the GRANT command, for example:

```
GRANT pg_signal_backend TO admin_user;
```

21.6. Function Security

Functions, triggers and row-level security policies allow users to insert code into the backend server that other users might execute unintentionally. Hence, these mechanisms permit users to “Trojan horse” others with relative ease. The strongest protection is tight control over who can define objects. Where that is infeasible, write queries referring only to objects having trusted owners. Remove from search_path the public schema and any other schemas that permit untrusted users to create objects.

Functions run inside the backend server process with the operating system permissions of the database server daemon. If the programming language used for the function allows unchecked memory accesses,

it is possible to change the server's internal data structures. Hence, among many other things, such functions can circumvent any system access controls. Function languages that allow such access are considered “untrusted”, and Postgres Pro allows only superusers to create functions written in those languages.

Chapter 22. Managing Databases

Every instance of a running Postgres Pro server manages one or more databases. Databases are therefore the topmost hierarchical level for organizing SQL objects (“database objects”). This chapter describes the properties of databases, and how to create, manage, and destroy them.

22.1. Overview

A small number of objects, like role, database, and tablespace names, are defined at the cluster level and stored in the `pg_global` tablespace. Inside the cluster are multiple databases, which are isolated from each other but can access cluster-level objects. Inside each database are multiple schemas, which contain objects like tables and functions. So the full hierarchy is: cluster, database, schema, table (or some other kind of object, such as a function).

When connecting to the database server, a client must specify the database name in its connection request. It is not possible to access more than one database per connection. However, clients can open multiple connections to the same database, or different databases. Database-level security has two components: access control (see Section 20.1), managed at the connection level, and authorization control (see Section 5.7), managed via the grant system. Foreign data wrappers (see postgres_fdw) allow for objects within one database to act as proxies for objects in other database or clusters. The older dblink module (see dblink) provides a similar capability. By default, all users can connect to all databases using all connection methods.

If one Postgres Pro server cluster is planned to contain unrelated projects or users that should be, for the most part, unaware of each other, it is recommended to put them into separate databases and adjust authorizations and access controls accordingly. If the projects or users are interrelated, and thus should be able to use each other's resources, they should be put in the same database but probably into separate schemas; this provides a modular structure with namespace isolation and authorization control. More information about managing schemas is in Section 5.9.

While multiple databases can be created within a single cluster, it is advised to consider carefully whether the benefits outweigh the risks and limitations. In particular, the impact that having a shared WAL (see Chapter 29) has on backup and recovery options. While individual databases in the cluster are isolated when considered from the user's perspective, they are closely bound from the database administrator's point-of-view.

Databases are created with the `CREATE DATABASE` command (see Section 22.2) and destroyed with the `DROP DATABASE` command (see Section 22.5). To determine the set of existing databases, examine the `pg_database` system catalog, for example

```
SELECT datname FROM pg_database;
```

The psql program's `\l` meta-command and `-l` command-line option are also useful for listing the existing databases.

> **Note**
>
> The SQL standard calls databases “catalogs”, but there is no difference in practice.

22.2. Creating a Database

In order to create a database, the Postgres Pro server must be up and running (see Section 18.3).

Databases are created with the SQL command CREATE DATABASE:

```
CREATE DATABASE name;
```

where *name* follows the usual rules for SQL identifiers. The current role automatically becomes the owner of the new database. It is the privilege of the owner of a database to remove it later (which also removes all the objects in it, even if they have a different owner).

The creation of databases is a restricted operation. See Section 21.2 for how to grant permission.

Since you need to be connected to the database server in order to execute the `CREATE DATABASE` command, the question remains how the *first* database at any given site can be created. The first database is always created by the `initdb` command when the data storage area is initialized. (See Section 18.2.) This database is called `postgres`. So to create the first "ordinary" database you can connect to `postgres`.

A second database, `template1`, is also created during database cluster initialization. Whenever a new database is created within the cluster, `template1` is essentially cloned. This means that any changes you make in `template1` are propagated to all subsequently created databases. Because of this, avoid creating objects in `template1` unless you want them propagated to every newly created database. More details appear in Section 22.3.

As a convenience, there is a program you can execute from the shell to create new databases, `createdb`.

```
createdb dbname
```

`createdb` does no magic. It connects to the `postgres` database and issues the `CREATE DATABASE` command, exactly as described above. The createdb reference page contains the invocation details. Note that `createdb` without any arguments will create a database with the current user name.

> **Note**
>
> Chapter 20 contains information about how to restrict who can connect to a given database.

Sometimes you want to create a database for someone else, and have them become the owner of the new database, so they can configure and manage it themselves. To achieve that, use one of the following commands:

```
CREATE DATABASE dbname OWNER rolename;
```

from the SQL environment, or:

```
createdb -O rolename dbname
```

from the shell. Only the superuser is allowed to create a database for someone else (that is, for a role you are not a member of).

22.3. Template Databases

`CREATE DATABASE` actually works by copying an existing database. By default, it copies the standard system database named `template1`. Thus that database is the "template" from which new databases are made. If you add objects to `template1`, these objects will be copied into subsequently created user databases. This behavior allows site-local modifications to the standard set of objects in databases. For example, if you install the procedural language PL/Perl in `template1`, it will automatically be available in user databases without any extra action being taken when those databases are created.

However, `CREATE DATABASE` does not copy database-level `GRANT` permissions attached to the source database. The new database has default database-level permissions.

There is a second standard system database named `template0`. This database contains the same data as the initial contents of `template1`, that is, only the standard objects predefined by your version of Postgres Pro. `template0` should never be changed after the database cluster has been initialized. By instructing `CREATE DATABASE` to copy `template0` instead of `template1`, you can create a "pristine" user database (one where no user-defined objects exist and where the system objects have not been altered) that contains none of the site-local additions in `template1`. This is particularly handy when restoring a `pg_dump` dump: the dump script should be restored in a pristine database to ensure that one recreates the correct contents of the dumped database, without conflicting with objects that might have been added to `template1` later on.

Another common reason for copying `template0` instead of `template1` is that new encoding and locale settings can be specified when copying `template0`, whereas a copy of `template1` must use the same settings it does. This is because `template1` might contain encoding-specific or locale-specific data, while `template0` is known not to.

To create a database by copying `template0`, use:

```
CREATE DATABASE dbname TEMPLATE template0;
```

from the SQL environment, or:

```
createdb -T template0 dbname
```

from the shell.

It is possible to create additional template databases, and indeed one can copy any database in a cluster by specifying its name as the template for `CREATE DATABASE`. It is important to understand, however, that this is not (yet) intended as a general-purpose "`COPY DATABASE`" facility. The principal limitation is that no other sessions can be connected to the source database while it is being copied. `CREATE DATABASE` will fail if any other connection exists when it starts; during the copy operation, new connections to the source database are prevented.

Two useful flags exist in `pg_database`for each database: the columns `datistemplate` and `datallowconn`. `datistemplate` can be set to indicate that a database is intended as a template for `CREATE DATABASE`. If this flag is set, the database can be cloned by any user with `CREATEDB` privileges; if it is not set, only superusers and the owner of the database can clone it. If `datallowconn` is false, then no new connections to that database will be allowed (but existing sessions are not terminated simply by setting the flag false). The `template0` database is normally marked `datallowconn = false` to prevent its modification. Both `template0` and `template1` should always be marked with `datistemplate = true`.

> **Note**
>
> `template1` and `template0` do not have any special status beyond the fact that the name `template1` is the default source database name for `CREATE DATABASE`. For example, one could drop `template1` and recreate it from `template0` without any ill effects. This course of action might be advisable if one has carelessly added a bunch of junk in `template1`. (To delete `template1`, it must have `pg_database.datistemplate = false`.)
>
> The `postgres` database is also created when a database cluster is initialized. This database is meant as a default database for users and applications to connect to. It is simply a copy of `template1` and can be dropped and recreated if necessary.

22.4. Database Configuration

Recall from Chapter 19 that the Postgres Pro server provides a large number of run-time configuration variables. You can set database-specific default values for many of these settings.

For example, if for some reason you want to disable the GEQO optimizer for a given database, you'd ordinarily have to either disable it for all databases or make sure that every connecting client is careful to issue `SET geqo TO off`. To make this setting the default within a particular database, you can execute the command:

```
ALTER DATABASE mydb SET geqo TO off;
```

This will save the setting (but not set it immediately). In subsequent connections to this database it will appear as though `SET geqo TO off;` had been executed just before the session started. Note that users can still alter this setting during their sessions; it will only be the default. To undo any such setting, use `ALTER DATABASE dbname RESET varname`.

22.5. Destroying a Database

Databases are destroyed with the command DROP DATABASE:

```
DROP DATABASE name;
```

Only the owner of the database, or a superuser, can drop a database. Dropping a database removes all objects that were contained within the database. The destruction of a database cannot be undone.

You cannot execute the `DROP DATABASE` command while connected to the victim database. You can, however, be connected to any other database, including the `template1` database. `template1` would be the only option for dropping the last user database of a given cluster.

For convenience, there is also a shell program to drop databases, dropdb:

```
dropdb dbname
```

(Unlike `createdb`, it is not the default action to drop the database with the current user name.)

22.6. Tablespaces

Tablespaces in Postgres Pro allow database administrators to define locations in the file system where the files representing database objects can be stored. Once created, a tablespace can be referred to by name when creating database objects.

By using tablespaces, an administrator can control the disk layout of a Postgres Pro installation. This is useful in at least two ways. First, if the partition or volume on which the cluster was initialized runs out of space and cannot be extended, a tablespace can be created on a different partition and used until the system can be reconfigured.

Second, tablespaces allow an administrator to use knowledge of the usage pattern of database objects to optimize performance. For example, an index which is very heavily used can be placed on a very fast, highly available disk, such as an expensive solid state device. At the same time a table storing archived data which is rarely used or not performance critical could be stored on a less expensive, slower disk system.

> **Warning**
>
> Even though located outside the main Postgres Pro data directory, tablespaces are an integral part of the database cluster and *cannot* be treated as an autonomous collection of data files. They are dependent on metadata contained in the main data directory, and therefore cannot be attached to a different database cluster or backed up individually. Similarly, if you lose a tablespace (file deletion, disk failure, etc), the database cluster might become unreadable or unable to start. Placing a tablespace on a temporary file system like a RAM disk risks the reliability of the entire cluster.

To define a tablespace, use the CREATE TABLESPACE command, for example::

```
CREATE TABLESPACE fastspace LOCATION '/ssd1/postgresql/data';
```

The location must be an existing, empty directory that is owned by the Postgres Pro operating system user. All objects subsequently created within the tablespace will be stored in files underneath this directory. The location must not be on removable or transient storage, as the cluster might fail to function if the tablespace is missing or lost.

> **Note**
>
> There is usually not much point in making more than one tablespace per logical file system, since you cannot control the location of individual files within a logical file system. However, Postgres Pro does not enforce any such limitation, and indeed it is not directly aware of the file system boundaries on your system. It just stores files in the directories you tell it to use.

Creation of the tablespace itself must be done as a database superuser, but after that you can allow ordinary database users to use it. To do that, grant them the `CREATE` privilege on it.

Tables, indexes, and entire databases can be assigned to particular tablespaces. To do so, a user with the `CREATE` privilege on a given tablespace must pass the tablespace name as a parameter to the relevant command. For example, the following creates a table in the tablespace `space1`:

```
CREATE TABLE foo(i int) TABLESPACE space1;
```

Alternatively, use the default_tablespace parameter:

```
SET default_tablespace = space1;
CREATE TABLE foo(i int);
```

When `default_tablespace` is set to anything but an empty string, it supplies an implicit `TABLESPACE` clause for `CREATE TABLE` and `CREATE INDEX` commands that do not have an explicit one.

There is also a temp_tablespaces parameter, which determines the placement of temporary tables and indexes, as well as temporary files that are used for purposes such as sorting large data sets. This can be a list of tablespace names, rather than only one, so that the load associated with temporary objects can be spread over multiple tablespaces. A random member of the list is picked each time a temporary object is to be created.

The tablespace associated with a database is used to store the system catalogs of that database. Furthermore, it is the default tablespace used for tables, indexes, and temporary files created within the database, if no `TABLESPACE` clause is given and no other selection is specified by `default_tablespace` or `temp_tablespaces` (as appropriate). If a database is created without specifying a tablespace for it, it uses the same tablespace as the template database it is copied from.

Two tablespaces are automatically created when the database cluster is initialized. The `pg_global` tablespace is used for shared system catalogs. The `pg_default` tablespace is the default tablespace of the `template1` and `template0` databases (and, therefore, will be the default tablespace for other databases as well, unless overridden by a `TABLESPACE` clause in `CREATE DATABASE`).

Once created, a tablespace can be used from any database, provided the requesting user has sufficient privilege. This means that a tablespace cannot be dropped until all objects in all databases using the tablespace have been removed.

To remove an empty tablespace, use the DROP TABLESPACE command.

To determine the set of existing tablespaces, examine the `pg_tablespace` system catalog, for example

```
SELECT spcname FROM pg_tablespace;
```

The psql program's `\db` meta-command is also useful for listing the existing tablespaces.

Postgres Pro makes use of symbolic links to simplify the implementation of tablespaces. This means that tablespaces can be used *only* on systems that support symbolic links.

The directory `$PGDATA/pg_tblspc` contains symbolic links that point to each of the non-built-in tablespaces defined in the cluster. Although not recommended, it is possible to adjust the tablespace layout by hand by redefining these links. Under no circumstances perform this operation while the server is running. Note that in PostgreSQL 9.1 and earlier you will also need to update the `pg_tablespace` catalog with the new locations. (If you do not, `pg_dump` will continue to output the old tablespace locations.)

Chapter 23. Localization

This chapter describes the available localization features from the point of view of the administrator. Postgres Pro supports two localization facilities:

- Using the locale features of the operating system to provide locale-specific collation order, number formatting, translated messages, and other aspects. This is covered in Section 23.1 and Section 23.2.
- Providing a number of different character sets to support storing text in all kinds of languages, and providing character set translation between client and server. This is covered in Section 23.3.

23.1. Locale Support

Locale support refers to an application respecting cultural preferences regarding alphabets, sorting, number formatting, etc. Postgres Pro uses the standard ISO C and POSIX locale facilities provided by the server operating system. For additional information refer to the documentation of your system.

23.1.1. Overview

Locale support is automatically initialized when a database cluster is created using `initdb`. `initdb` will initialize the database cluster with the locale setting of its execution environment by default, so if your system is already set to use the locale that you want in your database cluster then there is nothing else you need to do. If you want to use a different locale (or you are not sure which locale your system is set to), you can instruct `initdb` exactly which locale to use by specifying the `--locale` option. For example:

```
initdb --locale=ru_RU
```

This example for Unix systems sets the locale to Russian (`ru`) as spoken in Russia (`RU`). Other possibilities might include `en_US` (U.S. English) and `fr_CA` (French Canadian). If more than one character set can be used for a locale then the specifications can take the form *`language_territory.codeset`*. For example, `fr_BE.UTF-8` represents the French language (fr) as spoken in Belgium (BE), with a UTF-8 character set encoding.

What locales are available on your system under what names depends on what was provided by the operating system vendor and what was installed. On most Unix systems, the command `locale -a` will provide a list of available locales. Windows uses more verbose locale names, such as `German_Germany` or `Swedish_Sweden.1252`, but the principles are the same.

Occasionally it is useful to mix rules from several locales, e.g., use English collation rules but Spanish messages. To support that, a set of locale subcategories exist that control only certain aspects of the localization rules:

`LC_COLLATE`	String sort order
`LC_CTYPE`	Character classification (What is a letter? Its upper-case equivalent?)
`LC_MESSAGES`	Language of messages
`LC_MONETARY`	Formatting of currency amounts
`LC_NUMERIC`	Formatting of numbers
`LC_TIME`	Formatting of dates and times

The category names translate into names of `initdb` options to override the locale choice for a specific category. For instance, to set the locale to French Canadian, but use U.S. rules for formatting currency, use `initdb --locale=fr_CA --lc-monetary=en_US`.

If you want the system to behave as if it had no locale support, use the special locale name `C`, or equivalently `POSIX`.

Some locale categories must have their values fixed when the database is created. You can use different settings for different databases, but once a database is created, you cannot change them for that database anymore. `LC_COLLATE` and `LC_CTYPE` are these categories. They affect the sort order of indexes,

so they must be kept fixed, or indexes on text columns would become corrupt. (But you can alleviate this restriction using collations, as discussed in Section 23.2.) The default values for these categories are determined when `initdb` is run, and those values are used when new databases are created, unless specified otherwise in the `CREATE DATABASE` command.

The other locale categories can be changed whenever desired by setting the server configuration parameters that have the same name as the locale categories (see Section 19.11.2 for details). The values that are chosen by `initdb` are actually only written into the configuration file `postgresql.conf` to serve as defaults when the server is started. If you remove these assignments from `postgresql.conf` then the server will inherit the settings from its execution environment.

Note that the locale behavior of the server is determined by the environment variables seen by the server, not by the environment of any client. Therefore, be careful to configure the correct locale settings before starting the server. A consequence of this is that if client and server are set up in different locales, messages might appear in different languages depending on where they originated.

> **Note**
>
> When we speak of inheriting the locale from the execution environment, this means the following on most operating systems: For a given locale category, say the collation, the following environment variables are consulted in this order until one is found to be set: `LC_ALL`, `LC_COLLATE` (or the variable corresponding to the respective category), `LANG`. If none of these environment variables are set then the locale defaults to `C`.
>
> Some message localization libraries also look at the environment variable `LANGUAGE` which overrides all other locale settings for the purpose of setting the language of messages. If in doubt, please refer to the documentation of your operating system, in particular the documentation about gettext.

To enable messages to be translated to the user's preferred language, NLS must have been selected at build time (`configure --enable-nls`). All other locale support is built in automatically.

23.1.2. Behavior

The locale settings influence the following SQL features:

- Sort order in queries using `ORDER BY` or the standard comparison operators on textual data
- The `upper`, `lower`, and `initcap` functions
- Pattern matching operators (`LIKE`, `SIMILAR TO`, and POSIX-style regular expressions); locales affect both case insensitive matching and the classification of characters by character-class regular expressions
- The `to_char` family of functions
- The ability to use indexes with `LIKE` clauses

The drawback of using locales other than `C` or `POSIX` in Postgres Pro is its performance impact. It slows character handling and prevents ordinary indexes from being used by `LIKE`. For this reason use locales only if you actually need them.

As a workaround to allow Postgres Pro to use indexes with `LIKE` clauses under a non-C locale, several custom operator classes exist. These allow the creation of an index that performs a strict character-by-character comparison, ignoring locale comparison rules. Refer to Section 11.10 for more information. Another approach is to create indexes using the `C` collation, as discussed in Section 23.2.

23.1.3. Problems

If locale support doesn't work according to the explanation above, check that the locale support in your operating system is correctly configured. To check what locales are installed on your system, you can use the command `locale -a` if your operating system provides it.

Check that Postgres Pro is actually using the locale that you think it is. The LC_COLLATE and LC_CTYPE settings are determined when a database is created, and cannot be changed except by creating a new database. Other locale settings including LC_MESSAGES and LC_MONETARY are initially determined by the environment the server is started in, but can be changed on-the-fly. You can check the active locale settings using the SHOW command.

Client applications that handle server-side errors by parsing the text of the error message will obviously have problems when the server's messages are in a different language. Authors of such applications are advised to make use of the error code scheme instead.

23.2. Collation Support

The collation feature allows specifying the sort order and character classification behavior of data per-column, or even per-operation. This alleviates the restriction that the LC_COLLATE and LC_CTYPE settings of a database cannot be changed after its creation.

23.2.1. Concepts

Conceptually, every expression of a collatable data type has a collation. (The built-in collatable data types are text, varchar, and char. User-defined base types can also be marked collatable, and of course a domain over a collatable data type is collatable.) If the expression is a column reference, the collation of the expression is the defined collation of the column. If the expression is a constant, the collation is the default collation of the data type of the constant. The collation of a more complex expression is derived from the collations of its inputs, as described below.

The collation of an expression can be the “default” collation, which means the locale settings defined for the database. It is also possible for an expression's collation to be indeterminate. In such cases, ordering operations and other operations that need to know the collation will fail.

When the database system has to perform an ordering or a character classification, it uses the collation of the input expression. This happens, for example, with ORDER BY clauses and function or operator calls such as <. The collation to apply for an ORDER BY clause is simply the collation of the sort key. The collation to apply for a function or operator call is derived from the arguments, as described below. In addition to comparison operators, collations are taken into account by functions that convert between lower and upper case letters, such as lower, upper, and initcap; by pattern matching operators; and by to_char and related functions.

For a function or operator call, the collation that is derived by examining the argument collations is used at run time for performing the specified operation. If the result of the function or operator call is of a collatable data type, the collation is also used at parse time as the defined collation of the function or operator expression, in case there is a surrounding expression that requires knowledge of its collation.

The *collation derivation* of an expression can be implicit or explicit. This distinction affects how collations are combined when multiple different collations appear in an expression. An explicit collation derivation occurs when a COLLATE clause is used; all other collation derivations are implicit. When multiple collations need to be combined, for example in a function call, the following rules are used:

1. If any input expression has an explicit collation derivation, then all explicitly derived collations among the input expressions must be the same, otherwise an error is raised. If any explicitly derived collation is present, that is the result of the collation combination.
2. Otherwise, all input expressions must have the same implicit collation derivation or the default collation. If any non-default collation is present, that is the result of the collation combination. Otherwise, the result is the default collation.
3. If there are conflicting non-default implicit collations among the input expressions, then the combination is deemed to have indeterminate collation. This is not an error condition unless the particular function being invoked requires knowledge of the collation it should apply. If it does, an error will be raised at run-time.

For example, consider this table definition:

```
CREATE TABLE test1 (
    a text COLLATE "ru_RU",
    b text COLLATE "es_ES",
    ...
);
```

Then in

```
SELECT a < 'foo' FROM test1;
```

the < comparison is performed according to ru_RU rules, because the expression combines an implicitly derived collation with the default collation. But in

```
SELECT a < ('foo' COLLATE "fr_FR") FROM test1;
```

the comparison is performed using fr_FR rules, because the explicit collation derivation overrides the implicit one. Furthermore, given

```
SELECT a < b FROM test1;
```

the parser cannot determine which collation to apply, since the a and b columns have conflicting implicit collations. Since the < operator does need to know which collation to use, this will result in an error. The error can be resolved by attaching an explicit collation specifier to either input expression, thus:

```
SELECT a < b COLLATE "ru_RU" FROM test1;
```

or equivalently

```
SELECT a COLLATE "ru_RU" < b FROM test1;
```

On the other hand, the structurally similar case

```
SELECT a || b FROM test1;
```

does not result in an error, because the || operator does not care about collations: its result is the same regardless of the collation.

The collation assigned to a function or operator's combined input expressions is also considered to apply to the function or operator's result, if the function or operator delivers a result of a collatable data type. So, in

```
SELECT * FROM test1 ORDER BY a || 'foo';
```

the ordering will be done according to ru_RU rules. But this query:

```
SELECT * FROM test1 ORDER BY a || b;
```

results in an error, because even though the || operator doesn't need to know a collation, the ORDER BY clause does. As before, the conflict can be resolved with an explicit collation specifier:

```
SELECT * FROM test1 ORDER BY a || b COLLATE "fr_FR";
```

23.2.2. Managing Collations

A collation is an SQL schema object that maps an SQL name to locales provided by libraries installed in the operating system. A collation definition has a *provider* that specifies which library supplies the locale data. One standard provider name is libc, which uses the locales provided by the operating system C library. These are the locales that most tools provided by the operating system use. Another provider is icu, which uses the external ICU library. ICU locales can only be used if support for ICU was configured when Postgres Pro was built.

A collation object provided by libc maps to a combination of LC_COLLATE and LC_CTYPE settings, as accepted by the setlocale() system library call. (As the name would suggest, the main purpose of a collation is to set LC_COLLATE, which controls the sort order. But it is rarely necessary in practice to have an LC_CTYPE setting that is different from LC_COLLATE, so it is more convenient to collect these under one concept than to create another infrastructure for setting LC_CTYPE per expression.) Also, a libc collation is tied to a character set encoding (see Section 23.3). The same collation name may exist for different encodings.

A collation object provided by `icu` maps to a named collator provided by the ICU library. ICU does not support separate “collate” and “ctype” settings, so they are always the same. Also, ICU collations are independent of the encoding, so there is always only one ICU collation of a given name in a database.

You can specify the provider of the default collation with the `--locale` and `--lc-collate` options of the initdb or createdb commands, as follows:

```
--locale=locale[@provider]
--lc-collate=locale[@provider]
```

where *provider* can take the `icu` or `libc` value, and *locale* is specified in the `libc` format. You can only specify a single locale provider after the `@` symbol. The `--lc-collate` option overrides the `--locale` setting, regardless of whether the collation provider is specified.

If you do not specify the provider, `libc` is used for `C` and `POSIX` locales. For other locales, the default provider is:

- `icu` at the cluster level
- Provider of the default collation from the template database at the database level

> **Important**
>
> You can only use the `icu` collation provider for locales that are supported by `libc` in your operating system and satisfy all restrictions applicable to `icu`.

Before starting the server, Postgres Pro checks that the cluster was initialized by a server compiled with the same version of ICU, even if `icu` is not used as the provider for the default collation. If the ICU library versions do not match, Postgres Pro emits the appropriate informational message.

Before connecting to a database with an `icu` default collation, Postgres Pro compares this collation version to the one provided by the ICU library. If the collation version changes, you may need to rebuild the objects that depend on a changed collation if you think this change may affect the sort order of your data. Postgres Pro displays a warning if collation versions do not match, or it is impossible to compare them because the cluster does not provide any information about the collation version for the default collation. To suppress these warnings, you can use the `ALTER COLLATION "default" REFRESH VERSION` command, as explained in ALTER COLLATION.

You can find the default collation and its provider in `pg_database.datcollate`:

locale`@`*provider*

23.2.2.1. Standard Collations

On all platforms, the collations named `default`, `C`, and `POSIX` are available. Additional collations may be available depending on operating system support. The `default` collation selects the `LC_COLLATE` and `LC_CTYPE` values specified at database creation time. The `C` and `POSIX` collations both specify “traditional C” behavior, in which only the ASCII letters “`A`” through “`Z`” are treated as letters, and sorting is done strictly by character code byte values.

Additionally, the SQL standard collation name `ucs_basic` is available for encoding `UTF8`. It is equivalent to `C` and sorts by Unicode code point.

23.2.2.2. Predefined Collations

If the operating system provides support for using multiple locales within a single program (`newlocale` and related functions), or if support for ICU is configured, then when a database cluster is initialized, `initdb` populates the system catalog `pg_collation` with collations based on all the locales it finds in the operating system at the time.

To inspect the currently available locales, use the query `SELECT * FROM pg_collation`, or the command `\dOS+` in psql.

23.2.2.2.1. libc Collations

For example, the operating system might provide a locale named `ru_RU.utf8`. `initdb` would then create a collation named `ru_RU.utf8` for encoding `UTF8` that has both `LC_COLLATE` and `LC_CTYPE` set to `ru_RU.utf8`. It will also create a collation with the `.utf8` tag stripped off the name. So you could also use the collation under the name `ru_RU`, which is less cumbersome to write and makes the name less encoding-dependent. Note that, nevertheless, the initial set of collation names is platform-dependent.

The default set of collations provided by `libc` map directly to the locales installed in the operating system, which can be listed using the command `locale -a`. In case a `libc` collation is needed that has different values for `LC_COLLATE` and `LC_CTYPE`, or if new locales are installed in the operating system after the database system was initialized, then a new collation may be created using the CREATE COLLATION command. New operating system locales can also be imported en masse using the `pg_import_system_collations()` function.

Within any particular database, only collations that use that database's encoding are of interest. Other entries in `pg_collation` are ignored. Thus, a stripped collation name such as `ru_RU` can be considered unique within a given database even though it would not be unique globally. Use of the stripped collation names is recommended, since it will make one fewer thing you need to change if you decide to change to another database encoding. Note however that the `default`, `C`, and `POSIX` collations can be used regardless of the database encoding.

Postgres Pro considers distinct collation objects to be incompatible even when they have identical properties. Thus for example,

```
SELECT a COLLATE "C" < b COLLATE "POSIX" FROM test1;
```

will draw an error even though the `C` and `POSIX` collations have identical behaviors. Mixing stripped and non-stripped collation names is therefore not recommended.

23.2.2.2.2. ICU Collations

With ICU, it is not sensible to enumerate all possible locale names. ICU uses a particular naming system for locales, but there are many more ways to name a locale than there are actually distinct locales. `initdb` uses the ICU APIs to extract a set of distinct locales to populate the initial set of collations. Collations provided by ICU are created in the SQL environment with names in BCP 47 language tag format, with a “private use” extension `-x-icu` appended, to distinguish them from libc locales.

Here are some example collations that might be created:

`ru-x-icu`

Russian collation, default variant

`ru-UA-x-icu`

Russian collation for Ukraine, default variant

(There is also, say, `ru-RU-x-icu`, but as of this writing, it is equivalent to `ru-x-icu`.)

`und-x-icu` (for “undefined”)

ICU “root” collation. Use this to get a reasonable language-agnostic sort order.

Some (less frequently used) encodings are not supported by ICU. When the database encoding is one of these, ICU collation entries in `pg_collation` are ignored. Attempting to use one will draw an error along the lines of “collation "de-x-icu" for encoding "WIN874" does not exist”.

23.2.2.3. Creating New Collation Objects

If the standard and predefined collations are not sufficient, users can create their own collation objects using the SQL command CREATE COLLATION.

The standard and predefined collations are in the schema `pg_catalog`, like all predefined objects. User-defined collations should be created in user schemas. This also ensures that they are saved by `pg_dump`.

23.2.2.3.1. libc Collations

New libc collations can be created like this:

```
CREATE COLLATION russian (provider = libc, locale = 'ru_RU');
```

The exact values that are acceptable for the `locale` clause in this command depend on the operating system. On Unix-like systems, the command `locale -a` will show a list.

Since the predefined libc collations already include all collations defined in the operating system when the database instance is initialized, it is not often necessary to manually create new ones. Reasons might be if a different naming system is desired (in which case see also Section 23.2.2.3.3) or if the operating system has been upgraded to provide new locale definitions (in which case see also `pg_import_system_collations()`).

23.2.2.3.2. ICU Collations

ICU allows collations to be customized beyond the basic language+country set that is preloaded by `initdb`. Users are encouraged to define their own collation objects that make use of these facilities to suit the sorting behavior to their requirements. See *https://unicode-org.github.io/icu/userguide/locale/* and *https://unicode-org.github.io/icu/userguide/collation/api.html* for information on ICU locale naming. The set of acceptable names and attributes depends on the particular ICU version.

Here are some examples:

```
CREATE COLLATION "de-u-co-phonebk-x-icu" (provider = icu, locale = 'de-u-co-phonebk');
CREATE COLLATION "de-u-co-phonebk-x-icu" (provider = icu, locale = 'de@collation=phonebook');
```

German collation with phone book collation type

The first example selects the ICU locale using a “language tag” per BCP 47. The second example uses the traditional ICU-specific locale syntax. The first style is preferred going forward, but it is not supported by older ICU versions.

Note that you can name the collation objects in the SQL environment anything you want. In this example, we follow the naming style that the predefined collations use, which in turn also follow BCP 47, but that is not required for user-defined collations.

```
CREATE COLLATION "und-u-co-emoji-x-icu" (provider = icu, locale = 'und-u-co-emoji');
CREATE COLLATION "und-u-co-emoji-x-icu" (provider = icu, locale = '@collation=emoji');
```

Root collation with Emoji collation type, per Unicode Technical Standard #51

Observe how in the traditional ICU locale naming system, the root locale is selected by an empty string.

```
CREATE COLLATION latn_cyrl (provider = icu, locale = 'ru-RU-u-kr-latn-cyrl');
CREATE COLLATION latn_cyrl (provider = icu, locale = 'ru@colReorder=latn-cyrl');
```

Sort Latin letters before Cyrillic ones. (The default is Cyrillic before Latin.)

```
CREATE COLLATION upperfirst (provider = icu, locale = 'ru-RU-u-kf-upper');
CREATE COLLATION upperfirst (provider = icu, locale = 'ru@colCaseFirst=upper');
```

Sort upper-case letters before lower-case letters. (The default is lower-case letters first.)

```
CREATE COLLATION special (provider = icu, locale = 'ru-RU-u-kf-upper-kr-latn-cyrl');
CREATE COLLATION special (provider = icu, locale = 'ru@colCaseFirst=upper;colReorder=latn-cyrl');
```

Combines both of the above options.

```
CREATE COLLATION numeric (provider = icu, locale = 'en-u-kn-true');
CREATE COLLATION numeric (provider = icu, locale = 'en@colNumeric=yes');
```

Numeric ordering, sorts sequences of digits by their numeric value, for example: `A-21` < `A-123` (also known as natural sort).

See *Unicode Technical Standard #35* and *BCP 47* for details. The list of possible collation types (`co` subtag) can be found in the *CLDR repository*.

Note that while this system allows creating collations that “ignore case” or “ignore accents” or similar (using the `ks` key), in order for such collations to act in a truly case- or accent-insensitive manner, they also need to be declared as not *deterministic* in `CREATE COLLATION`; see Section 23.2.2.4. Otherwise, any strings that compare equal according to the collation but are not byte-wise equal will be sorted according to their byte values.

> **Note**
>
> By design, ICU will accept almost any string as a locale name and match it to the closest locale it can provide, using the fallback procedure described in its documentation. Thus, there will be no direct feedback if a collation specification is composed using features that the given ICU installation does not actually support. It is therefore recommended to create application-level test cases to check that the collation definitions satisfy one's requirements.

23.2.2.3.3. Copying Collations

The command CREATE COLLATION can also be used to create a new collation from an existing collation, which can be useful to be able to use operating-system-independent collation names in applications, create compatibility names, or use an ICU-provided collation under a more readable name. For example:

```
CREATE COLLATION russian FROM "ru_RU";
CREATE COLLATION french FROM "fr-x-icu";
```

23.2.2.4. Nondeterministic Collations

A collation is either *deterministic* or *nondeterministic*. A deterministic collation uses deterministic comparisons, which means that it considers strings to be equal only if they consist of the same byte sequence. Nondeterministic comparison may determine strings to be equal even if they consist of different bytes. Typical situations include case-insensitive comparison, accent-insensitive comparison, as well as comparison of strings in different Unicode normal forms. It is up to the collation provider to actually implement such insensitive comparisons; the deterministic flag only determines whether ties are to be broken using bytewise comparison. See also *Unicode Technical Standard 10* for more information on the terminology.

To create a nondeterministic collation, specify the property `deterministic = false` to `CREATE COLLATION`, for example:

```
CREATE COLLATION ndcoll (provider = icu, locale = 'und', deterministic = false);
```

This example would use the standard Unicode collation in a nondeterministic way. In particular, this would allow strings in different normal forms to be compared correctly. More interesting examples make use of the ICU customization facilities explained above. For example:

```
CREATE COLLATION case_insensitive (provider = icu, locale = 'und-u-ks-level2',
 deterministic = false);
CREATE COLLATION ignore_accents (provider = icu, locale = 'und-u-ks-level1-kc-true',
 deterministic = false);
```

All standard and predefined collations are deterministic, all user-defined collations are deterministic by default. While nondeterministic collations give a more “correct” behavior, especially when considering the full power of Unicode and its many special cases, they also have some drawbacks. Foremost, their use leads to a performance penalty. Note, in particular, that B-tree cannot use deduplication with indexes that use a nondeterministic collation. Also, certain operations are not possible with nondeterministic collations, such as pattern matching operations. Therefore, they should be used only in cases where they are specifically wanted.

> **Tip**
>
> To deal with text in different Unicode normalization forms, it is also an option to use the functions/expressions `normalize` and `is normalized` to preprocess or check the strings, instead of using nondeterministic collations. There are different trade-offs for each approach.

23.3. Character Set Support

The character set support in Postgres Pro allows you to store text in a variety of character sets (also called encodings), including single-byte character sets such as the ISO 8859 series and multiple-byte character sets such as EUC (Extended Unix Code), UTF-8, and Mule internal code. All supported character sets can be used transparently by clients, but a few are not supported for use within the server (that is, as a server-side encoding). The default character set is selected while initializing your Postgres Pro database cluster using `initdb`. It can be overridden when you create a database, so you can have multiple databases each with a different character set.

An important restriction, however, is that each database's character set must be compatible with the database's `LC_CTYPE` (character classification) and `LC_COLLATE` (string sort order) locale settings. For `C` or `POSIX` locale, any character set is allowed, but for other libc-provided locales there is only one character set that will work correctly. (On Windows, however, UTF-8 encoding can be used with any locale.) If you have ICU support configured, ICU-provided locales can be used with most but not all server-side encodings.

23.3.1. Supported Character Sets

Table 23.1 shows the character sets available for use in Postgres Pro.

Table 23.1. Postgres Pro Character Sets

Name	Description	Language	Server?	ICU?	Bytes/ Char	Aliases
`BIG5`	Big Five	Traditional Chinese	No	No	1–2	`WIN950`, `Windows950`
`EUC_CN`	Extended UNIX Code-CN	Simplified Chinese	Yes	Yes	1–3	
`EUC_JP`	Extended UNIX Code-JP	Japanese	Yes	Yes	1–3	
`EUC_JIS_2004`	Extended UNIX Code-JP, JIS X 0213	Japanese	Yes	No	1–3	
`EUC_KR`	Extended UNIX Code-KR	Korean	Yes	Yes	1–3	
`EUC_TW`	Extended UNIX Code-TW	Traditional Chinese, Taiwanese	Yes	Yes	1–4	
`GB18030`	National Standard	Chinese	No	No	1–4	
`GBK`	Extended National Standard	Simplified Chinese	No	No	1–2	`WIN936`, `Windows936`
`ISO_8859_5`	ISO 8859-5, ECMA 113	Latin/Cyrillic	Yes	Yes	1	
`ISO_8859_6`	ISO 8859-6, ECMA 114	Latin/Arabic	Yes	Yes	1	

Name	Description	Language	Server?	ICU?	Bytes/ Char	Aliases
ISO_8859_7	ISO 8859-7, ECMA 118	Latin/Greek	Yes	Yes	1	
ISO_8859_8	ISO 8859-8, ECMA 121	Latin/Hebrew	Yes	Yes	1	
JOHAB	JOHAB	Korean (Hangul)	No	No	1–3	
KOI8R	KOI8-R	Cyrillic (Russ- ian)	Yes	Yes	1	KOI8
KOI8U	KOI8-U	Cyrillic (Ukrainian)	Yes	Yes	1	
LATIN1	ISO 8859-1, ECMA 94	Western Euro- pean	Yes	Yes	1	ISO88591
LATIN2	ISO 8859-2, ECMA 94	Central Euro- pean	Yes	Yes	1	ISO88592
LATIN3	ISO 8859-3, ECMA 94	South Euro- pean	Yes	Yes	1	ISO88593
LATIN4	ISO 8859-4, ECMA 94	North Euro- pean	Yes	Yes	1	ISO88594
LATIN5	ISO 8859-9, ECMA 128	Turkish	Yes	Yes	1	ISO88599
LATIN6	ISO 8859-10, ECMA 144	Nordic	Yes	Yes	1	ISO885910
LATIN7	ISO 8859-13	Baltic	Yes	Yes	1	ISO885913
LATIN8	ISO 8859-14	Celtic	Yes	Yes	1	ISO885914
LATIN9	ISO 8859-15	LATIN1 with Euro and ac- cents	Yes	Yes	1	ISO885915
LATIN10	ISO 8859-16, ASRO SR 14111	Romanian	Yes	No	1	ISO885916
MULE_INTERNAL	Mule internal code	Multilingual Emacs	Yes	No	1–4	
SJIS	Shift JIS	Japanese	No	No	1–2	Mskanji, ShiftJIS, WIN932, Win- dows932
SHIFT_JIS_2004	Shift JIS, JIS X 0213	Japanese	No	No	1–2	
SQL_ASCII	unspecified (see text)	*any*	Yes	No	1	
UHC	Unified Hangul Code	Korean	No	No	1–2	WIN949, Win- dows949
UTF8	Unicode, 8-bit	*all*	Yes	Yes	1–4	Unicode
WIN866	Windows CP866	Cyrillic	Yes	Yes	1	ALT

Name	Description	Language	Server?	ICU?	Bytes/ Char	Aliases
WIN874	Windows CP874	Thai	Yes	No	1	
WIN1250	Windows CP1250	Central European	Yes	Yes	1	
WIN1251	Windows CP1251	Cyrillic	Yes	Yes	1	WIN
WIN1252	Windows CP1252	Western European	Yes	Yes	1	
WIN1253	Windows CP1253	Greek	Yes	Yes	1	
WIN1254	Windows CP1254	Turkish	Yes	Yes	1	
WIN1255	Windows CP1255	Hebrew	Yes	Yes	1	
WIN1256	Windows CP1256	Arabic	Yes	Yes	1	
WIN1257	Windows CP1257	Baltic	Yes	Yes	1	
WIN1258	Windows CP1258	Vietnamese	Yes	Yes	1	ABC, TCVN, TCVN5712, VSCII

Not all client APIs support all the listed character sets. For example, the Postgres Pro JDBC driver does not support MULE_INTERNAL, LATIN6, LATIN8, and LATIN10.

The SQL_ASCII setting behaves considerably differently from the other settings. When the server character set is SQL_ASCII, the server interprets byte values 0–127 according to the ASCII standard, while byte values 128–255 are taken as uninterpreted characters. No encoding conversion will be done when the setting is SQL_ASCII. Thus, this setting is not so much a declaration that a specific encoding is in use, as a declaration of ignorance about the encoding. In most cases, if you are working with any non-ASCII data, it is unwise to use the SQL_ASCII setting because Postgres Pro will be unable to help you by converting or validating non-ASCII characters.

23.3.2. Setting the Character Set

initdb defines the default character set (encoding) for a Postgres Pro cluster. For example,

```
initdb -E EUC_JP
```

sets the default character set to EUC_JP (Extended Unix Code for Japanese). You can use --encoding instead of -E if you prefer longer option strings. If no -E or --encoding option is given, initdb attempts to determine the appropriate encoding to use based on the specified or default locale.

You can specify a non-default encoding at database creation time, provided that the encoding is compatible with the selected locale:

```
createdb -E EUC_KR -T template0 --lc-collate=ko_KR.euckr --lc-ctype=ko_KR.euckr korean
```

This will create a database named korean that uses the character set EUC_KR, and locale ko_KR. Another way to accomplish this is to use this SQL command:

```
CREATE DATABASE korean WITH ENCODING 'EUC_KR' LC_COLLATE='ko_KR.euckr'
 LC_CTYPE='ko_KR.euckr' TEMPLATE=template0;
```

Notice that the above commands specify copying the template0 database. When copying any other database, the encoding and locale settings cannot be changed from those of the source database, because that might result in corrupt data. For more information see Section 22.3.

The encoding for a database is stored in the system catalog `pg_database`. You can see it by using the `psql -l` option or the `\l` command.

```
$ psql -l
                                        List of databases
   Name    |  Owner   | Encoding  |  Collation  |    Ctype    |          Access
 Privileges
-----------+----------+-----------+-------------+-------------
+-----------------------------------
 clocaledb | hlinnaka | SQL_ASCII | C           | C           |
 englishdb | hlinnaka | UTF8      | en_GB.UTF8  | en_GB.UTF8  |
 japanese  | hlinnaka | UTF8      | ja_JP.UTF8  | ja_JP.UTF8  |
 korean    | hlinnaka | EUC_KR    | ko_KR.euckr | ko_KR.euckr |
 postgres  | hlinnaka | UTF8      | fi_FI.UTF8  | fi_FI.UTF8  |
 template0 | hlinnaka | UTF8      | fi_FI.UTF8  | fi_FI.UTF8  | {=c/
hlinnaka,hlinnaka=CTc/hlinnaka}
 template1 | hlinnaka | UTF8      | fi_FI.UTF8  | fi_FI.UTF8  | {=c/
hlinnaka,hlinnaka=CTc/hlinnaka}
(7 rows)
```

> **Important**
>
> On most modern operating systems, Postgres Pro can determine which character set is implied by the `LC_CTYPE` setting, and it will enforce that only the matching database encoding is used. On older systems it is your responsibility to ensure that you use the encoding expected by the locale you have selected. A mistake in this area is likely to lead to strange behavior of locale-dependent operations such as sorting.
>
> Postgres Pro will allow superusers to create databases with `SQL_ASCII` encoding even when `LC_CTYPE` is not `C` or `POSIX`. As noted above, `SQL_ASCII` does not enforce that the data stored in the database has any particular encoding, and so this choice poses risks of locale-dependent misbehavior. Using this combination of settings is deprecated and may someday be forbidden altogether.

23.3.3. Automatic Character Set Conversion Between Server and Client

Postgres Pro supports automatic character set conversion between server and client for many combinations of character sets (Section 23.3.4 shows which ones).

To enable automatic character set conversion, you have to tell Postgres Pro the character set (encoding) you would like to use in the client. There are several ways to accomplish this:

- Using the `\encoding` command in psql. `\encoding` allows you to change client encoding on the fly. For example, to change the encoding to `SJIS`, type:

  ```
  \encoding SJIS
  ```

- libpq (Section 36.11) has functions to control the client encoding.
- Using `SET client_encoding TO`. Setting the client encoding can be done with this SQL command:

  ```
  SET CLIENT_ENCODING TO 'value';
  ```

  Also you can use the standard SQL syntax `SET NAMES` for this purpose:

  ```
  SET NAMES 'value';
  ```

  To query the current client encoding:

  ```
  SHOW client_encoding;
  ```

  To return to the default encoding:

  ```
  RESET client_encoding;
  ```

- Using PGCLIENTENCODING. If the environment variable PGCLIENTENCODING is defined in the client's environment, that client encoding is automatically selected when a connection to the server is made. (This can subsequently be overridden using any of the other methods mentioned above.)
- Using the configuration variable client_encoding. If the client_encoding variable is set, that client encoding is automatically selected when a connection to the server is made. (This can subsequently be overridden using any of the other methods mentioned above.)

If the conversion of a particular character is not possible — suppose you chose EUC_JP for the server and LATIN1 for the client, and some Japanese characters are returned that do not have a representation in LATIN1 — an error is reported.

If the client character set is defined as SQL_ASCII, encoding conversion is disabled, regardless of the server's character set. (However, if the server's character set is not SQL_ASCII, the server will still check that incoming data is valid for that encoding; so the net effect is as though the client character set were the same as the server's.) Just as for the server, use of SQL_ASCII is unwise unless you are working with all-ASCII data.

23.3.4. Available Character Set Conversions

Postgres Pro allows conversion between any two character sets for which a conversion function is listed in the pg_conversion system catalog. Postgres Pro comes with some predefined conversions, as summarized in Table 23.2 and shown in more detail in Table 23.3. You can create a new conversion using the SQL command CREATE CONVERSION. (To be used for automatic client/server conversions, a conversion must be marked as “default” for its character set pair.)

Table 23.2. Built-in Client/Server Character Set Conversions

Server Character Set	Available Client Character Sets
BIG5	*not supported as a server encoding*
EUC_CN	*EUC_CN*, MULE_INTERNAL , UTF8
EUC_JP	*EUC_JP*, MULE_INTERNAL , SJIS, UTF8
EUC_JIS_2004	*EUC_JIS_2004*, SHIFT_JIS_2004 , UTF8
EUC_KR	*EUC_KR*, MULE_INTERNAL , UTF8
EUC_TW	*EUC_TW*, BIG5, MULE_INTERNAL , UTF8
GB18030	*not supported as a server encoding*
GBK	*not supported as a server encoding*
ISO_8859_5	*ISO_8859_5*, KOI8R, MULE_INTERNAL , UTF8, WIN866, WIN1251
ISO_8859_6	*ISO_8859_6*, UTF8
ISO_8859_7	*ISO_8859_7*, UTF8
ISO_8859_8	*ISO_8859_8*, UTF8
JOHAB	*not supported as a server encoding*
KOI8R	*KOI8R*, ISO_8859_5 , MULE_INTERNAL , UTF8, WIN866, WIN1251
KOI8U	*KOI8U*, UTF8
LATIN1	*LATIN1*, MULE_INTERNAL , UTF8
LATIN2	*LATIN2*, MULE_INTERNAL , UTF8, WIN1250
LATIN3	*LATIN3*, MULE_INTERNAL , UTF8
LATIN4	*LATIN4*, MULE_INTERNAL , UTF8
LATIN5	*LATIN5*, UTF8
LATIN6	*LATIN6*, UTF8
LATIN7	*LATIN7*, UTF8

Server Character Set	Available Client Character Sets
LATIN8	*LATIN8*, UTF8
LATIN9	*LATIN9*, UTF8
LATIN10	*LATIN10*, UTF8
MULE_INTERNAL	*MULE_INTERNAL*, BIG5, EUC_CN , EUC_JP , EUC_KR , EUC_TW , ISO_8859_5 , KOI8R, LATIN1 to LATIN4, SJIS, WIN866, WIN1250, WIN1251
SJIS	*not supported as a server encoding*
SHIFT_JIS_2004	*not supported as a server encoding*
SQL_ASCII	*any (no conversion will be performed)*
UHC	*not supported as a server encoding*
UTF8	*all supported encodings*
WIN866	*WIN866*, ISO_8859_5 , KOI8R, MULE_INTERNAL , UTF8, WIN1251
WIN874	*WIN874*, UTF8
WIN1250	*WIN1250*, LATIN2, MULE_INTERNAL , UTF8
WIN1251	*WIN1251*, ISO_8859_5 , KOI8R, MULE_INTERNAL , UTF8, WIN866
WIN1252	*WIN1252*, UTF8
WIN1253	*WIN1253*, UTF8
WIN1254	*WIN1254*, UTF8
WIN1255	*WIN1255*, UTF8
WIN1256	*WIN1256*, UTF8
WIN1257	*WIN1257*, UTF8
WIN1258	*WIN1258*, UTF8

Table 23.3. All Built-in Character Set Conversions

Conversion Name [a]	Source Encoding	Destination Encoding
big5_to_euc_tw	BIG5	EUC_TW
big5_to_mic	BIG5	MULE_INTERNAL
big5_to_utf8	BIG5	UTF8
euc_cn_to_mic	EUC_CN	MULE_INTERNAL
euc_cn_to_utf8	EUC_CN	UTF8
euc_jp_to_mic	EUC_JP	MULE_INTERNAL
euc_jp_to_sjis	EUC_JP	SJIS
euc_jp_to_utf8	EUC_JP	UTF8
euc_kr_to_mic	EUC_KR	MULE_INTERNAL
euc_kr_to_utf8	EUC_KR	UTF8
euc_tw_to_big5	EUC_TW	BIG5
euc_tw_to_mic	EUC_TW	MULE_INTERNAL
euc_tw_to_utf8	EUC_TW	UTF8
gb18030_to_utf8	GB18030	UTF8
gbk_to_utf8	GBK	UTF8
iso_8859_10_to_utf8	LATIN6	UTF8
iso_8859_13_to_utf8	LATIN7	UTF8

Conversion Name [a]	Source Encoding	Destination Encoding
iso_8859_14_to_utf8	LATIN8	UTF8
iso_8859_15_to_utf8	LATIN9	UTF8
iso_8859_16_to_utf8	LATIN10	UTF8
iso_8859_1_to_mic	LATIN1	MULE_INTERNAL
iso_8859_1_to_utf8	LATIN1	UTF8
iso_8859_2_to_mic	LATIN2	MULE_INTERNAL
iso_8859_2_to_utf8	LATIN2	UTF8
iso_8859_2_to_windows_1250	LATIN2	WIN1250
iso_8859_3_to_mic	LATIN3	MULE_INTERNAL
iso_8859_3_to_utf8	LATIN3	UTF8
iso_8859_4_to_mic	LATIN4	MULE_INTERNAL
iso_8859_4_to_utf8	LATIN4	UTF8
iso_8859_5_to_koi8_r	ISO_8859_5	KOI8R
iso_8859_5_to_mic	ISO_8859_5	MULE_INTERNAL
iso_8859_5_to_utf8	ISO_8859_5	UTF8
iso_8859_5_to_windows_1251	ISO_8859_5	WIN1251
iso_8859_5_to_windows_866	ISO_8859_5	WIN866
iso_8859_6_to_utf8	ISO_8859_6	UTF8
iso_8859_7_to_utf8	ISO_8859_7	UTF8
iso_8859_8_to_utf8	ISO_8859_8	UTF8
iso_8859_9_to_utf8	LATIN5	UTF8
johab_to_utf8	JOHAB	UTF8
koi8_r_to_iso_8859_5	KOI8R	ISO_8859_5
koi8_r_to_mic	KOI8R	MULE_INTERNAL
koi8_r_to_utf8	KOI8R	UTF8
koi8_r_to_windows_1251	KOI8R	WIN1251
koi8_r_to_windows_866	KOI8R	WIN866
koi8_u_to_utf8	KOI8U	UTF8
mic_to_big5	MULE_INTERNAL	BIG5
mic_to_euc_cn	MULE_INTERNAL	EUC_CN
mic_to_euc_jp	MULE_INTERNAL	EUC_JP
mic_to_euc_kr	MULE_INTERNAL	EUC_KR
mic_to_euc_tw	MULE_INTERNAL	EUC_TW
mic_to_iso_8859_1	MULE_INTERNAL	LATIN1
mic_to_iso_8859_2	MULE_INTERNAL	LATIN2
mic_to_iso_8859_3	MULE_INTERNAL	LATIN3
mic_to_iso_8859_4	MULE_INTERNAL	LATIN4
mic_to_iso_8859_5	MULE_INTERNAL	ISO_8859_5
mic_to_koi8_r	MULE_INTERNAL	KOI8R
mic_to_sjis	MULE_INTERNAL	SJIS

Conversion Name [a]	Source Encoding	Destination Encoding
mic_to_windows_1250	MULE_INTERNAL	WIN1250
mic_to_windows_1251	MULE_INTERNAL	WIN1251
mic_to_windows_866	MULE_INTERNAL	WIN866
sjis_to_euc_jp	SJIS	EUC_JP
sjis_to_mic	SJIS	MULE_INTERNAL
sjis_to_utf8	SJIS	UTF8
windows_1258_to_utf8	WIN1258	UTF8
uhc_to_utf8	UHC	UTF8
utf8_to_big5	UTF8	BIG5
utf8_to_euc_cn	UTF8	EUC_CN
utf8_to_euc_jp	UTF8	EUC_JP
utf8_to_euc_kr	UTF8	EUC_KR
utf8_to_euc_tw	UTF8	EUC_TW
utf8_to_gb18030	UTF8	GB18030
utf8_to_gbk	UTF8	GBK
utf8_to_iso_8859_1	UTF8	LATIN1
utf8_to_iso_8859_10	UTF8	LATIN6
utf8_to_iso_8859_13	UTF8	LATIN7
utf8_to_iso_8859_14	UTF8	LATIN8
utf8_to_iso_8859_15	UTF8	LATIN9
utf8_to_iso_8859_16	UTF8	LATIN10
utf8_to_iso_8859_2	UTF8	LATIN2
utf8_to_iso_8859_3	UTF8	LATIN3
utf8_to_iso_8859_4	UTF8	LATIN4
utf8_to_iso_8859_5	UTF8	ISO_8859_5
utf8_to_iso_8859_6	UTF8	ISO_8859_6
utf8_to_iso_8859_7	UTF8	ISO_8859_7
utf8_to_iso_8859_8	UTF8	ISO_8859_8
utf8_to_iso_8859_9	UTF8	LATIN5
utf8_to_johab	UTF8	JOHAB
utf8_to_koi8_r	UTF8	KOI8R
utf8_to_koi8_u	UTF8	KOI8U
utf8_to_sjis	UTF8	SJIS
utf8_to_windows_1258	UTF8	WIN1258
utf8_to_uhc	UTF8	UHC
utf8_to_windows_1250	UTF8	WIN1250
utf8_to_windows_1251	UTF8	WIN1251
utf8_to_windows_1252	UTF8	WIN1252
utf8_to_windows_1253	UTF8	WIN1253
utf8_to_windows_1254	UTF8	WIN1254

Conversion Name [a]	Source Encoding	Destination Encoding
utf8_to_windows_1255	UTF8	WIN1255
utf8_to_windows_1256	UTF8	WIN1256
utf8_to_windows_1257	UTF8	WIN1257
utf8_to_windows_866	UTF8	WIN866
utf8_to_windows_874	UTF8	WIN874
windows_1250_to_iso_8859_2	WIN1250	LATIN2
windows_1250_to_mic	WIN1250	MULE_INTERNAL
windows_1250_to_utf8	WIN1250	UTF8
windows_1251_to_iso_8859_5	WIN1251	ISO_8859_5
windows_1251_to_koi8_r	WIN1251	KOI8R
windows_1251_to_mic	WIN1251	MULE_INTERNAL
windows_1251_to_utf8	WIN1251	UTF8
windows_1251_to_windows_866	WIN1251	WIN866
windows_1252_to_utf8	WIN1252	UTF8
windows_1256_to_utf8	WIN1256	UTF8
windows_866_to_iso_8859_5	WIN866	ISO_8859_5
windows_866_to_koi8_r	WIN866	KOI8R
windows_866_to_mic	WIN866	MULE_INTERNAL
windows_866_to_utf8	WIN866	UTF8
windows_866_to_windows_1251	WIN866	WIN
windows_874_to_utf8	WIN874	UTF8
euc_jis_2004_to_utf8	EUC_JIS_2004	UTF8
utf8_to_euc_jis_2004	UTF8	EUC_JIS_2004
shift_jis_2004_to_utf8	SHIFT_JIS_2004	UTF8
utf8_to_shift_jis_2004	UTF8	SHIFT_JIS_2004
euc_jis_2004_to_shift_jis_2004	EUC_JIS_2004	SHIFT_JIS_2004
shift_jis_2004_to_euc_jis_2004	SHIFT_JIS_2004	EUC_JIS_2004

[a] The conversion names follow a standard naming scheme: The official name of the source encoding with all non-alphanumeric characters replaced by underscores, followed by `_to_`, followed by the similarly processed destination encoding name. Therefore, these names sometimes deviate from the customary encoding names shown in Table 23.1.

23.3.5. Further Reading

These are good sources to start learning about various kinds of encoding systems.

CJKV Information Processing: Chinese, Japanese, Korean & Vietnamese Computing

Contains detailed explanations of `EUC_JP`, `EUC_CN`, `EUC_KR`, `EUC_TW`.

https://www.unicode.org/

The web site of the Unicode Consortium.

RFC 3629

UTF-8 (8-bit UCS/Unicode Transformation Format) is defined here.

Chapter 24. Routine Database Maintenance Tasks

Postgres Pro, like any database software, requires that certain tasks be performed regularly to achieve optimum performance. The tasks discussed here are *required*, but they are repetitive in nature and can easily be automated using standard tools such as cron scripts or Windows' Task Scheduler. It is the database administrator's responsibility to set up appropriate scripts, and to check that they execute successfully.

One obvious maintenance task is the creation of backup copies of the data on a regular schedule. Without a recent backup, you have no chance of recovery after a catastrophe (disk failure, fire, mistakenly dropping a critical table, etc.). The backup and recovery mechanisms available in Postgres Pro are discussed at length in Chapter 25.

The other main category of maintenance task is periodic “vacuuming” of the database. This activity is discussed in Section 24.1. Closely related to this is updating the statistics that will be used by the query planner, as discussed in Section 24.1.3.

Another task that might need periodic attention is log file management. This is discussed in Section 24.3.

check_postgres is available for monitoring database health and reporting unusual conditions. check_postgres integrates with Nagios and MRTG, but can be run standalone too.

Postgres Pro is low-maintenance compared to some other database management systems. Nonetheless, appropriate attention to these tasks will go far towards ensuring a pleasant and productive experience with the system.

24.1. Routine Vacuuming

Postgres Pro databases require periodic maintenance known as *vacuuming*. For many installations, it is sufficient to let vacuuming be performed by the *autovacuum daemon*, which is described in Section 24.1.6. You might need to adjust the autovacuuming parameters described there to obtain best results for your situation. Some database administrators will want to supplement or replace the daemon's activities with manually-managed `VACUUM` commands, which typically are executed according to a schedule by cron or Task Scheduler scripts. To set up manually-managed vacuuming properly, it is essential to understand the issues discussed in the next few subsections. Administrators who rely on autovacuuming may still wish to skim this material to help them understand and adjust autovacuuming.

24.1.1. Vacuuming Basics

Postgres Pro's `VACUUM` command has to process each table on a regular basis for several reasons:

1. To recover or reuse disk space occupied by updated or deleted rows.
2. To update data statistics used by the Postgres Pro query planner.
3. To update the visibility map, which speeds up index-only scans.
4. To shrink `pg_xact` and `pg_multixact`.

Each of these reasons dictates performing `VACUUM` operations of varying frequency and scope, as explained in the following subsections.

There are two variants of `VACUUM`: standard `VACUUM` and `VACUUM FULL`. `VACUUM FULL` can reclaim more disk space but runs much more slowly. Also, the standard form of `VACUUM` can run in parallel with production database operations. (Commands such as `SELECT`, `INSERT`, `UPDATE`, and `DELETE` will continue to function normally, though you will not be able to modify the definition of a table with commands such as `ALTER TABLE` while it is being vacuumed.) `VACUUM FULL` requires an `ACCESS EXCLUSIVE` lock on the table it is

working on, and therefore cannot be done in parallel with other use of the table. Generally, therefore, administrators should strive to use standard VACUUM and avoid VACUUM FULL.

VACUUM creates a substantial amount of I/O traffic, which can cause poor performance for other active sessions. There are configuration parameters that can be adjusted to reduce the performance impact of background vacuuming — see Section 19.4.4.

24.1.2. Recovering Disk Space

In Postgres Pro, an UPDATE or DELETE of a row does not immediately remove the old version of the row. This approach is necessary to gain the benefits of multiversion concurrency control (MVCC, see Chapter 13): the row version must not be deleted while it is still potentially visible to other transactions. But eventually, an outdated or deleted row version is no longer of interest to any transaction. The space it occupies must then be reclaimed for reuse by new rows, to avoid unbounded growth of disk space requirements. This is done by running VACUUM.

The standard form of VACUUM removes dead row versions in tables and indexes and marks the space available for future reuse. However, it will not return the space to the operating system, except in the special case where one or more pages at the end of a table become entirely free and an exclusive table lock can be easily obtained. In contrast, VACUUM FULL actively compacts tables by writing a complete new version of the table file with no dead space. This minimizes the size of the table, but can take a long time. It also requires extra disk space for the new copy of the table, until the operation completes.

The usual goal of routine vacuuming is to do standard VACUUMs often enough to avoid needing VACUUM FULL. The autovacuum daemon attempts to work this way, and in fact will never issue VACUUM FULL. In this approach, the idea is not to keep tables at their minimum size, but to maintain steady-state usage of disk space: each table occupies space equivalent to its minimum size plus however much space gets used up between vacuum runs. Although VACUUM FULL can be used to shrink a table back to its minimum size and return the disk space to the operating system, there is not much point in this if the table will just grow again in the future. Thus, moderately-frequent standard VACUUM runs are a better approach than infrequent VACUUM FULL runs for maintaining heavily-updated tables.

Some administrators prefer to schedule vacuuming themselves, for example doing all the work at night when load is low. The difficulty with doing vacuuming according to a fixed schedule is that if a table has an unexpected spike in update activity, it may get bloated to the point that VACUUM FULL is really necessary to reclaim space. Using the autovacuum daemon alleviates this problem, since the daemon schedules vacuuming dynamically in response to update activity. It is unwise to disable the daemon completely unless you have an extremely predictable workload. One possible compromise is to set the daemon's parameters so that it will only react to unusually heavy update activity, thus keeping things from getting out of hand, while scheduled VACUUMs are expected to do the bulk of the work when the load is typical.

For those not using autovacuum, a typical approach is to schedule a database-wide VACUUM once a day during a low-usage period, supplemented by more frequent vacuuming of heavily-updated tables as necessary. (Some installations with extremely high update rates vacuum their busiest tables as often as once every few minutes.) If you have multiple databases in a cluster, don't forget to VACUUM each one; the program vacuumdb might be helpful.

> **Tip**
>
> Plain VACUUM may not be satisfactory when a table contains large numbers of dead row versions as a result of massive update or delete activity. If you have such a table and you need to reclaim the excess disk space it occupies, you will need to use VACUUM FULL, or alternatively CLUSTER or one of the table-rewriting variants of ALTER TABLE. These commands rewrite an entire new copy of the table and build new indexes for it. All these options require an ACCESS EXCLUSIVE lock. Note that they also temporarily use extra disk space approximately equal to the size of the table, since the old copies of the table and indexes can't be released until the new ones are complete.

> **Tip**
>
> If you have a table whose entire contents are deleted on a periodic basis, consider doing it with TRUNCATE rather than using DELETE followed by VACUUM. TRUNCATE removes the entire content of the table immediately, without requiring a subsequent VACUUM or VACUUM FULL to reclaim the now-unused disk space. The disadvantage is that strict MVCC semantics are violated.

24.1.3. Updating Planner Statistics

The Postgres Pro query planner relies on statistical information about the contents of tables in order to generate good plans for queries. These statistics are gathered by the ANALYZE command, which can be invoked by itself or as an optional step in VACUUM. It is important to have reasonably accurate statistics, otherwise poor choices of plans might degrade database performance.

The autovacuum daemon, if enabled, will automatically issue ANALYZE commands whenever the content of a table has changed sufficiently. However, administrators might prefer to rely on manually-scheduled ANALYZE operations, particularly if it is known that update activity on a table will not affect the statistics of “interesting” columns. The daemon schedules ANALYZE strictly as a function of the number of rows inserted or updated; it has no knowledge of whether that will lead to meaningful statistical changes.

Tuples changed in partitions and inheritance children do not trigger analyze on the parent table. If the parent table is empty or rarely changed, it may never be processed by autovacuum, and the statistics for the inheritance tree as a whole won't be collected. It is necessary to run ANALYZE on the parent table manually in order to keep the statistics up to date.

As with vacuuming for space recovery, frequent updates of statistics are more useful for heavily-updated tables than for seldom-updated ones. But even for a heavily-updated table, there might be no need for statistics updates if the statistical distribution of the data is not changing much. A simple rule of thumb is to think about how much the minimum and maximum values of the columns in the table change. For example, a timestamp column that contains the time of row update will have a constantly-increasing maximum value as rows are added and updated; such a column will probably need more frequent statistics updates than, say, a column containing URLs for pages accessed on a website. The URL column might receive changes just as often, but the statistical distribution of its values probably changes relatively slowly.

It is possible to run ANALYZE on specific tables and even just specific columns of a table, so the flexibility exists to update some statistics more frequently than others if your application requires it. In practice, however, it is usually best to just analyze the entire database, because it is a fast operation. ANALYZE uses a statistically random sampling of the rows of a table rather than reading every single row.

> **Tip**
>
> Although per-column tweaking of ANALYZE frequency might not be very productive, you might find it worthwhile to do per-column adjustment of the level of detail of the statistics collected by ANALYZE. Columns that are heavily used in WHERE clauses and have highly irregular data distributions might require a finer-grain data histogram than other columns. See ALTER TABLE SET STATISTICS, or change the database-wide default using the default_statistics_target configuration parameter.
>
> Also, by default there is limited information available about the selectivity of functions. However, if you create a statistics object or an expression index that uses a function call, useful statistics will be gathered about the function, which can greatly improve query plans that use the expression index.

> **Tip**
>
> The autovacuum daemon does not issue ANALYZE commands for foreign tables, since it has no means of determining how often that might be useful. If your queries require statistics on foreign

tables for proper planning, it's a good idea to run manually-managed `ANALYZE` commands on those tables on a suitable schedule.

Tip

The autovacuum daemon does not issue `ANALYZE` commands for partitioned tables. Inheritance parents will only be analyzed if the parent itself is changed - changes to child tables do not trigger autoanalyze on the parent table. If your queries require statistics on parent tables for proper planning, it is necessary to periodically run a manual `ANALYZE` on those tables to keep the statistics up to date.

24.1.4. Updating the Visibility Map

Vacuum maintains a visibility map for each table to keep track of which pages contain only tuples that are known to be visible to all active transactions (and all future transactions, until the page is again modified). This has two purposes. First, vacuum itself can skip such pages on the next run, since there is nothing to clean up.

Second, it allows Postgres Pro to answer some queries using only the index, without reference to the underlying table. Since Postgres Pro indexes don't contain tuple visibility information, a normal index scan fetches the heap tuple for each matching index entry, to check whether it should be seen by the current transaction. An *index-only scan*, on the other hand, checks the visibility map first. If it's known that all tuples on the page are visible, the heap fetch can be skipped. This is most useful on large data sets where the visibility map can prevent disk accesses. The visibility map is vastly smaller than the heap, so it can easily be cached even when the heap is very large.

24.1.5. Forced shrinking `pg_xact` and `pg_multixact`

Postgres Pro's MVCC transaction semantics depend on being able to compare transaction ID (XID) numbers: a row version with an insertion XID greater than the current transaction's XID is “in the future” and should not be visible to the current transaction.

Postgres Pro Enterprise 9.6 introduced 64-bit transaction IDs, which are not subject to wraparound and do not need modulo-2^{32} arithmetic to be compared. Each tuple header contains two XIDs, so extending them would lead to a significant overhead by occupying a lot of disk space. For that reason, when saved on disk on-tuple XIDs are 32-bit, but each page special area contains an offset, called *base XID*.

The reason that periodic vacuuming solves the problem is that `VACUUM` will mark rows as *frozen*, indicating that they were inserted by a transaction that committed sufficiently far in the past that the effects of the inserting transaction are certain to be visible to all current and future transactions. Postgres Pro reserves a special XID, `FrozenTransactionId`, which is always considered older than every normal XID. Frozen row versions are treated as if the inserting XID were `FrozenTransactionId`, so that they will appear to be “in the past” to all normal transactions.

When a new XID can't fit into the existing page according to its base XID, this offset is shifted. Single page freezing takes place if needed. Both actions are performed "on the fly". Page-level wraparound can happen only when someone holds snapshot, which has more than 4 billions transactions. Even in highly loaded systems that may have up to 2^32 transactions per day, it would take 2^31 days before the first enforced "vacuum to prevent wraparound". The routine vacuuming is not enforced, and a database administrator can plan this operation during periods of low system load and minimal impact on database performance. Moreover, it can be done less frequently on systems with transaction rates similar to those mentioned above: several times a year instead of every few days.

Freezing data by `VACUUM` is needed to shrink `pg_xact` and `pg_multixact`. For historical reasons, the wording "autovacuum to prevent wraparound" is preserved for forced autovacuum shrinking `pg_xact` and `pg_multixact`.

> **Note**
>
> In PostgreSQL versions before 9.4, freezing was implemented by actually replacing a row's insertion XID with `FrozenTransactionId`, which was visible in the row's `xmin` system column. Newer versions just set a flag bit, preserving the row's original `xmin` for possible forensic use. However, rows with `xmin` equal to `FrozenTransactionId` (2) may still be found in databases pg_upgrade'd from pre-9.4 versions.
>
> Also, system catalogs may contain rows with `xmin` equal to `BootstrapTransactionId` (1), indicating that they were inserted during the first phase of initdb. Like `FrozenTransactionId`, this special XID is treated as older than every normal XID.

vacuum_freeze_min_age controls how old an XID value has to be before rows bearing that XID will be frozen. Increasing this setting may avoid unnecessary work if the rows that would otherwise be frozen will soon be modified again, but decreasing this setting increases the number of transactions that can elapse before the table must be vacuumed again.

`VACUUM` uses the visibility map to determine which pages of a table must be scanned. Normally, it will skip pages that don't have any dead row versions even if those pages might still have row versions with old XID values. Therefore, normal `VACUUM`s won't always freeze every old row version in the table. Periodically, `VACUUM` will perform an *aggressive vacuum*, skipping only those pages which contain neither dead rows nor any unfrozen XID or MXID values. vacuum_freeze_table_age controls when `VACUUM` does that: all-visible but not all-frozen pages are scanned if the number of transactions that have passed since the last such scan is greater than `vacuum_freeze_table_age` minus `vacuum_freeze_min_age`. Setting `vacuum_freeze_table_age` to 0 forces `VACUUM` to use this more aggressive strategy for all scans.

Autovacuum is invoked on any table that might contain unfrozen rows with XIDs older than the age specified by the configuration parameter autovacuum_freeze_max_age. (This will happen even if autovacuum is disabled.)

This implies that if a table is not otherwise vacuumed, autovacuum will be invoked on it approximately once every `autovacuum_freeze_max_age` minus `vacuum_freeze_min_age` transactions. For tables that are regularly vacuumed for space reclamation purposes, this is of little importance. However, for static tables (including tables that receive inserts, but no updates or deletes), there is no need to vacuum for space reclamation, so it can be useful to try to maximize the interval between forced autovacuums on very large static tables. Obviously one can do this either by increasing `autovacuum_freeze_max_age` or decreasing `vacuum_freeze_min_age`.

The effective maximum for `vacuum_freeze_table_age` is 0.95 * `autovacuum_freeze_max_age`; a setting higher than that will be capped to the maximum. A value higher than `autovacuum_freeze_max_age` wouldn't make sense because an autovacuum to shrink `pg_xact` and `pg_multixact` would be triggered at that point anyway, and the 0.95 multiplier leaves some breathing room to run a manual `VACUUM` before that happens. As a rule of thumb, `vacuum_freeze_table_age` should be set to a value somewhat below `autovacuum_freeze_max_age`, leaving enough gap so that a regularly scheduled `VACUUM` or an autovacuum triggered by normal delete and update activity is run in that window. Setting it too close could lead to autovacuums to shrink `pg_xact` and `pg_multixact`, even though the table was recently vacuumed to reclaim space, whereas lower values lead to more frequent aggressive vacuuming.

The sole disadvantage of increasing `autovacuum_freeze_max_age` (and `vacuum_freeze_table_age` along with it) is that the `pg_xact` and `pg_commit_ts` subdirectories of the database cluster will take more space, because it must store the commit status and (if `track_commit_timestamp` is enabled) timestamp of all transactions back to the `autovacuum_freeze_max_age` horizon. The commit status uses two bits per transaction, so if `autovacuum_freeze_max_age` is set to its maximum allowed value of two billion, `pg_xact` can be expected to grow to about half a gigabyte and `pg_commit_ts` to about 20GB. If this is trivial compared to your total database size, setting `autovacuum_freeze_max_age` to its maximum allowed value is recommended. Otherwise, set it depending on what you are willing to allow for `pg_xact`

and pg_commit_ts storage. (The default, 200 million transactions, translates to about 50MB of pg_xact storage and about 2GB of pg_commit_ts storage.)

One disadvantage of decreasing vacuum_freeze_min_age is that it might cause VACUUM to do useless work: freezing a row version is a waste of time if the row is modified soon thereafter (causing it to acquire a new XID). So the setting should be large enough that rows are not frozen until they are unlikely to change any more.

To track the age of the oldest unfrozen XIDs in a database, VACUUM stores XID statistics in the system tables pg_class and pg_database. In particular, the relfrozenxid column of a table's pg_class row contains the freeze cutoff XID that was used by the last aggressive VACUUM for that table. All rows inserted by transactions with XIDs older than this cutoff XID are guaranteed to have been frozen. Similarly, the datfrozenxid column of a database's pg_database row is a lower bound on the unfrozen XIDs appearing in that database — it is just the minimum of the per-table relfrozenxid values within the database. A convenient way to examine this information is to execute queries such as:

```
SELECT c.oid::regclass as table_name,
       greatest(age(c.relfrozenxid),age(t.relfrozenxid)) as age
FROM pg_class c
LEFT JOIN pg_class t ON c.reltoastrelid = t.oid
WHERE c.relkind IN ('r', 'm');

SELECT datname, age(datfrozenxid) FROM pg_database;
```

The age column measures the number of transactions from the cutoff XID to the current transaction's XID.

VACUUM normally only scans pages that have been modified since the last vacuum, but relfrozenxid can only be advanced when every page of the table that might contain unfrozen XIDs is scanned. This happens when relfrozenxid is more than vacuum_freeze_table_age transactions old, when VACUUM's FREEZE option is used, or when all pages that are not already all-frozen happen to require vacuuming to remove dead row versions. When VACUUM scans every page in the table that is not already all-frozen, it should set age(relfrozenxid) to a value just a little more than the vacuum_freeze_min_age setting that was used (more by the number of transactions started since the VACUUM started). If no relfrozenxid-advancing VACUUM is issued on the table until autovacuum_freeze_max_age is reached, an autovacuum will soon be forced for the table.

24.1.5.1. Shrinking pg_multixact

Multixact IDs are used to support row locking by multiple transactions. Since there is only limited space in a tuple header to store lock information, that information is encoded as a "multiple transaction ID", or multixact ID for short, whenever there is more than one transaction concurrently locking a row. Information about which transaction IDs are included in any particular multixact ID is stored separately in the pg_multixact subdirectory, and only the multixact ID appears in the xmax field in the tuple header. Like transaction IDs, multixact IDs are implemented on disk page as a 64-bit counter with an offset, and corresponding storage, which requires careful aging management, and storage cleanup. There is a separate storage area which holds the list of members in each multixact, which uses a 64-bit counter.

Whenever VACUUM scans any part of a table, it will replace any multixact ID it encounters which is older than vacuum_multixact_freeze_min_age by a different value, which can be the zero value, a single transaction ID, or a newer multixact ID. For each table, pg_class.relminmxid stores the oldest possible multixact ID still appearing in any tuple of that table. If this value is older than vacuum_multixact_freeze_table_age, an aggressive vacuum is forced. As discussed in the previous section, an aggressive vacuum means that only those pages which are known to be all-frozen will be skipped. mxid_age() can be used on pg_class.relminmxid to find its age.

Aggressive VACUUM scans, regardless of what causes them, enable advancing the value for that table. Eventually, as all tables in all databases are scanned and their oldest multixact values are advanced, on-disk storage for older multixacts can be removed.

An aggressive vacuum scan will occur for any table whose multixact-age is greater than autovacuum_multixact_freeze_max_age.

24.1.6. The Autovacuum Daemon

Postgres Pro has an optional but highly recommended feature called *autovacuum*, whose purpose is to automate the execution of VACUUM and ANALYZE commands. When enabled, autovacuum checks for tables that have had a large number of inserted, updated or deleted tuples. These checks use the statistics collection facility; therefore, autovacuum cannot be used unless track_counts is set to true. In the default configuration, autovacuuming is enabled and the related configuration parameters are appropriately set.

The "autovacuum daemon" actually consists of multiple processes. There is a persistent daemon process, called the *autovacuum launcher*, which is in charge of starting *autovacuum worker* processes for all databases. The launcher will distribute the work across time, attempting to start one worker within each database every autovacuum_naptime seconds. (Therefore, if the installation has *N* databases, a new worker will be launched every autovacuum_naptime/*N* seconds.) A maximum of autovacuum_max_workers worker processes are allowed to run at the same time. If there are more than autovacuum_max_workers databases to be processed, the next database will be processed as soon as the first worker finishes. Each worker process will check each table within its database and execute VACUUM and/or ANALYZE as needed. log_autovacuum_min_duration can be set to monitor autovacuum workers' activity.

If several large tables all become eligible for vacuuming in a short amount of time, all autovacuum workers might become occupied with vacuuming those tables for a long period. This would result in other tables and databases not being vacuumed until a worker becomes available. There is no limit on how many workers might be in a single database, but workers do try to avoid repeating work that has already been done by other workers. Note that the number of running workers does not count towards max_connections or superuser_reserved_connections limits.

Tables whose relfrozenxid value is more than autovacuum_freeze_max_age transactions old are always vacuumed (this also applies to those tables whose freeze max age has been modified via storage parameters; see below). Otherwise, if the number of tuples obsoleted since the last VACUUM exceeds the "vacuum threshold", the table is vacuumed. The vacuum threshold is defined as:

```
vacuum threshold = vacuum base threshold + vacuum scale factor * number of tuples
```

where the vacuum base threshold is autovacuum_vacuum_threshold, the vacuum scale factor is autovacuum_vacuum_scale_factor, and the number of tuples is pg_class.reltuples.

The table is also vacuumed if the number of tuples inserted since the last vacuum has exceeded the defined insert threshold, which is defined as:

```
vacuum insert threshold = vacuum base insert threshold + vacuum insert scale factor *
 number of tuples
```

where the vacuum insert base threshold is autovacuum_vacuum_insert_threshold, and vacuum insert scale factor is autovacuum_vacuum_insert_scale_factor. Such vacuums may allow portions of the table to be marked as *all visible* and also allow tuples to be frozen, which can reduce the work required in subsequent vacuums. For tables which receive INSERT operations but no or almost no UPDATE/DELETE operations, it may be beneficial to lower the table's autovacuum_freeze_min_age as this may allow tuples to be frozen by earlier vacuums. The number of obsolete tuples and the number of inserted tuples are obtained from the statistics collector; it is a semi-accurate count updated by each UPDATE, DELETE and INSERT operation. (It is only semi-accurate because some information might be lost under heavy load.) If the relfrozenxid value of the table is more than vacuum_freeze_table_age transactions old, an aggressive vacuum is performed to freeze old tuples and advance relfrozenxid; otherwise, only pages that have been modified since the last vacuum are scanned.

For analyze, a similar condition is used: the threshold, defined as:

```
analyze threshold = analyze base threshold + analyze scale factor * number of tuples
```

is compared to the total number of tuples inserted, updated, or deleted since the last ANALYZE.

Partitioned tables do not directly store tuples and consequently are not processed by autovacuum. (Autovacuum does process table partitions just like other tables.) Unfortunately, this means that autovacuum does not run ANALYZE on partitioned tables, and this can cause suboptimal plans for queries that reference partitioned table statistics. You can work around this problem by manually running ANALYZE on partitioned tables when they are first populated, and again whenever the distribution of data in their partitions changes significantly.

Temporary tables cannot be accessed by autovacuum. Therefore, appropriate vacuum and analyze operations should be performed via session SQL commands.

The default thresholds and scale factors are taken from postgresql.conf, but it is possible to override them (and many other autovacuum control parameters) on a per-table basis; see Storage Parameters for more information. If a setting has been changed via a table's storage parameters, that value is used when processing that table; otherwise the global settings are used. See Section 19.10 for more details on the global settings.

When multiple workers are running, the autovacuum cost delay parameters (see Section 19.4.4) are "balanced" among all the running workers, so that the total I/O impact on the system is the same regardless of the number of workers actually running. However, any workers processing tables whose per-table autovacuum_vacuum_cost_delay or autovacuum_vacuum_cost_limit storage parameters have been set are not considered in the balancing algorithm.

Autovacuum workers generally don't block other commands. If a process attempts to acquire a lock that conflicts with the SHARE UPDATE EXCLUSIVE lock held by autovacuum, lock acquisition will interrupt the autovacuum. For conflicting lock modes, see Table 13.2. However, if the autovacuum is running to prevent transaction ID wraparound (i.e., the autovacuum query name in the pg_stat_activity view ends with (to prevent wraparound)), the autovacuum is not automatically interrupted.

> **Warning**
>
> Regularly running commands that acquire locks conflicting with a SHARE UPDATE EXCLUSIVE lock (e.g., ANALYZE) can effectively prevent autovacuums from ever completing.

24.2. Routine Reindexing

In some situations it is worthwhile to rebuild indexes periodically with the REINDEX command or a series of individual rebuilding steps.

B-tree index pages that have become completely empty are reclaimed for re-use. However, there is still a possibility of inefficient use of space: if all but a few index keys on a page have been deleted, the page remains allocated. Therefore, a usage pattern in which most, but not all, keys in each range are eventually deleted will see poor use of space. For such usage patterns, periodic reindexing is recommended.

The potential for bloat in non-B-tree indexes has not been well researched. It is a good idea to periodically monitor the index's physical size when using any non-B-tree index type.

Also, for B-tree indexes, a freshly-constructed index is slightly faster to access than one that has been updated many times because logically adjacent pages are usually also physically adjacent in a newly built index. (This consideration does not apply to non-B-tree indexes.) It might be worthwhile to reindex periodically just to improve access speed.

REINDEX can be used safely and easily in all cases. This command requires an ACCESS EXCLUSIVE lock by default, hence it is often preferable to execute it with its CONCURRENTLY option, which requires only a SHARE UPDATE EXCLUSIVE lock.

24.3. Log File Maintenance

It is a good idea to save the database server's log output somewhere, rather than just discarding it via `/dev/null`. The log output is invaluable when diagnosing problems.

> **Note**
>
> The server log can contain sensitive information and needs to be protected, no matter how or where it is stored, or the destination to which it is routed. For example, some DDL statements might contain plaintext passwords or other authentication details. Logged statements at the `ERROR` level might show the SQL source code for applications and might also contain some parts of data rows. Recording data, events and related information is the intended function of this facility, so this is not a leakage or a bug. Please ensure the server logs are visible only to appropriately authorized people.

Log output tends to be voluminous (especially at higher debug levels) so you won't want to save it indefinitely. You need to *rotate* the log files so that new log files are started and old ones removed after a reasonable period of time.

If you simply direct the stderr of `postgres` into a file, you will have log output, but the only way to truncate the log file is to stop and restart the server. This might be acceptable if you are using Postgres Pro in a development environment, but few production servers would find this behavior acceptable.

A better approach is to send the server's stderr output to some type of log rotation program. There is a built-in log rotation facility, which you can use by setting the configuration parameter `logging_collector` to `true` in `postgresql.conf`. The control parameters for this program are described in Section 19.8.1. You can also use this approach to capture the log data in machine readable CSV (comma-separated values) format.

Alternatively, you might prefer to use an external log rotation program if you have one that you are already using with other server software. For example, the rotatelogs tool included in the Apache distribution can be used with Postgres Pro. One way to do this is to pipe the server's stderr output to the desired program. If you start the server with `pg_ctl`, then stderr is already redirected to stdout, so you just need a pipe command, for example:

```
pg_ctl start | rotatelogs /var/log/pgsql_log 86400
```

You can combine these approaches by setting up logrotate to collect log files produced by Postgres Pro built-in logging collector. In this case, the logging collector defines the names and location of the log files, while logrotate periodically archives these files. When initiating log rotation, logrotate must ensure that the application sends further output to the new file. This is commonly done with a `postrotate` script that sends a `SIGHUP` signal to the application, which then reopens the log file. In Postgres Pro, you can run `pg_ctl` with the `logrotate` option instead. When the server receives this command, the server either switches to a new log file or reopens the existing file, depending on the logging configuration (see Section 19.8.1).

> **Note**
>
> When using static log file names, the server might fail to reopen the log file if the max open file limit is reached or a file table overflow occurs. In this case, log messages are sent to the old log file until a successful log rotation. If logrotate is configured to compress the log file and delete it, the server may lose the messages logged in this time frame. To avoid this issue, you can configure the logging collector to dynamically assign log file names and use a `prerotate` script to ignore open log files.

Another production-grade approach to managing log output is to send it to syslog and let syslog deal with file rotation. To do this, set the configuration parameter `log_destination` to `syslog` (to log to syslog only) in `postgresql.conf`. Then you can send a `SIGHUP` signal to the syslog daemon whenever you want

to force it to start writing a new log file. If you want to automate log rotation, the logrotate program can be configured to work with log files from syslog.

On many systems, however, syslog is not very reliable, particularly with large log messages; it might truncate or drop messages just when you need them the most. Also, on Linux, syslog will flush each message to disk, yielding poor performance. (You can use a "–" at the start of the file name in the syslog configuration file to disable syncing.)

Note that all the solutions described above take care of starting new log files at configurable intervals, but they do not handle deletion of old, no-longer-useful log files. You will probably want to set up a batch job to periodically delete old log files. Another possibility is to configure the rotation program so that old log files are overwritten cyclically.

pgbadger does sophisticated log file analysis. *check_postgres* provides Nagios alerts when important messages appear in the log files, as well as detection of many other extraordinary conditions.

Chapter 25. Backup and Restore

As with everything that contains valuable data, Postgres Pro databases should be backed up regularly. While the procedure is essentially simple, it is important to have a clear understanding of the underlying techniques and assumptions.

There are three fundamentally different approaches to backing up Postgres Pro data:

- SQL dump
- File system level backup
- Continuous archiving

Each has its own strengths and weaknesses; each is discussed in turn in the following sections.

25.1. SQL Dump

The idea behind this dump method is to generate a file with SQL commands that, when fed back to the server, will recreate the database in the same state as it was at the time of the dump. Postgres Pro provides the utility program pg_dump for this purpose. The basic usage of this command is:

```
pg_dump dbname > dumpfile
```

As you see, pg_dump writes its result to the standard output. We will see below how this can be useful. While the above command creates a text file, pg_dump can create files in other formats that allow for parallelism and more fine-grained control of object restoration.

pg_dump is a regular Postgres Pro client application (albeit a particularly clever one). This means that you can perform this backup procedure from any remote host that has access to the database. But remember that pg_dump does not operate with special permissions. In particular, it must have read access to all tables that you want to back up, so in order to back up the entire database you almost always have to run it as a database superuser. (If you do not have sufficient privileges to back up the entire database, you can still back up portions of the database to which you do have access using options such as `-n schema` or `-t table`.)

To specify which database server pg_dump should contact, use the command line options `-h host` and `-p port`. The default host is the local host or whatever your `PGHOST` environment variable specifies. Similarly, the default port is indicated by the `PGPORT` environment variable or, failing that, by the compiled-in default. (Conveniently, the server will normally have the same compiled-in default.)

Like any other Postgres Pro client application, pg_dump will by default connect with the database user name that is equal to the current operating system user name. To override this, either specify the `-U` option or set the environment variable `PGUSER`. Remember that pg_dump connections are subject to the normal client authentication mechanisms (which are described in Chapter 20).

An important advantage of pg_dump over the other backup methods described later is that pg_dump's output can generally be re-loaded into newer versions of Postgres Pro, whereas file-level backups and continuous archiving are both extremely server-version-specific. pg_dump is also the only method that will work when transferring a database to a different machine architecture, such as going from a 32-bit to a 64-bit server.

Dumps created by pg_dump are internally consistent, meaning, the dump represents a snapshot of the database at the time pg_dump began running. pg_dump does not block other operations on the database while it is working. (Exceptions are those operations that need to operate with an exclusive lock, such as most forms of `ALTER TABLE`.)

25.1.1. Restoring the Dump

Text files created by pg_dump are intended to be read by the psql program using its default settings. The general command form to restore a text dump is

```
psql -X dbname < dumpfile
```

where *dumpfile* is the file output by the pg_dump command. The database *dbname* will not be created by this command, so you must create it yourself from `template0` before executing psql (e.g., with `createdb -T template0 dbname`). To ensure psql runs with its default settings, use the `-X` (`--no-psqlrc`) option. psql supports options similar to pg_dump for specifying the database server to connect to and the user name to use. See the psql reference page for more information.

Non-text file dumps should be restored using the pg_restore utility.

Before restoring an SQL dump, all the users who own objects or were granted permissions on objects in the dumped database must already exist. If they do not, the restore will fail to recreate the objects with the original ownership and/or permissions. (Sometimes this is what you want, but usually it is not.)

By default, the psql script will continue to execute after an SQL error is encountered. You might wish to run psql with the `ON_ERROR_STOP` variable set to alter that behavior and have psql exit with an exit status of 3 if an SQL error occurs:

```
psql -X --set ON_ERROR_STOP=on dbname < dumpfile
```

Either way, you will only have a partially restored database. Alternatively, you can specify that the whole dump should be restored as a single transaction, so the restore is either fully completed or fully rolled back. This mode can be specified by passing the `-1` or `--single-transaction` command-line options to psql. When using this mode, be aware that even a minor error can rollback a restore that has already run for many hours. However, that might still be preferable to manually cleaning up a complex database after a partially restored dump.

The ability of pg_dump and psql to write to or read from pipes makes it possible to dump a database directly from one server to another, for example:

```
pg_dump -h host1 dbname | psql -X -h host2 dbname
```

> **Important**
>
> The dumps produced by pg_dump are relative to `template0`. This means that any languages, procedures, etc. added via `template1` will also be dumped by pg_dump. As a result, when restoring, if you are using a customized `template1`, you must create the empty database from `template0`, as in the example above.

After restoring a backup, it is wise to run `ANALYZE` on each database so the query optimizer has useful statistics; see Section 24.1.3 and Section 24.1.6 for more information. For more advice on how to load large amounts of data into Postgres Pro efficiently, refer to Section 14.4.

25.1.2. Using pg_dumpall

pg_dump dumps only a single database at a time, and it does not dump information about roles or tablespaces (because those are cluster-wide rather than per-database). To support convenient dumping of the entire contents of a database cluster, the pg_dumpall program is provided. pg_dumpall backs up each database in a given cluster, and also preserves cluster-wide data such as role and tablespace definitions. The basic usage of this command is:

```
pg_dumpall > dumpfile
```

The resulting dump can be restored with psql:

```
psql -X -f dumpfile postgres
```

(Actually, you can specify any existing database name to start from, but if you are loading into an empty cluster then `postgres` should usually be used.) It is always necessary to have database superuser access when restoring a pg_dumpall dump, as that is required to restore the role and tablespace information. If you use tablespaces, make sure that the tablespace paths in the dump are appropriate for the new installation.

pg_dumpall works by emitting commands to re-create roles, tablespaces, and empty databases, then invoking pg_dump for each database. This means that while each database will be internally consistent, the snapshots of different databases are not synchronized.

Cluster-wide data can be dumped alone using the pg_dumpall `--globals-only` option. This is necessary to fully backup the cluster if running the pg_dump command on individual databases.

25.1.3. Handling Large Databases

Some operating systems have maximum file size limits that cause problems when creating large pg_dump output files. Fortunately, pg_dump can write to the standard output, so you can use standard Unix tools to work around this potential problem. There are several possible methods:

Use compressed dumps. You can use your favorite compression program, for example gzip:

```
pg_dump dbname | gzip > filename.gz
```

Reload with:

```
gunzip -c filename.gz | psql dbname
```

or:

```
cat filename.gz | gunzip | psql dbname
```

Use `split`. The `split` command allows you to split the output into smaller files that are acceptable in size to the underlying file system. For example, to make 2 gigabyte chunks:

```
pg_dump dbname | split -b 2G - filename
```

Reload with:

```
cat filename* | psql dbname
```

If using GNU split, it is possible to use it and gzip together:

```
pg_dump dbname | split -b 2G --filter='gzip > $FILE.gz'
```

It can be restored using `zcat`.

Use pg_dump's custom dump format. If Postgres Pro was built on a system with the zlib compression library installed, the custom dump format will compress data as it writes it to the output file. This will produce dump file sizes similar to using `gzip`, but it has the added advantage that tables can be restored selectively. The following command dumps a database using the custom dump format:

```
pg_dump -Fc dbname > filename
```

A custom-format dump is not a script for psql, but instead must be restored with pg_restore, for example:

```
pg_restore -d dbname filename
```

See the pg_dump and pg_restore reference pages for details.

For very large databases, you might need to combine `split` with one of the other two approaches.

Use pg_dump's parallel dump feature. To speed up the dump of a large database, you can use pg_dump's parallel mode. This will dump multiple tables at the same time. You can control the degree of parallelism with the `-j` parameter. Parallel dumps are only supported for the "directory" archive format.

```
pg_dump -j num -F d -f out.dir dbname
```

You can use `pg_restore -j` to restore a dump in parallel. This will work for any archive of either the "custom" or the "directory" archive mode, whether or not it has been created with `pg_dump -j`.

25.2. File System Level Backup

An alternative backup strategy is to directly copy the files that Postgres Pro uses to store the data in the database; Section 18.2 explains where these files are located. You can use whatever method you prefer for doing file system backups; for example:

```
tar -cf backup.tar /usr/local/pgsql/data
```

There are two restrictions, however, which make this method impractical, or at least inferior to the pg_dump method:

1. The database server *must* be shut down in order to get a usable backup. Half-way measures such as disallowing all connections will *not* work (in part because `tar` and similar tools do not take an atomic snapshot of the state of the file system, but also because of internal buffering within the server). Information about stopping the server can be found in Section 18.5. Needless to say, you also need to shut down the server before restoring the data.
2. If you have dug into the details of the file system layout of the database, you might be tempted to try to back up or restore only certain individual tables or databases from their respective files or directories. This will *not* work because the information contained in these files is not usable without the commit log files, `pg_xact/*`, which contain the commit status of all transactions. A table file is only usable with this information. Of course it is also impossible to restore only a table and the associated `pg_xact` data because that would render all other tables in the database cluster useless. So file system backups only work for complete backup and restoration of an entire database cluster.

An alternative file-system backup approach is to make a “consistent snapshot” of the data directory, if the file system supports that functionality (and you are willing to trust that it is implemented correctly). The typical procedure is to make a “frozen snapshot” of the volume containing the database, then copy the whole data directory (not just parts, see above) from the snapshot to a backup device, then release the frozen snapshot. This will work even while the database server is running. However, a backup created in this way saves the database files in a state as if the database server was not properly shut down; therefore, when you start the database server on the backed-up data, it will think the previous server instance crashed and will replay the WAL log. This is not a problem; just be aware of it (and be sure to include the WAL files in your backup). You can perform a `CHECKPOINT` before taking the snapshot to reduce recovery time.

If your database is spread across multiple file systems, there might not be any way to obtain exactly-simultaneous frozen snapshots of all the volumes. For example, if your data files and WAL log are on different disks, or if tablespaces are on different file systems, it might not be possible to use snapshot backup because the snapshots *must* be simultaneous. Read your file system documentation very carefully before trusting the consistent-snapshot technique in such situations.

If simultaneous snapshots are not possible, one option is to shut down the database server long enough to establish all the frozen snapshots. Another option is to perform a continuous archiving base backup (Section 25.3.2) because such backups are immune to file system changes during the backup. This requires enabling continuous archiving just during the backup process; restore is done using continuous archive recovery (Section 25.3.4).

Another option is to use rsync to perform a file system backup. This is done by first running rsync while the database server is running, then shutting down the database server long enough to do an `rsync --checksum`. (`--checksum` is necessary because `rsync` only has file modification-time granularity of one second.) The second rsync will be quicker than the first, because it has relatively little data to transfer, and the end result will be consistent because the server was down. This method allows a file system backup to be performed with minimal downtime.

Note that a file system backup will typically be larger than an SQL dump. (pg_dump does not need to dump the contents of indexes for example, just the commands to recreate them.) However, taking a file system backup might be faster.

25.3. Continuous Archiving and Point-in-Time Recovery (PITR)

At all times, Postgres Pro maintains a *write ahead log* (WAL) in the `pg_wal/` subdirectory of the cluster's data directory. The log records every change made to the database's data files. This log exists primarily for crash-safety purposes: if the system crashes, the database can be restored to consistency by “replay-

ing" the log entries made since the last checkpoint. However, the existence of the log makes it possible to use a third strategy for backing up databases: we can combine a file-system-level backup with backup of the WAL files. If recovery is needed, we restore the file system backup and then replay from the backed-up WAL files to bring the system to a current state. This approach is more complex to administer than either of the previous approaches, but it has some significant benefits:

- We do not need a perfectly consistent file system backup as the starting point. Any internal inconsistency in the backup will be corrected by log replay (this is not significantly different from what happens during crash recovery). So we do not need a file system snapshot capability, just tar or a similar archiving tool.
- Since we can combine an indefinitely long sequence of WAL files for replay, continuous backup can be achieved simply by continuing to archive the WAL files. This is particularly valuable for large databases, where it might not be convenient to take a full backup frequently.
- It is not necessary to replay the WAL entries all the way to the end. We could stop the replay at any point and have a consistent snapshot of the database as it was at that time. Thus, this technique supports *point-in-time recovery*: it is possible to restore the database to its state at any time since your base backup was taken.
- If we continuously feed the series of WAL files to another machine that has been loaded with the same base backup file, we have a *warm standby* system: at any point we can bring up the second machine and it will have a nearly-current copy of the database.

> **Note**
>
> pg_dump and pg_dumpall do not produce file-system-level backups and cannot be used as part of a continuous-archiving solution. Such dumps are *logical* and do not contain enough information to be used by WAL replay.

As with the plain file-system-backup technique, this method can only support restoration of an entire database cluster, not a subset. Also, it requires a lot of archival storage: the base backup might be bulky, and a busy system will generate many megabytes of WAL traffic that have to be archived. Still, it is the preferred backup technique in many situations where high reliability is needed.

To recover successfully using continuous archiving (also called "online backup" by many database vendors), you need a continuous sequence of archived WAL files that extends back at least as far as the start time of your backup. So to get started, you should set up and test your procedure for archiving WAL files *before* you take your first base backup. Accordingly, we first discuss the mechanics of archiving WAL files.

25.3.1. Setting Up WAL Archiving

In an abstract sense, a running Postgres Pro system produces an indefinitely long sequence of WAL records. The system physically divides this sequence into WAL *segment files*, which are normally 16MB apiece (although the segment size can be altered during initdb). The segment files are given numeric names that reflect their position in the abstract WAL sequence. When not using WAL archiving, the system normally creates just a few segment files and then "recycles" them by renaming no-longer-needed segment files to higher segment numbers. It's assumed that segment files whose contents precede the last checkpoint are no longer of interest and can be recycled.

When archiving WAL data, we need to capture the contents of each segment file once it is filled, and save that data somewhere before the segment file is recycled for reuse. Depending on the application and the available hardware, there could be many different ways of "saving the data somewhere": we could copy the segment files to an NFS-mounted directory on another machine, write them onto a tape drive (ensuring that you have a way of identifying the original name of each file), or batch them together and burn them onto CDs, or something else entirely. To provide the database administrator with flexibility, Postgres Pro tries not to make any assumptions about how the archiving will be done. Instead, Postgres Pro lets the administrator specify a shell command to be executed to copy a completed segment file to

wherever it needs to go. The command could be as simple as a `cp`, or it could invoke a complex shell script — it's all up to you.

To enable WAL archiving, set the wal_level configuration parameter to `replica` or higher, archive_mode to `on`, and specify the shell command to use in the archive_command configuration parameter. In practice these settings will always be placed in the `postgresql.conf` file. In `archive_command`, `%p` is replaced by the path name of the file to archive, while `%f` is replaced by only the file name. (The path name is relative to the current working directory, i.e., the cluster's data directory.) Use `%%` if you need to embed an actual `%` character in the command. The simplest useful command is something like:

```
archive_command = 'test ! -f /mnt/server/archivedir/%f && cp %p /mnt/server/archivedir/
%f'  # Unix
archive_command = 'copy "%p" "C:\\server\\archivedir\\%f"'  # Windows
```

which will copy archivable WAL segments to the directory `/mnt/server/archivedir`. (This is an example, not a recommendation, and might not work on all platforms.) After the `%p` and `%f` parameters have been replaced, the actual command executed might look like this:

```
test ! -f /mnt/server/archivedir/000000010000000A900000065 && cp
 pg_wal/000000010000000A900000065 /mnt/server/archivedir/000000010000000A900000065
```

A similar command will be generated for each new file to be archived.

The archive command will be executed under the ownership of the same user that the Postgres Pro server is running as. Since the series of WAL files being archived contains effectively everything in your database, you will want to be sure that the archived data is protected from prying eyes; for example, archive into a directory that does not have group or world read access.

It is important that the archive command return zero exit status if and only if it succeeds. Upon getting a zero result, Postgres Pro will assume that the file has been successfully archived, and will remove or recycle it. However, a nonzero status tells Postgres Pro that the file was not archived; it will try again periodically until it succeeds.

When the archive command is terminated by a signal (other than SIGTERM that is used as part of a server shutdown) or an error by the shell with an exit status greater than 125 (such as command not found), the archiver process aborts and gets restarted by the postmaster. In such cases, the failure is not reported in pg_stat_archiver.

The archive command should generally be designed to refuse to overwrite any pre-existing archive file. This is an important safety feature to preserve the integrity of your archive in case of administrator error (such as sending the output of two different servers to the same archive directory).

It is advisable to test your proposed archive command to ensure that it indeed does not overwrite an existing file, *and that it returns nonzero status in this case*. The example command above for Unix ensures this by including a separate `test` step. On some Unix platforms, `cp` has switches such as `-i` that can be used to do the same thing less verbosely, but you should not rely on these without verifying that the right exit status is returned. (In particular, GNU `cp` will return status zero when `-i` is used and the target file already exists, which is *not* the desired behavior.)

While designing your archiving setup, consider what will happen if the archive command fails repeatedly because some aspect requires operator intervention or the archive runs out of space. For example, this could occur if you write to tape without an autochanger; when the tape fills, nothing further can be archived until the tape is swapped. You should ensure that any error condition or request to a human operator is reported appropriately so that the situation can be resolved reasonably quickly. The `pg_wal/` directory will continue to fill with WAL segment files until the situation is resolved. (If the file system containing `pg_wal/` fills up, Postgres Pro will do a PANIC shutdown. No committed transactions will be lost, but the database will remain offline until you free some space.)

The speed of the archiving command is unimportant as long as it can keep up with the average rate at which your server generates WAL data. Normal operation continues even if the archiving process falls a little behind. If archiving falls significantly behind, this will increase the amount of data that would be lost in the event of a disaster. It will also mean that the `pg_wal/` directory will contain large numbers of

not-yet-archived segment files, which could eventually exceed available disk space. You are advised to monitor the archiving process to ensure that it is working as you intend.

In writing your archive command, you should assume that the file names to be archived can be up to 64 characters long and can contain any combination of ASCII letters, digits, and dots. It is not necessary to preserve the original relative path (`%p`) but it is necessary to preserve the file name (`%f`).

Note that although WAL archiving will allow you to restore any modifications made to the data in your Postgres Pro database, it will not restore changes made to configuration files (that is, `postgresql.conf`, `pg_hba.conf` and `pg_ident.conf`), since those are edited manually rather than through SQL operations. You might wish to keep the configuration files in a location that will be backed up by your regular file system backup procedures. See Section 19.2 for how to relocate the configuration files.

The archive command is only invoked on completed WAL segments. Hence, if your server generates only little WAL traffic (or has slack periods where it does so), there could be a long delay between the completion of a transaction and its safe recording in archive storage. To put a limit on how old unarchived data can be, you can set archive_timeout to force the server to switch to a new WAL segment file at least that often. Note that archived files that are archived early due to a forced switch are still the same length as completely full files. It is therefore unwise to set a very short `archive_timeout` — it will bloat your archive storage. `archive_timeout` settings of a minute or so are usually reasonable.

Also, you can force a segment switch manually with `pg_switch_wal` if you want to ensure that a just-finished transaction is archived as soon as possible. Other utility functions related to WAL management are listed in Table 9.87.

When `wal_level` is `minimal` some SQL commands are optimized to avoid WAL logging, as described in Section 14.4.7. If archiving or streaming replication were turned on during execution of one of these statements, WAL would not contain enough information for archive recovery. (Crash recovery is unaffected.) For this reason, `wal_level` can only be changed at server start. However, `archive_command` can be changed with a configuration file reload. If you wish to temporarily stop archiving, one way to do it is to set `archive_command` to the empty string (`''`). This will cause WAL files to accumulate in `pg_wal/` until a working `archive_command` is re-established.

25.3.2. Making a Base Backup

The easiest way to perform a base backup is to use the pg_basebackup tool. It can create a base backup either as regular files or as a tar archive. If more flexibility than pg_basebackup can provide is required, you can also make a base backup using the low level API (see Section 25.3.3).

It is not necessary to be concerned about the amount of time it takes to make a base backup. However, if you normally run the server with `full_page_writes` disabled, you might notice a drop in performance while the backup runs since `full_page_writes` is effectively forced on during backup mode.

To make use of the backup, you will need to keep all the WAL segment files generated during and after the file system backup. To aid you in doing this, the base backup process creates a *backup history file* that is immediately stored into the WAL archive area. This file is named after the first WAL segment file that you need for the file system backup. For example, if the starting WAL file is `000000010000123400000055CD` the backup history file will be named something like `000000010000123400000055CD.007C9330.backup`. (The second part of the file name stands for an exact position within the WAL file, and can ordinarily be ignored.) Once you have safely archived the file system backup and the WAL segment files used during the backup (as specified in the backup history file), all archived WAL segments with names numerically less are no longer needed to recover the file system backup and can be deleted. However, you should consider keeping several backup sets to be absolutely certain that you can recover your data.

The backup history file is just a small text file. It contains the label string you gave to pg_basebackup, as well as the starting and ending times and WAL segments of the backup. If you used the label to identify the associated dump file, then the archived history file is enough to tell you which dump file to restore.

Since you have to keep around all the archived WAL files back to your last base backup, the interval between base backups should usually be chosen based on how much storage you want to expend on

archived WAL files. You should also consider how long you are prepared to spend recovering, if recovery should be necessary — the system will have to replay all those WAL segments, and that could take awhile if it has been a long time since the last base backup.

25.3.3. Making a Base Backup Using the Low Level API

The procedure for making a base backup using the low level APIs contains a few more steps than the pg_basebackup method, but is relatively simple. It is very important that these steps are executed in sequence, and that the success of a step is verified before proceeding to the next step.

Low level base backups can be made in a non-exclusive or an exclusive way. The non-exclusive method is recommended and the exclusive one is deprecated and will eventually be removed.

25.3.3.1. Making a Non-Exclusive Low-Level Backup

A non-exclusive low level backup is one that allows other concurrent backups to be running (both those started using the same backup API and those started using pg_basebackup).

1. Ensure that WAL archiving is enabled and working.
2. Connect to the server (it does not matter which database) as a user with rights to run pg_start_backup (superuser, or a user who has been granted EXECUTE on the function) and issue the command:

   ```
   SELECT pg_start_backup('label', false, false);
   ```

   where `label` is any string you want to use to uniquely identify this backup operation. The connection calling `pg_start_backup` must be maintained until the end of the backup, or the backup will be automatically aborted.

   By default, `pg_start_backup` can take a long time to finish. This is because it performs a checkpoint, and the I/O required for the checkpoint will be spread out over a significant period of time, by default half your inter-checkpoint interval (see the configuration parameter checkpoint_completion_target). This is usually what you want, because it minimizes the impact on query processing. If you want to start the backup as soon as possible, change the second parameter to `true`, which will issue an immediate checkpoint using as much I/O as available.

   The third parameter being `false` tells `pg_start_backup` to initiate a non-exclusive base backup.
3. Perform the backup, using any convenient file-system-backup tool such as tar or cpio (not pg_dump or pg_dumpall). It is neither necessary nor desirable to stop normal operation of the database while you do this. See Section 25.3.3.3 for things to consider during this backup.
4. In the same connection as before, issue the command:

   ```
   SELECT * FROM pg_stop_backup(false, true);
   ```

   This terminates backup mode. On a primary, it also performs an automatic switch to the next WAL segment. On a standby, it is not possible to automatically switch WAL segments, so you may wish to run `pg_switch_wal` on the primary to perform a manual switch. The reason for the switch is to arrange for the last WAL segment file written during the backup interval to be ready to archive.

   The `pg_stop_backup` will return one row with three values. The second of these fields should be written to a file named `backup_label` in the root directory of the backup. The third field should be written to a file named `tablespace_map` unless the field is empty. These files are vital to the backup working and must be written byte for byte without modification, which may require opening the file in binary mode.
5. Once the WAL segment files active during the backup are archived, you are done. The file identified by `pg_stop_backup`'s first return value is the last segment that is required to form a complete set of backup files. On a primary, if `archive_mode` is enabled and the `wait_for_archive` parameter is `true`, `pg_stop_backup` does not return until the last segment has been archived. On a standby, `archive_mode` must be `always` in order for `pg_stop_backup` to wait. Archiving of these files happens automatically since you have already configured `archive_command`. In most cases this happens quickly, but you are advised to monitor your archive system to ensure there are no delays. If the archive

process has fallen behind because of failures of the archive command, it will keep retrying until the archive succeeds and the backup is complete. If you wish to place a time limit on the execution of pg_stop_backup, set an appropriate statement_timeout value, but make note that if pg_stop_backup terminates because of this your backup may not be valid.

If the backup process monitors and ensures that all WAL segment files required for the backup are successfully archived then the wait_for_archive parameter (which defaults to true) can be set to false to have pg_stop_backup return as soon as the stop backup record is written to the WAL. By default, pg_stop_backup will wait until all WAL has been archived, which can take some time. This option must be used with caution: if WAL archiving is not monitored correctly then the backup might not include all of the WAL files and will therefore be incomplete and not able to be restored.

25.3.3.2. Making an Exclusive Low-Level Backup

> **Note**
>
> The exclusive backup method is deprecated and should be avoided. Prior to PostgreSQL 9.6, this was the only low-level method available, but it is now recommended that all users upgrade their scripts to use non-exclusive backups.

The process for an exclusive backup is mostly the same as for a non-exclusive one, but it differs in a few key steps. This type of backup can only be taken on a primary and does not allow concurrent backups. Moreover, because it creates a backup label file, as described below, it can block automatic restart of the primary server after a crash. On the other hand, the erroneous removal of this file from a backup or standby is a common mistake, which can result in serious data corruption. If it is necessary to use this method, the following steps may be used.

1. Ensure that WAL archiving is enabled and working.
2. Connect to the server (it does not matter which database) as a user with rights to run pg_start_backup (superuser, or a user who has been granted EXECUTE on the function) and issue the command:

   ```
   SELECT pg_start_backup('label');
   ```

   where label is any string you want to use to uniquely identify this backup operation. pg_start_backup creates a *backup label* file, called backup_label, in the cluster directory with information about your backup, including the start time and label string. The function also creates a *tablespace map* file, called tablespace_map, in the cluster directory with information about tablespace symbolic links in pg_tblspc/ if one or more such link is present. Both files are critical to the integrity of the backup, should you need to restore from it.

   By default, pg_start_backup can take a long time to finish. This is because it performs a checkpoint, and the I/O required for the checkpoint will be spread out over a significant period of time, by default half your inter-checkpoint interval (see the configuration parameter checkpoint_completion_target). This is usually what you want, because it minimizes the impact on query processing. If you want to start the backup as soon as possible, use:

   ```
   SELECT pg_start_backup('label', true);
   ```

   This forces the checkpoint to be done as quickly as possible.
3. Perform the backup, using any convenient file-system-backup tool such as tar or cpio (not pg_dump or pg_dumpall). It is neither necessary nor desirable to stop normal operation of the database while you do this. See Section 25.3.3.3 for things to consider during this backup.

   As noted above, if the server crashes during the backup it may not be possible to restart until the backup_label file has been manually deleted from the PGDATA directory. Note that it is very important to never remove the backup_label file when restoring a backup, because this will result in corruption. Confusion about when it is appropriate to remove this file is a common cause of data corruption when using this method; be very certain that you remove the file only on an existing primary and never when

building a standby or restoring a backup, even if you are building a standby that will subsequently be promoted to a new primary.

4. Again connect to the database as a user with rights to run pg_stop_backup (superuser, or a user who has been granted EXECUTE on the function), and issue the command:

   ```
   SELECT pg_stop_backup();
   ```

   This function terminates backup mode and performs an automatic switch to the next WAL segment. The reason for the switch is to arrange for the last WAL segment written during the backup interval to be ready to archive.

5. Once the WAL segment files active during the backup are archived, you are done. The file identified by `pg_stop_backup`'s result is the last segment that is required to form a complete set of backup files. If `archive_mode` is enabled, `pg_stop_backup` does not return until the last segment has been archived. Archiving of these files happens automatically since you have already configured `archive_command`. In most cases this happens quickly, but you are advised to monitor your archive system to ensure there are no delays. If the archive process has fallen behind because of failures of the archive command, it will keep retrying until the archive succeeds and the backup is complete.

   When using exclusive backup mode, it is absolutely imperative to ensure that `pg_stop_backup` completes successfully at the end of the backup. Even if the backup itself fails, for example due to lack of disk space, failure to call `pg_stop_backup` will leave the server in backup mode indefinitely, causing future backups to fail and increasing the risk of a restart failure during the time that `backup_label` exists.

25.3.3.3. Backing Up the Data Directory

Some file system backup tools emit warnings or errors if the files they are trying to copy change while the copy proceeds. When taking a base backup of an active database, this situation is normal and not an error. However, you need to ensure that you can distinguish complaints of this sort from real errors. For example, some versions of rsync return a separate exit code for “vanished source files”, and you can write a driver script to accept this exit code as a non-error case. Also, some versions of GNU tar return an error code indistinguishable from a fatal error if a file was truncated while tar was copying it. Fortunately, GNU tar versions 1.16 and later exit with 1 if a file was changed during the backup, and 2 for other errors. With GNU tar version 1.23 and later, you can use the warning options `--warning=no-file-changed --warning=no-file-removed` to hide the related warning messages.

Be certain that your backup includes all of the files under the database cluster directory (e.g., `/usr/local/pgsql/data`). If you are using tablespaces that do not reside underneath this directory, be careful to include them as well (and be sure that your backup archives symbolic links as links, otherwise the restore will corrupt your tablespaces).

You should, however, omit from the backup the files within the cluster's `pg_wal/` subdirectory. This slight adjustment is worthwhile because it reduces the risk of mistakes when restoring. This is easy to arrange if `pg_wal/` is a symbolic link pointing to someplace outside the cluster directory, which is a common setup anyway for performance reasons. You might also want to exclude `postmaster.pid` and `postmaster.opts`, which record information about the running postmaster, not about the postmaster which will eventually use this backup. (These files can confuse pg_ctl.)

It is often a good idea to also omit from the backup the files within the cluster's `pg_replslot/` directory, so that replication slots that exist on the primary do not become part of the backup. Otherwise, the subsequent use of the backup to create a standby may result in indefinite retention of WAL files on the standby, and possibly bloat on the primary if hot standby feedback is enabled, because the clients that are using those replication slots will still be connecting to and updating the slots on the primary, not the standby. Even if the backup is only intended for use in creating a new primary, copying the replication slots isn't expected to be particularly useful, since the contents of those slots will likely be badly out of date by the time the new primary comes on line.

The contents of the directories `pg_dynshmem/`, `pg_notify/`, `pg_serial/`, `pg_snapshots/`, `pg_stat_tmp/`, and `pg_subtrans/` (but not the directories themselves) can be omitted from the backup as they will be

initialized on postmaster startup. If stats_temp_directory is set and is under the data directory then the contents of that directory can also be omitted.

Any file or directory beginning with pgsql_tmp can be omitted from the backup. These files are removed on postmaster start and the directories will be recreated as needed.

pg_internal.init files can be omitted from the backup whenever a file of that name is found. These files contain relation cache data that is always rebuilt when recovering.

The backup label file includes the label string you gave to pg_start_backup, as well as the time at which pg_start_backup was run, and the name of the starting WAL file. In case of confusion it is therefore possible to look inside a backup file and determine exactly which backup session the dump file came from. The tablespace map file includes the symbolic link names as they exist in the directory pg_tblspc/ and the full path of each symbolic link. These files are not merely for your information; their presence and contents are critical to the proper operation of the system's recovery process.

It is also possible to make a backup while the server is stopped. In this case, you obviously cannot use pg_start_backup or pg_stop_backup, and you will therefore be left to your own devices to keep track of which backup is which and how far back the associated WAL files go. It is generally better to follow the continuous archiving procedure above.

25.3.4. Recovering Using a Continuous Archive Backup

Okay, the worst has happened and you need to recover from your backup. Here is the procedure:

1. Stop the server, if it's running.
2. If you have the space to do so, copy the whole cluster data directory and any tablespaces to a temporary location in case you need them later. Note that this precaution will require that you have enough free space on your system to hold two copies of your existing database. If you do not have enough space, you should at least save the contents of the cluster's pg_wal subdirectory, as it might contain logs which were not archived before the system went down.
3. Remove all existing files and subdirectories under the cluster data directory and under the root directories of any tablespaces you are using.
4. Restore the database files from your file system backup. Be sure that they are restored with the right ownership (the database system user, not root!) and with the right permissions. If you are using tablespaces, you should verify that the symbolic links in pg_tblspc/ were correctly restored.
5. Remove any files present in pg_wal/; these came from the file system backup and are therefore probably obsolete rather than current. If you didn't archive pg_wal/ at all, then recreate it with proper permissions, being careful to ensure that you re-establish it as a symbolic link if you had it set up that way before.
6. If you have unarchived WAL segment files that you saved in step 2, copy them into pg_wal/. (It is best to copy them, not move them, so you still have the unmodified files if a problem occurs and you have to start over.)
7. Set recovery configuration settings in postgresql.conf (see Section 19.5.4) and create a file recovery.signal in the cluster data directory. You might also want to temporarily modify pg_hba.conf to prevent ordinary users from connecting until you are sure the recovery was successful.
8. Start the server. The server will go into recovery mode and proceed to read through the archived WAL files it needs. Should the recovery be terminated because of an external error, the server can simply be restarted and it will continue recovery. Upon completion of the recovery process, the server will remove recovery.signal (to prevent accidentally re-entering recovery mode later) and then commence normal database operations.
9. Inspect the contents of the database to ensure you have recovered to the desired state. If not, return to step 1. If all is well, allow your users to connect by restoring pg_hba.conf to normal.

The key part of all this is to set up a recovery configuration that describes how you want to recover and how far the recovery should run. The one thing that you absolutely must specify is the restore_command,

which tells Postgres Pro how to retrieve archived WAL file segments. Like the `archive_command`, this is a shell command string. It can contain `%f`, which is replaced by the name of the desired log file, and `%p`, which is replaced by the path name to copy the log file to. (The path name is relative to the current working directory, i.e., the cluster's data directory.) Write `%%` if you need to embed an actual `%` character in the command. The simplest useful command is something like:

```
restore_command = 'cp /mnt/server/archivedir/%f %p'
```

which will copy previously archived WAL segments from the directory `/mnt/server/archivedir`. Of course, you can use something much more complicated, perhaps even a shell script that requests the operator to mount an appropriate tape.

It is important that the command return nonzero exit status on failure. The command *will* be called requesting files that are not present in the archive; it must return nonzero when so asked. This is not an error condition. An exception is that if the command was terminated by a signal (other than SIGTERM, which is used as part of a database server shutdown) or an error by the shell (such as command not found), then recovery will abort and the server will not start up.

Not all of the requested files will be WAL segment files; you should also expect requests for files with a suffix of `.history`. Also be aware that the base name of the `%p` path will be different from `%f`; do not expect them to be interchangeable.

WAL segments that cannot be found in the archive will be sought in `pg_wal/`; this allows use of recent un-archived segments. However, segments that are available from the archive will be used in preference to files in `pg_wal/`.

Normally, recovery will proceed through all available WAL segments, thereby restoring the database to the current point in time (or as close as possible given the available WAL segments). Therefore, a normal recovery will end with a “file not found” message, the exact text of the error message depending upon your choice of `restore_command`. You may also see an error message at the start of recovery for a file named something like `00000001.history`. This is also normal and does not indicate a problem in simple recovery situations; see Section 25.3.5 for discussion.

If you want to recover to some previous point in time (say, right before the junior DBA dropped your main transaction table), just specify the required stopping point. You can specify the stop point, known as the “recovery target”, either by date/time, named restore point or by completion of a specific transaction ID. As of this writing only the date/time and named restore point options are very usable, since there are no tools to help you identify with any accuracy which transaction ID to use.

> **Note**
>
> The stop point must be after the ending time of the base backup, i.e., the end time of `pg_stop_backup`. You cannot use a base backup to recover to a time when that backup was in progress. (To recover to such a time, you must go back to your previous base backup and roll forward from there.)

If recovery finds corrupted WAL data, recovery will halt at that point and the server will not start. In such a case the recovery process could be re-run from the beginning, specifying a “recovery target” before the point of corruption so that recovery can complete normally. If recovery fails for an external reason, such as a system crash or if the WAL archive has become inaccessible, then the recovery can simply be restarted and it will restart almost from where it failed. Recovery restart works much like checkpointing in normal operation: the server periodically forces all its state to disk, and then updates the `pg_control` file to indicate that the already-processed WAL data need not be scanned again.

25.3.5. Timelines

The ability to restore the database to a previous point in time creates some complexities that are akin to science-fiction stories about time travel and parallel universes. For example, in the original history of

the database, suppose you dropped a critical table at 5:15PM on Tuesday evening, but didn't realize your mistake until Wednesday noon. Unfazed, you get out your backup, restore to the point-in-time 5:14PM Tuesday evening, and are up and running. In *this* history of the database universe, you never dropped the table. But suppose you later realize this wasn't such a great idea, and would like to return to sometime Wednesday morning in the original history. You won't be able to if, while your database was up-and-running, it overwrote some of the WAL segment files that led up to the time you now wish you could get back to. Thus, to avoid this, you need to distinguish the series of WAL records generated after you've done a point-in-time recovery from those that were generated in the original database history.

To deal with this problem, Postgres Pro has a notion of *timelines*. Whenever an archive recovery completes, a new timeline is created to identify the series of WAL records generated after that recovery. The timeline ID number is part of WAL segment file names so a new timeline does not overwrite the WAL data generated by previous timelines. It is in fact possible to archive many different timelines. While that might seem like a useless feature, it's often a lifesaver. Consider the situation where you aren't quite sure what point-in-time to recover to, and so have to do several point-in-time recoveries by trial and error until you find the best place to branch off from the old history. Without timelines this process would soon generate an unmanageable mess. With timelines, you can recover to *any* prior state, including states in timeline branches that you abandoned earlier.

Every time a new timeline is created, Postgres Pro creates a “timeline history” file that shows which timeline it branched off from and when. These history files are necessary to allow the system to pick the right WAL segment files when recovering from an archive that contains multiple timelines. Therefore, they are archived into the WAL archive area just like WAL segment files. The history files are just small text files, so it's cheap and appropriate to keep them around indefinitely (unlike the segment files which are large). You can, if you like, add comments to a history file to record your own notes about how and why this particular timeline was created. Such comments will be especially valuable when you have a thicket of different timelines as a result of experimentation.

The default behavior of recovery is to recover to the latest timeline found in the archive. If you wish to recover to the timeline that was current when the base backup was taken or into a specific child timeline (that is, you want to return to some state that was itself generated after a recovery attempt), you need to specify `current` or the target timeline ID in recovery_target_timeline. You cannot recover into timelines that branched off earlier than the base backup.

25.3.6. Tips and Examples

Some tips for configuring continuous archiving are given here.

25.3.6.1. Standalone Hot Backups

It is possible to use Postgres Pro's backup facilities to produce standalone hot backups. These are backups that cannot be used for point-in-time recovery, yet are typically much faster to backup and restore than pg_dump dumps. (They are also much larger than pg_dump dumps, so in some cases the speed advantage might be negated.)

As with base backups, the easiest way to produce a standalone hot backup is to use the pg_basebackup tool. If you include the `-X` parameter when calling it, all the write-ahead log required to use the backup will be included in the backup automatically, and no special action is required to restore the backup.

If more flexibility in copying the backup files is needed, a lower level process can be used for standalone hot backups as well. To prepare for low level standalone hot backups, make sure `wal_level` is set to `replica` or higher, `archive_mode` to `on`, and set up an `archive_command` that performs archiving only when a *switch file* exists. For example:

```
archive_command = 'test ! -f /var/lib/pgsql/backup_in_progress || (test ! -f /var/lib/
pgsql/archive/%f && cp %p /var/lib/pgsql/archive/%f)'
```

This command will perform archiving when `/var/lib/pgsql/backup_in_progress` exists, and otherwise silently return zero exit status (allowing Postgres Pro to recycle the unwanted WAL file).

With this preparation, a backup can be taken using a script like the following:

```
touch /var/lib/pgsql/backup_in_progress
psql -c "select pg_start_backup('hot_backup');"
tar -cf /var/lib/pgsql/backup.tar /var/lib/pgsql/data/
psql -c "select pg_stop_backup();"
rm /var/lib/pgsql/backup_in_progress
tar -rf /var/lib/pgsql/backup.tar /var/lib/pgsql/archive/
```

The switch file `/var/lib/pgsql/backup_in_progress` is created first, enabling archiving of completed WAL files to occur. After the backup the switch file is removed. Archived WAL files are then added to the backup so that both base backup and all required WAL files are part of the same tar file. Please remember to add error handling to your backup scripts.

25.3.6.2. Compressed Archive Logs

If archive storage size is a concern, you can use gzip to compress the archive files:

```
archive_command = 'gzip < %p > /mnt/server/archivedir/%f.gz'
```

You will then need to use gunzip during recovery:

```
restore_command = 'gunzip < /mnt/server/archivedir/%f.gz > %p'
```

25.3.6.3. `archive_command` Scripts

Many people choose to use scripts to define their `archive_command`, so that their `postgresql.conf` entry looks very simple:

```
archive_command = 'local_backup_script.sh "%p" "%f"'
```

Using a separate script file is advisable any time you want to use more than a single command in the archiving process. This allows all complexity to be managed within the script, which can be written in a popular scripting language such as bash or perl.

Examples of requirements that might be solved within a script include:

- Copying data to secure off-site data storage
- Batching WAL files so that they are transferred every three hours, rather than one at a time
- Interfacing with other backup and recovery software
- Interfacing with monitoring software to report errors

> **Tip**
>
> When using an `archive_command` script, it's desirable to enable logging_collector. Any messages written to stderr from the script will then appear in the database server log, allowing complex configurations to be diagnosed easily if they fail.

25.3.7. Caveats

At this writing, there are several limitations of the continuous archiving technique. These will probably be fixed in future releases:

- If a `CREATE DATABASE` command is executed while a base backup is being taken, and then the template database that the `CREATE DATABASE` copied is modified while the base backup is still in progress, it is possible that recovery will cause those modifications to be propagated into the created database as well. This is of course undesirable. To avoid this risk, it is best not to modify any template databases while taking a base backup.
- `CREATE TABLESPACE` commands are WAL-logged with the literal absolute path, and will therefore be replayed as tablespace creations with the same absolute path. This might be undesirable if the log is being replayed on a different machine. It can be dangerous even if the log is being replayed on the same machine, but into a new data directory: the replay will still overwrite the contents of the

original tablespace. To avoid potential gotchas of this sort, the best practice is to take a new base backup after creating or dropping tablespaces.

It should also be noted that the default WAL format is fairly bulky since it includes many disk page snapshots. These page snapshots are designed to support crash recovery, since we might need to fix partially-written disk pages. Depending on your system hardware and software, the risk of partial writes might be small enough to ignore, in which case you can significantly reduce the total volume of archived logs by turning off page snapshots using the full_page_writes parameter. (Read the notes and warnings in Chapter 29 before you do so.) Turning off page snapshots does not prevent use of the logs for PITR operations. An area for future development is to compress archived WAL data by removing unnecessary page copies even when `full_page_writes` is on. In the meantime, administrators might wish to reduce the number of page snapshots included in WAL by increasing the checkpoint interval parameters as much as feasible.

Chapter 26. High Availability, Load Balancing, and Replication

Database servers can work together to allow a second server to take over quickly if the primary server fails (high availability), or to allow several computers to serve the same data (load balancing). Ideally, database servers could work together seamlessly. Web servers serving static web pages can be combined quite easily by merely load-balancing web requests to multiple machines. In fact, read-only database servers can be combined relatively easily too. Unfortunately, most database servers have a read/write mix of requests, and read/write servers are much harder to combine. This is because though read-only data needs to be placed on each server only once, a write to any server has to be propagated to all servers so that future read requests to those servers return consistent results.

This synchronization problem is the fundamental difficulty for servers working together. Because there is no single solution that eliminates the impact of the sync problem for all use cases, there are multiple solutions. Each solution addresses this problem in a different way, and minimizes its impact for a specific workload.

Some solutions deal with synchronization by allowing only one server to modify the data. Servers that can modify data are called read/write, *master* or *primary* servers. Servers that track changes in the primary are called *standby* or *secondary* servers. A standby server that cannot be connected to until it is promoted to a primary server is called a *warm standby* server, and one that can accept connections and serves read-only queries is called a *hot standby* server.

Some solutions are synchronous, meaning that a data-modifying transaction is not considered committed until all servers have committed the transaction. This guarantees that a failover will not lose any data and that all load-balanced servers will return consistent results no matter which server is queried. In contrast, asynchronous solutions allow some delay between the time of a commit and its propagation to the other servers, opening the possibility that some transactions might be lost in the switch to a backup server, and that load balanced servers might return slightly stale results. Asynchronous communication is used when synchronous would be too slow.

Solutions can also be categorized by their granularity. Some solutions can deal only with an entire database server, while others allow control at the per-table or per-database level.

Performance must be considered in any choice. There is usually a trade-off between functionality and performance. For example, a fully synchronous solution over a slow network might cut performance by more than half, while an asynchronous one might have a minimal performance impact.

The remainder of this section outlines various failover, replication, and load balancing solutions.

26.1. Comparison of Different Solutions

Shared Disk Failover

Shared disk failover avoids synchronization overhead by having only one copy of the database. It uses a single disk array that is shared by multiple servers. If the main database server fails, the standby server is able to mount and start the database as though it were recovering from a database crash. This allows rapid failover with no data loss.

Shared hardware functionality is common in network storage devices. Using a network file system is also possible, though care must be taken that the file system has full POSIX behavior (see Section 18.2.2.1). One significant limitation of this method is that if the shared disk array fails or becomes corrupt, the primary and standby servers are both nonfunctional. Another issue is that the standby server should never access the shared storage while the primary server is running.

File System (Block Device) Replication

A modified version of shared hardware functionality is file system replication, where all changes to a file system are mirrored to a file system residing on another computer. The only restriction is that

the mirroring must be done in a way that ensures the standby server has a consistent copy of the file system — specifically, writes to the standby must be done in the same order as those on the primary. DRBD is a popular file system replication solution for Linux.

Write-Ahead Log Shipping

Warm and hot standby servers can be kept current by reading a stream of write-ahead log (WAL) records. If the main server fails, the standby contains almost all of the data of the main server, and can be quickly made the new primary database server. This can be synchronous or asynchronous and can only be done for the entire database server.

A standby server can be implemented using file-based log shipping (Section 26.2) or streaming replication (see Section 26.2.5), or a combination of both. For information on hot standby, see Section 26.4.

Logical Replication

Logical replication allows a database server to send a stream of data modifications to another server. Postgres Pro logical replication constructs a stream of logical data modifications from the WAL. Logical replication allows replication of data changes on a per-table basis. In addition, a server that is publishing its own changes can also subscribe to changes from another server, allowing data to flow in multiple directions. For more information on logical replication, see Chapter 30. Through the logical decoding interface (Chapter 51), third-party extensions can also provide similar functionality.

Trigger-Based Primary-Standby Replication

A trigger-based replication setup typically funnels data modification queries to a designated primary server. Operating on a per-table basis, the primary server sends data changes (typically) asynchronously to the standby servers. Standby servers can answer queries while the primary is running, and may allow some local data changes or write activity. This form of replication is often used for offloading large analytical or data warehouse queries.

Slony-I is an example of this type of replication, with per-table granularity, and support for multiple standby servers. Because it updates the standby server asynchronously (in batches), there is possible data loss during fail over.

SQL-Based Replication Middleware

With SQL-based replication middleware, a program intercepts every SQL query and sends it to one or all servers. Each server operates independently. Read-write queries must be sent to all servers, so that every server receives any changes. But read-only queries can be sent to just one server, allowing the read workload to be distributed among them.

If queries are simply broadcast unmodified, functions like `random()`, `CURRENT_TIMESTAMP`, and sequences can have different values on different servers. This is because each server operates independently, and because SQL queries are broadcast rather than actual data changes. If this is unacceptable, either the middleware or the application must determine such values from a single source and then use those values in write queries. Care must also be taken that all transactions either commit or abort on all servers, perhaps using two-phase commit (PREPARE TRANSACTION and COMMIT PREPARED). Pgpool-II and Continuent Tungsten are examples of this type of replication.

Asynchronous Multimaster Replication

For servers that are not regularly connected or have slow communication links, like laptops or remote servers, keeping data consistent among servers is a challenge. Using asynchronous multimaster replication, each server works independently, and periodically communicates with the other servers to identify conflicting transactions. The conflicts can be resolved by users or conflict resolution rules. Bucardo is an example of this type of replication.

Synchronous Multimaster Replication

In synchronous multimaster replication, each server can accept write requests, and modified data is transmitted from the original server to every other server before each transaction commits. Heavy write activity can cause excessive locking and commit delays, leading to poor performance. Read

requests can be sent to any server. Some implementations use shared disk to reduce the communication overhead. Synchronous multimaster replication is best for mostly read workloads, though its big advantage is that any server can accept write requests — there is no need to partition workloads between primary and standby servers, and because the data changes are sent from one server to another, there is no problem with non-deterministic functions like `random()`.

Postgres Pro Enterprise provides `multimaster` extension that implements this type of replication. Using `multimaster`, you can configure a synchronous shared-nothing cluster that provides Online Transaction Processing (OLTP) scalability for read transactions, as well as ensures high availability with automatic disaster recovery. For details, see multimaster.

Table 26.1 summarizes the capabilities of the various solutions listed above.

Table 26.1. High Availability, Load Balancing, and Replication Feature Matrix

Feature	Shared Disk	File System Repl.	Write-Ahead Log Shipping	Logical Repl.	Trigger-Based Repl.	SQL Repl. Middle-ware	Async. MM Repl.	Sync. MM Repl.
Popular examples	NAS	DRBD	built-in streaming repl.	built-in logical repl., pglogical	Londiste, Slony	pgpool-II	Bucardo	`multimaster` extension of Postgres Pro Enterprise
Comm. method	shared disk	disk blocks	WAL	logical decoding	table rows	SQL	table rows	table rows and row locks
No special hardware required		•	•	•	•	•	•	•
Allows multiple primary servers				•		•	•	•
No overhead on primary	•		•	•		•		
No waiting for multiple servers	•		with sync off	with sync off	•		•	
Primary failure will never lose data	•	•	with sync on	with sync on		•		•
Replicas accept read-only queries			with hot standby	•	•	•	•	•
Per-table granularity				•	•		•	•
No conflict resolution necessary	•	•	•		•	•		•

There are a few solutions that do not fit into the above categories:

Data Partitioning

Data partitioning splits tables into data sets. Each set can be modified by only one server. For example, data can be partitioned by offices, e.g., London and Paris, with a server in each office. If queries combining London and Paris data are necessary, an application can query both servers, or primary/standby replication can be used to keep a read-only copy of the other office's data on each server.

Multiple-Server Parallel Query Execution

Many of the above solutions allow multiple servers to handle multiple queries, but none allow a single query to use multiple servers to complete faster. This solution allows multiple servers to work concurrently on a single query. It is usually accomplished by splitting the data among servers and having each server execute its part of the query and return results to a central server where they are combined and returned to the user. This can be implemented using the PL/Proxy tool set.

26.2. Log-Shipping Standby Servers

Continuous archiving can be used to create a *high availability* (HA) cluster configuration with one or more *standby servers* ready to take over operations if the primary server fails. This capability is widely referred to as *warm standby* or *log shipping*.

The primary and standby server work together to provide this capability, though the servers are only loosely coupled. The primary server operates in continuous archiving mode, while each standby server operates in continuous recovery mode, reading the WAL files from the primary. No changes to the database tables are required to enable this capability, so it offers low administration overhead compared to some other replication solutions. This configuration also has relatively low performance impact on the primary server.

Directly moving WAL records from one database server to another is typically described as log shipping. Postgres Pro implements file-based log shipping by transferring WAL records one file (WAL segment) at a time. WAL files (16MB) can be shipped easily and cheaply over any distance, whether it be to an adjacent system, another system at the same site, or another system on the far side of the globe. The bandwidth required for this technique varies according to the transaction rate of the primary server. Record-based log shipping is more granular and streams WAL changes incrementally over a network connection (see Section 26.2.5).

It should be noted that log shipping is asynchronous, i.e., the WAL records are shipped after transaction commit. As a result, there is a window for data loss should the primary server suffer a catastrophic failure; transactions not yet shipped will be lost. The size of the data loss window in file-based log shipping can be limited by use of the `archive_timeout` parameter, which can be set as low as a few seconds. However such a low setting will substantially increase the bandwidth required for file shipping. Streaming replication (see Section 26.2.5) allows a much smaller window of data loss.

Recovery performance is sufficiently good that the standby will typically be only moments away from full availability once it has been activated. As a result, this is called a warm standby configuration which offers high availability. Restoring a server from an archived base backup and rollforward will take considerably longer, so that technique only offers a solution for disaster recovery, not high availability. A standby server can also be used for read-only queries, in which case it is called a Hot Standby server. See Section 26.4 for more information.

26.2.1. Planning

It is usually wise to create the primary and standby servers so that they are as similar as possible, at least from the perspective of the database server. In particular, the path names associated with tablespaces will be passed across unmodified, so both primary and standby servers must have the same mount paths for tablespaces if that feature is used. Keep in mind that if CREATE TABLESPACE is executed on the primary, any new mount point needed for it must be created on the primary and all standby servers before the command is executed. Hardware need not be exactly the same, but experience shows that

maintaining two identical systems is easier than maintaining two dissimilar ones over the lifetime of the application and system. In any case the hardware architecture must be the same — shipping from, say, a 32-bit to a 64-bit system will not work.

In general, log shipping between servers running different major Postgres Pro release levels is not possible. It is the policy of the Postgres Pro Global Development Group not to make changes to disk formats during minor release upgrades, so it is likely that running different minor release levels on primary and standby servers will work successfully. However, no formal support for that is offered and you are advised to keep primary and standby servers at the same release level as much as possible. When updating to a new minor release, the safest policy is to update the standby servers first — a new minor release is more likely to be able to read WAL files from a previous minor release than vice versa.

26.2.2. Standby Server Operation

A server enters standby mode if a `standby.signal` file exists in the data directory when the server is started.

In standby mode, the server continuously applies WAL received from the primary server. The standby server can read WAL from a WAL archive (see restore_command) or directly from the primary over a TCP connection (streaming replication). The standby server will also attempt to restore any WAL found in the standby cluster's `pg_wal` directory. That typically happens after a server restart, when the standby replays again WAL that was streamed from the primary before the restart, but you can also manually copy files to `pg_wal` at any time to have them replayed.

At startup, the standby begins by restoring all WAL available in the archive location, calling `restore_command`. Once it reaches the end of WAL available there and `restore_command` fails, it tries to restore any WAL available in the `pg_wal` directory. If that fails, and streaming replication has been configured, the standby tries to connect to the primary server and start streaming WAL from the last valid record found in archive or `pg_wal`. If that fails or streaming replication is not configured, or if the connection is later disconnected, the standby goes back to step 1 and tries to restore the file from the archive again. This loop of retries from the archive, `pg_wal`, and via streaming replication goes on until the server is stopped or is promoted.

Standby mode is exited and the server switches to normal operation when `pg_ctl promote` is run, `pg_promote()` is called, or a trigger file is found (`promote_trigger_file`). Before failover, any WAL immediately available in the archive or in `pg_wal` will be restored, but no attempt is made to connect to the primary.

26.2.3. Preparing the Primary for Standby Servers

Set up continuous archiving on the primary to an archive directory accessible from the standby, as described in Section 25.3. The archive location should be accessible from the standby even when the primary is down, i.e., it should reside on the standby server itself or another trusted server, not on the primary server.

If you want to use streaming replication, set up authentication on the primary server to allow replication connections from the standby server(s); that is, create a role and provide a suitable entry or entries in `pg_hba.conf` with the database field set to `replication`. Also ensure `max_wal_senders` is set to a sufficiently large value in the configuration file of the primary server. If replication slots will be used, ensure that `max_replication_slots` is set sufficiently high as well.

Take a base backup as described in Section 25.3.2 to bootstrap the standby server.

26.2.4. Setting Up a Standby Server

To set up the standby server, restore the base backup taken from primary server (see Section 25.3.4). Create a file `standby.signal`in the standby's cluster data directory. Set restore_command to a simple command to copy files from the WAL archive. If you plan to have multiple standby servers for high availability purposes, make sure that `recovery_target_timeline` is set to `latest` (the default), to make the standby server follow the timeline change that occurs at failover to another standby.

> **Note**
>
> restore_command should return immediately if the file does not exist; the server will retry the command again if necessary.

If you want to use streaming replication, fill in primary_conninfo with a libpq connection string, including the host name (or IP address) and any additional details needed to connect to the primary server. If the primary needs a password for authentication, the password needs to be specified in primary_conninfo as well.

If you're setting up the standby server for high availability purposes, set up WAL archiving, connections and authentication like the primary server, because the standby server will work as a primary server after failover.

If you're using a WAL archive, its size can be minimized using the archive_cleanup_command parameter to remove files that are no longer required by the standby server. The pg_archivecleanup utility is designed specifically to be used with `archive_cleanup_command` in typical single-standby configurations, see pg_archivecleanup. Note however, that if you're using the archive for backup purposes, you need to retain files needed to recover from at least the latest base backup, even if they're no longer needed by the standby.

A simple example of configuration is:

```
primary_conninfo = 'host=192.168.1.50 port=5432 user=foo password=foopass options=''-c
 wal_sender_timeout=5000'''
restore_command = 'cp /path/to/archive/%f %p'
archive_cleanup_command = 'pg_archivecleanup /path/to/archive %r'
```

You can have any number of standby servers, but if you use streaming replication, make sure you set `max_wal_senders` high enough in the primary to allow them to be connected simultaneously.

26.2.5. Streaming Replication

Streaming replication allows a standby server to stay more up-to-date than is possible with file-based log shipping. The standby connects to the primary, which streams WAL records to the standby as they're generated, without waiting for the WAL file to be filled.

Streaming replication is asynchronous by default (see Section 26.2.8), in which case there is a small delay between committing a transaction in the primary and the changes becoming visible in the standby. This delay is however much smaller than with file-based log shipping, typically under one second assuming the standby is powerful enough to keep up with the load. With streaming replication, `archive_timeout` is not required to reduce the data loss window.

If you use streaming replication without file-based continuous archiving, the server might recycle old WAL segments before the standby has received them. If this occurs, the standby will need to be reinitialized from a new base backup. You can avoid this by setting `wal_keep_size` to a value large enough to ensure that WAL segments are not recycled too early, or by configuring a replication slot for the standby. If you set up a WAL archive that's accessible from the standby, these solutions are not required, since the standby can always use the archive to catch up provided it retains enough segments.

To use streaming replication, set up a file-based log-shipping standby server as described in Section 26.2. The step that turns a file-based log-shipping standby into streaming replication standby is setting the `primary_conninfo` setting to point to the primary server. Set listen_addresses and authentication options (see `pg_hba.conf`) on the primary so that the standby server can connect to the `replication` pseudo-database on the primary server (see Section 26.2.5.1).

On systems that support the keepalive socket option, setting tcp_keepalives_idle, tcp_keepalives_interval and tcp_keepalives_count helps the primary promptly notice a broken connection.

Set the maximum number of concurrent connections from the standby servers (see max_wal_senders for details).

When the standby is started and primary_conninfo is set correctly, the standby will connect to the primary after replaying all WAL files available in the archive. If the connection is established successfully, you will see a walreceiver in the standby, and a corresponding walsender process in the primary.

26.2.5.1. Authentication

It is very important that the access privileges for replication be set up so that only trusted users can read the WAL stream, because it is easy to extract privileged information from it. Standby servers must authenticate to the primary as an account that has the REPLICATION privilege or a superuser. It is recommended to create a dedicated user account with REPLICATION and LOGIN privileges for replication. While REPLICATION privilege gives very high permissions, it does not allow the user to modify any data on the primary system, which the SUPERUSER privilege does.

Client authentication for replication is controlled by a pg_hba.conf record specifying replication in the *database* field. For example, if the standby is running on host IP 192.168.1.100 and the account name for replication is foo, the administrator can add the following line to the pg_hba.conf file on the primary:

```
# Allow the user "foo" from host 192.168.1.100 to connect to the primary
# as a replication standby if the user's password is correctly supplied.
#
# TYPE  DATABASE        USER            ADDRESS                 METHOD
host    replication     foo             192.168.1.100/32        md5
```

The host name and port number of the primary, connection user name, and password are specified in the primary_conninfo. The password can also be set in the ~/.pgpass file on the standby (specify replication in the *database* field). For example, if the primary is running on host IP 192.168.1.50, port 5432, the account name for replication is foo, and the password is foopass, the administrator can add the following line to the postgresql.conf file on the standby:

```
# The standby connects to the primary that is running on host 192.168.1.50
# and port 5432 as the user "foo" whose password is "foopass".
primary_conninfo = 'host=192.168.1.50 port=5432 user=foo password=foopass'
```

26.2.5.2. Monitoring

An important health indicator of streaming replication is the amount of WAL records generated in the primary, but not yet applied in the standby. You can calculate this lag by comparing the current WAL write location on the primary with the last WAL location received by the standby. These locations can be retrieved using pg_current_wal_lsn on the primary and pg_last_wal_receive_lsn on the standby, respectively (see Table 9.87 and Table 9.88 for details). The last WAL receive location in the standby is also displayed in the process status of the WAL receiver process, displayed using the ps command (see Section 27.1 for details).

You can retrieve a list of WAL sender processes via the pg_stat_replication view. Large differences between pg_current_wal_lsn and the view's sent_lsn field might indicate that the primary server is under heavy load, while differences between sent_lsn and pg_last_wal_receive_lsn on the standby might indicate network delay, or that the standby is under heavy load.

On a hot standby, the status of the WAL receiver process can be retrieved via the pg_stat_wal_receiver view. A large difference between pg_last_wal_replay_lsn and the view's flushed_lsn indicates that WAL is being received faster than it can be replayed.

26.2.5.3. Repairing a Data Page from Standby

If you have enabled checksums when initializing your database, the I/O system can detect and report data corruption that may be caused by a system error or disk failure. On clusters with streaming replication configured between the primary and standby servers, a corrupted data page can be repaired automatically via streaming replication from standby.

To enable automatic page repair, set the page_repair variable to `true` on the primary server.

A typical page repair workflow is as follows:

1. Once the system detects a checksum mismatch when reading a data page, Postgres Pro Enterprise blocks the backend and starts the repair process.
2. The WAL sender sends a request to the WAL receiver on the standby server to read the same data page.
3. If the standby server contains a valid page copy, the backend overwrites the corrupted page with this copy received from the WAL receiver and gets unblocked.

   If the page on the standby is broken as well, an error occurs on standby, and the backend fails with the corresponding error message. In this case, you can try to restore the page from a backup.

> **Note**
>
> Page repair cannot be done in parallel. If another backend detects a different corrupted data page while page repair is in progress, it has to wait until the repair is complete.

26.2.6. Replication Slots

Replication slots provide an automated way to ensure that the primary does not remove WAL segments until they have been received by all standbys, and that the primary does not remove rows which could cause a recovery conflict even when the standby is disconnected.

In lieu of using replication slots, it is possible to prevent the removal of old WAL segments using wal_keep_size, or by storing the segments in an archive using archive_command. However, these methods often result in retaining more WAL segments than required, whereas replication slots retain only the number of segments known to be needed. On the other hand, replication slots can retain so many WAL segments that they fill up the space allocated for `pg_wal`; max_slot_wal_keep_size limits the size of WAL files retained by replication slots.

Similarly, hot_standby_feedback and vacuum_defer_cleanup_age provide protection against relevant rows being removed by vacuum, but the former provides no protection during any time period when the standby is not connected, and the latter often needs to be set to a high value to provide adequate protection. Replication slots overcome these disadvantages.

26.2.6.1. Querying and Manipulating Replication Slots

Each replication slot has a name, which can contain lower-case letters, numbers, and the underscore character.

Existing replication slots and their state can be seen in the `pg_replication_slots` view.

Slots can be created and dropped either via the streaming replication protocol (see Section 55.4) or via SQL functions (see Section 9.27.6).

26.2.6.2. Configuration Example

You can create a replication slot like this:

```
postgres=# SELECT * FROM pg_create_physical_replication_slot('node_a_slot');
  slot_name  | lsn
-------------+-----
 node_a_slot |

postgres=# SELECT slot_name, slot_type, active FROM pg_replication_slots;
  slot_name  | slot_type | active
```

```
-------------+-----------+--------
 node_a_slot | physical  | f
(1 row)
```

To configure the standby to use this slot, `primary_slot_name` should be configured on the standby. Here is a simple example:

```
primary_conninfo = 'host=192.168.1.50 port=5432 user=foo password=foopass'
primary_slot_name = 'node_a_slot'
```

26.2.7. Cascading Replication

The cascading replication feature allows a standby server to accept replication connections and stream WAL records to other standbys, acting as a relay. This can be used to reduce the number of direct connections to the primary and also to minimize inter-site bandwidth overheads.

A standby acting as both a receiver and a sender is known as a cascading standby. Standbys that are more directly connected to the primary are known as upstream servers, while those standby servers further away are downstream servers. Cascading replication does not place limits on the number or arrangement of downstream servers, though each standby connects to only one upstream server which eventually links to a single primary server.

A cascading standby sends not only WAL records received from the primary but also those restored from the archive. So even if the replication connection in some upstream connection is terminated, streaming replication continues downstream for as long as new WAL records are available.

Cascading replication is currently asynchronous. Synchronous replication (see Section 26.2.8) settings have no effect on cascading replication at present.

Hot Standby feedback propagates upstream, whatever the cascaded arrangement.

If an upstream standby server is promoted to become the new primary, downstream servers will continue to stream from the new primary if `recovery_target_timeline` is set to `'latest'` (the default).

To use cascading replication, set up the cascading standby so that it can accept replication connections (that is, set max_wal_senders and hot_standby, and configure host-based authentication). You will also need to set `primary_conninfo` in the downstream standby to point to the cascading standby.

26.2.8. Synchronous Replication

Postgres Pro streaming replication is asynchronous by default. If the primary server crashes then some transactions that were committed may not have been replicated to the standby server, causing data loss. The amount of data loss is proportional to the replication delay at the time of failover.

Synchronous replication offers the ability to confirm that all changes made by a transaction have been transferred to one or more synchronous standby servers. This extends that standard level of durability offered by a transaction commit. This level of protection is referred to as 2-safe replication in computer science theory, and group-1-safe (group-safe and 1-safe) when `synchronous_commit` is set to `remote_write`.

When requesting synchronous replication, each commit of a write transaction will wait until confirmation is received that the commit has been written to the write-ahead log on disk of both the primary and standby server. The only possibility that data can be lost is if both the primary and the standby suffer crashes at the same time. This can provide a much higher level of durability, though only if the sysadmin is cautious about the placement and management of the two servers. Waiting for confirmation increases the user's confidence that the changes will not be lost in the event of server crashes but it also necessarily increases the response time for the requesting transaction. The minimum wait time is the round-trip time between primary and standby.

Read-only transactions and transaction rollbacks need not wait for replies from standby servers. Subtransaction commits do not wait for responses from standby servers, only top-level commits. Long run-

ning actions such as data loading or index building do not wait until the very final commit message. All two-phase commit actions require commit waits, including both prepare and commit.

A synchronous standby can be a physical replication standby or a logical replication subscriber. It can also be any other physical or logical WAL replication stream consumer that knows how to send the appropriate feedback messages. Besides the built-in physical and logical replication systems, this includes special programs such as `pg_receivewal` and `pg_recvlogical` as well as some third-party replication systems and custom programs. Check the respective documentation for details on synchronous replication support.

26.2.8.1. Basic Configuration

Once streaming replication has been configured, configuring synchronous replication requires only one additional configuration step: synchronous_standby_names must be set to a non-empty value. `synchronous_commit` must also be set to `on`, but since this is the default value, typically no change is required. (See Section 19.5.1 and Section 19.6.2.) This configuration will cause each commit to wait for confirmation that the standby has written the commit record to durable storage. `synchronous_commit` can be set by individual users, so it can be configured in the configuration file, for particular users or databases, or dynamically by applications, in order to control the durability guarantee on a per-transaction basis.

After a commit record has been written to disk on the primary, the WAL record is then sent to the standby. The standby sends reply messages each time a new batch of WAL data is written to disk, unless `wal_receiver_status_interval` is set to zero on the standby. In the case that `synchronous_commit` is set to `remote_apply`, the standby sends reply messages when the commit record is replayed, making the transaction visible. If the standby is chosen as a synchronous standby, according to the setting of `synchronous_standby_names` on the primary, the reply messages from that standby will be considered along with those from other synchronous standbys to decide when to release transactions waiting for confirmation that the commit record has been received. These parameters allow the administrator to specify which standby servers should be synchronous standbys. Note that the configuration of synchronous replication is mainly on the primary. Named standbys must be directly connected to the primary; the primary knows nothing about downstream standby servers using cascaded replication.

Setting `synchronous_commit` to `remote_write` will cause each commit to wait for confirmation that the standby has received the commit record and written it out to its own operating system, but not for the data to be flushed to disk on the standby. This setting provides a weaker guarantee of durability than `on` does: the standby could lose the data in the event of an operating system crash, though not a Postgres Pro crash. However, it's a useful setting in practice because it can decrease the response time for the transaction. Data loss could only occur if both the primary and the standby crash and the database of the primary gets corrupted at the same time.

Setting `synchronous_commit` to `remote_apply` will cause each commit to wait until the current synchronous standbys report that they have replayed the transaction, making it visible to user queries. In simple cases, this allows for load balancing with causal consistency.

By default, if you add new synchronous standbys or reconnect a standby after a failure, the primary server is blocked until all standbys catch up with its current state. To minimize downtime, you can configure the synchronous_standby_gap setting on the primary. This option specifies the WAL data gap between the primary and its synchronous standbys, in kilobytes, which serves as a threshold for primary blocking. For the specified positive value to work, you should specify the `MIN` option along with other suitable options in the `synchronous_standby_names` parameter. For example:

```
synchronous_standby_names = 'FIRST 1 MIN 0 (s1)'
synchronous_standby_gap = 1
```

In this case the primary server will continue running while WAL data is being replayed on standby, until the specified gap is reached. Then the primary is blocked to complete the synchronization. The smaller the gap, the shorter the blocking time.

Users will stop waiting if a fast shutdown is requested. However, as when using asynchronous replication, the server will not fully shutdown until all outstanding WAL records are transferred to the currently connected standby servers.

26.2.8.2. Multiple Synchronous Standbys

Synchronous replication supports one or more synchronous standby servers; transactions will wait until all the standby servers which are considered as synchronous confirm receipt of their data. The number of synchronous standbys that transactions must wait for replies from is specified in `synchronous_standby_names`. This parameter also specifies a list of standby names and the method (`FIRST` and `ANY`) to choose synchronous standbys from the listed ones.

The method `FIRST` specifies a priority-based synchronous replication and makes transaction commits wait until their WAL records are replicated to the requested number of synchronous standbys chosen based on their priorities. The standbys whose names appear earlier in the list are given higher priority and will be considered as synchronous. Other standby servers appearing later in this list represent potential synchronous standbys. If any of the current synchronous standbys disconnects for whatever reason, it will be replaced immediately with the next-highest-priority standby.

An example of `synchronous_standby_names` for a priority-based multiple synchronous standbys is:

```
synchronous_standby_names = 'FIRST 2 (s1, s2, s3)'
```

In this example, if four standby servers `s1`, `s2`, `s3` and `s4` are running, the two standbys `s1` and `s2` will be chosen as synchronous standbys because their names appear early in the list of standby names. `s3` is a potential synchronous standby and will take over the role of synchronous standby when either of `s1` or `s2` fails. `s4` is an asynchronous standby since its name is not in the list.

The method `ANY` specifies a quorum-based synchronous replication and makes transaction commits wait until their WAL records are replicated to *at least* the requested number of synchronous standbys in the list.

An example of `synchronous_standby_names` for a quorum-based multiple synchronous standbys is:

```
synchronous_standby_names = 'ANY 2 (s1, s2, s3)'
```

In this example, if four standby servers `s1`, `s2`, `s3` and `s4` are running, transaction commits will wait for replies from at least any two standbys of `s1`, `s2` and `s3`. `s4` is an asynchronous standby since its name is not in the list.

The `FIRST` and `ANY` methods can be used together with the `MIN` option that specifies the minimum number of synchronous standbys that must be connected to the primary at all times. You can use this option if some of the synchronous standbys are unstable or have poor connection to the primary. It allows to prevent blocking of the primary server if one or more synchronous standbys temporarily go offline.

An example of using priority-based multiple synchronous standbys with the `MIN` option:

```
synchronous_standby_names = 'FIRST 3 MIN 2 (s1, s2, s3, s4)'
```

In this example, the primary will continue running even if only two standbys remain available.

For the quorum-based case, the syntax is quite similar:

```
synchronous_standby_names = 'ANY 3 MIN 2 (s1, s2, s3, s4)'
```

Once the connection is restored, the behavior of the primary server depends on the synchronous_standby_gap setting.

The synchronous states of standby servers can be viewed using the `pg_stat_replication` view.

26.2.8.3. Planning for Performance

Synchronous replication usually requires carefully planned and placed standby servers to ensure applications perform acceptably. Waiting doesn't utilize system resources, but transaction locks continue to be held until the transfer is confirmed. As a result, incautious use of synchronous replication will reduce performance for database applications because of increased response times and higher contention.

Postgres Pro allows the application developer to specify the durability level required via replication. This can be specified for the system overall, though it can also be specified for specific users or connections, or even individual transactions.

For example, an application workload might consist of: 10% of changes are important customer details, while 90% of changes are less important data that the business can more easily survive if it is lost, such as chat messages between users.

With synchronous replication options specified at the application level (on the primary) we can offer synchronous replication for the most important changes, without slowing down the bulk of the total workload. Application level options are an important and practical tool for allowing the benefits of synchronous replication for high performance applications.

You should consider that the network bandwidth must be higher than the rate of generation of WAL data.

26.2.8.4. Planning for High Availability

`synchronous_standby_names` specifies the number and names of synchronous standbys that transaction commits made when `synchronous_commit` is set to `on`, `remote_apply` or `remote_write` will wait for responses from. Such transaction commits may never be completed if any one of the synchronous standbys should crash.

The best solution for high availability is to ensure you keep as many synchronous standbys as requested. This can be achieved by naming multiple potential synchronous standbys using `synchronous_standby_names`.

In a priority-based synchronous replication, the standbys whose names appear earlier in the list will be used as synchronous standbys. Standbys listed after these will take over the role of synchronous standby if one of current ones should fail.

In a quorum-based synchronous replication, all the standbys appearing in the list will be used as candidates for synchronous standbys. Even if one of them should fail, the other standbys will keep performing the role of candidates of synchronous standby.

When a standby first attaches to the primary, it will not yet be properly synchronized. This is described as `catchup` mode. Once the lag between standby and primary reaches zero for the first time we move to real-time `streaming` state. The catch-up duration may be long immediately after the standby has been created. If the standby is shut down, then the catch-up period will increase according to the length of time the standby has been down. The standby is only able to become a synchronous standby once it has reached `streaming` state. This state can be viewed using the `pg_stat_replication` view.

If primary restarts while commits are waiting for acknowledgment, those waiting transactions will be marked fully committed once the primary database recovers. There is no way to be certain that all standbys have received all outstanding WAL data at time of the crash of the primary. Some transactions may not show as committed on the standby, even though they show as committed on the primary. The guarantee we offer is that the application will not receive explicit acknowledgment of the successful commit of a transaction until the WAL data is known to be safely received by all the synchronous standbys.

If you really cannot keep as many synchronous standbys as requested then you should decrease the number of synchronous standbys that transaction commits must wait for responses from in `synchronous_standby_names` (or disable it) and reload the configuration file on the primary server.

If the primary is isolated from remaining standby servers you should fail over to the best candidate of those other remaining standby servers.

If you need to re-create a standby server while transactions are waiting, make sure that the commands pg_start_backup() and pg_stop_backup() are run in a session with `synchronous_commit` = `off`, otherwise those requests will wait forever for the standby to appear.

26.2.9. Continuous Archiving in Standby

When continuous WAL archiving is used in a standby, there are two different scenarios: the WAL archive can be shared between the primary and the standby, or the standby can have its own WAL archive. When the standby has its own WAL archive, set `archive_mode` to `always`, and the standby will call the archive command for every WAL segment it receives, whether it's by restoring from the archive or by streaming replication. The shared archive can be handled similarly, but the `archive_command` must test if the file being archived exists already, and if the existing file has identical contents. This requires more care in the `archive_command`, as it must be careful to not overwrite an existing file with different contents, but return success if the exactly same file is archived twice. And all that must be done free of race conditions, if two servers attempt to archive the same file at the same time.

If `archive_mode` is set to `on`, the archiver is not enabled during recovery or standby mode. If the standby server is promoted, it will start archiving after the promotion, but will not archive any WAL or timeline history files that it did not generate itself. To get a complete series of WAL files in the archive, you must ensure that all WAL is archived, before it reaches the standby. This is inherently true with file-based log shipping, as the standby can only restore files that are found in the archive, but not if streaming replication is enabled. When a server is not in recovery mode, there is no difference between `on` and `always` modes.

26.3. Failover

If the primary server fails then the standby server should begin failover procedures.

If the standby server fails then no failover need take place. If the standby server can be restarted, even some time later, then the recovery process can also be restarted immediately, taking advantage of restartable recovery. If the standby server cannot be restarted, then a full new standby server instance should be created.

If the primary server fails and the standby server becomes the new primary, and then the old primary restarts, you must have a mechanism for informing the old primary that it is no longer the primary. This is sometimes known as STONITH (Shoot The Other Node In The Head), which is necessary to avoid situations where both systems think they are the primary, which will lead to confusion and ultimately data loss.

Many failover systems use just two systems, the primary and the standby, connected by some kind of heartbeat mechanism to continually verify the connectivity between the two and the viability of the primary. It is also possible to use a third system (called a witness server) to prevent some cases of inappropriate failover, but the additional complexity might not be worthwhile unless it is set up with sufficient care and rigorous testing.

Postgres Pro does not provide the system software required to identify a failure on the primary and notify the standby database server. Many such tools exist and are well integrated with the operating system facilities required for successful failover, such as IP address migration.

Once failover to the standby occurs, there is only a single server in operation. This is known as a degenerate state. The former standby is now the primary, but the former primary is down and might stay down. To return to normal operation, a standby server must be recreated, either on the former primary system when it comes up, or on a third, possibly new, system. The pg_rewind utility can be used to speed up this process on large clusters. Once complete, the primary and standby can be considered to have switched roles. Some people choose to use a third server to provide backup for the new primary until the new standby server is recreated, though clearly this complicates the system configuration and operational processes.

So, switching from primary to standby server can be fast but requires some time to re-prepare the failover cluster. Regular switching from primary to standby is useful, since it allows regular downtime on each system for maintenance. This also serves as a test of the failover mechanism to ensure that it will really work when you need it. Written administration procedures are advised.

To trigger failover of a log-shipping standby server, run `pg_ctl promote`, call `pg_promote()`, or create a trigger file with the file name and path specified by the `promote_trigger_file`. If you're planning to use

`pg_ctl promote` or to call `pg_promote()` to fail over, `promote_trigger_file` is not required. If you're setting up the reporting servers that are only used to offload read-only queries from the primary, not for high availability purposes, you don't need to promote it.

26.4. Hot Standby

Hot Standby is the term used to describe the ability to connect to the server and run read-only queries while the server is in archive recovery or standby mode. This is useful both for replication purposes and for restoring a backup to a desired state with great precision. The term Hot Standby also refers to the ability of the server to move from recovery through to normal operation while users continue running queries and/or keep their connections open.

Running queries in hot standby mode is similar to normal query operation, though there are several usage and administrative differences explained below.

26.4.1. User's Overview

When the hot_standby parameter is set to true on a standby server, it will begin accepting connections once the recovery has brought the system to a consistent state. All such connections are strictly read-only; not even temporary tables may be written.

The data on the standby takes some time to arrive from the primary server so there will be a measurable delay between primary and standby. Running the same query nearly simultaneously on both primary and standby might therefore return differing results. We say that data on the standby is *eventually consistent* with the primary. Once the commit record for a transaction is replayed on the standby, the changes made by that transaction will be visible to any new snapshots taken on the standby. Snapshots may be taken at the start of each query or at the start of each transaction, depending on the current transaction isolation level. For more details, see Section 13.2.

Transactions started during hot standby may issue the following commands:

- Query access: `SELECT`, `COPY TO`
- Cursor commands: `DECLARE`, `FETCH`, `CLOSE`
- Settings: `SHOW`, `SET`, `RESET`
- Transaction management commands:
  - `BEGIN`, `END`, `ABORT`, `START TRANSACTION`
  - `SAVEPOINT`, `RELEASE`, `ROLLBACK TO SAVEPOINT`
  - `EXCEPTION` blocks and other internal subtransactions
- `LOCK TABLE`, though only when explicitly in one of these modes: `ACCESS SHARE`, `ROW SHARE` or `ROW EXCLUSIVE`.
- Plans and resources: `PREPARE`, `EXECUTE`, `DEALLOCATE`, `DISCARD`
- Plugins and extensions: `LOAD`
- `UNLISTEN`

Transactions started during hot standby will never be assigned a transaction ID and cannot write to the system write-ahead log. Therefore, the following actions will produce error messages:

- Data Manipulation Language (DML): `INSERT`, `UPDATE`, `DELETE`, `COPY FROM`, `TRUNCATE`. Note that there are no allowed actions that result in a trigger being executed during recovery. This restriction applies even to temporary tables, because table rows cannot be read or written without assigning a transaction ID, which is currently not possible in a Hot Standby environment.
- Data Definition Language (DDL): `CREATE`, `DROP`, `ALTER`, `COMMENT`. This restriction applies even to temporary tables, because carrying out these operations would require updating the system catalog tables.

- `SELECT ... FOR SHARE | UPDATE`, because row locks cannot be taken without updating the underlying data files.
- Rules on `SELECT` statements that generate DML commands.
- `LOCK` that explicitly requests a mode higher than `ROW EXCLUSIVE MODE`.
- `LOCK` in short default form, since it requests `ACCESS EXCLUSIVE MODE`.
- Transaction management commands that explicitly set non-read-only state:
  - `BEGIN READ WRITE`, `START TRANSACTION READ WRITE`
  - `SET TRANSACTION READ WRITE`, `SET SESSION CHARACTERISTICS AS TRANSACTION READ WRITE`
  - `SET transaction_read_only = off`
- Two-phase commit commands: `PREPARE TRANSACTION`, `COMMIT PREPARED`, `ROLLBACK PREPARED` because even read-only transactions need to write WAL in the prepare phase (the first phase of two phase commit).
- Sequence updates: `nextval()`, `setval()`
- `LISTEN`, `NOTIFY`

In normal operation, "read-only" transactions are allowed to use `LISTEN` and `NOTIFY`, so Hot Standby sessions operate under slightly tighter restrictions than ordinary read-only sessions. It is possible that some of these restrictions might be loosened in a future release.

During hot standby, the parameter `transaction_read_only` is always true and may not be changed. But as long as no attempt is made to modify the database, connections during hot standby will act much like any other database connection. If failover or switchover occurs, the database will switch to normal processing mode. Sessions will remain connected while the server changes mode. Once hot standby finishes, it will be possible to initiate read-write transactions (even from a session begun during hot standby).

Users can determine whether hot standby is currently active for their session by issuing `SHOW in_hot_standby`. (In server versions before 14, the `in_hot_standby` parameter did not exist; a workable substitute method for older servers is `SHOW transaction_read_only`.) In addition, a set of functions (Table 9.88) allow users to access information about the standby server. These allow you to write programs that are aware of the current state of the database. These can be used to monitor the progress of recovery, or to allow you to write complex programs that restore the database to particular states.

26.4.2. Handling Query Conflicts

The primary and standby servers are in many ways loosely connected. Actions on the primary will have an effect on the standby. As a result, there is potential for negative interactions or conflicts between them. The easiest conflict to understand is performance: if a huge data load is taking place on the primary then this will generate a similar stream of WAL records on the standby, so standby queries may contend for system resources, such as I/O.

There are also additional types of conflict that can occur with Hot Standby. These conflicts are *hard conflicts* in the sense that queries might need to be canceled and, in some cases, sessions disconnected to resolve them. The user is provided with several ways to handle these conflicts. Conflict cases include:

- Access Exclusive locks taken on the primary server, including both explicit `LOCK` commands and various DDL actions, conflict with table accesses in standby queries.
- Dropping a tablespace on the primary conflicts with standby queries using that tablespace for temporary work files.
- Dropping a database on the primary conflicts with sessions connected to that database on the standby.
- Application of a vacuum cleanup record from WAL conflicts with standby transactions whose snapshots can still "see" any of the rows to be removed.

- Application of a vacuum cleanup record from WAL conflicts with queries accessing the target page on the standby, whether or not the data to be removed is visible.

On the primary server, these cases simply result in waiting; and the user might choose to cancel either of the conflicting actions. However, on the standby there is no choice: the WAL-logged action already occurred on the primary so the standby must not fail to apply it. Furthermore, allowing WAL application to wait indefinitely may be very undesirable, because the standby's state will become increasingly far behind the primary's. Therefore, a mechanism is provided to forcibly cancel standby queries that conflict with to-be-applied WAL records.

An example of the problem situation is an administrator on the primary server running `DROP TABLE` on a table that is currently being queried on the standby server. Clearly the standby query cannot continue if the `DROP TABLE` is applied on the standby. If this situation occurred on the primary, the `DROP TABLE` would wait until the other query had finished. But when `DROP TABLE` is run on the primary, the primary doesn't have information about what queries are running on the standby, so it will not wait for any such standby queries. The WAL change records come through to the standby while the standby query is still running, causing a conflict. The standby server must either delay application of the WAL records (and everything after them, too) or else cancel the conflicting query so that the `DROP TABLE` can be applied.

When a conflicting query is short, it's typically desirable to allow it to complete by delaying WAL application for a little bit; but a long delay in WAL application is usually not desirable. So the cancel mechanism has parameters, max_standby_archive_delay and max_standby_streaming_delay, that define the maximum allowed delay in WAL application. Conflicting queries will be canceled once it has taken longer than the relevant delay setting to apply any newly-received WAL data. There are two parameters so that different delay values can be specified for the case of reading WAL data from an archive (i.e., initial recovery from a base backup or “catching up” a standby server that has fallen far behind) versus reading WAL data via streaming replication.

In a standby server that exists primarily for high availability, it's best to set the delay parameters relatively short, so that the server cannot fall far behind the primary due to delays caused by standby queries. However, if the standby server is meant for executing long-running queries, then a high or even infinite delay value may be preferable. Keep in mind however that a long-running query could cause other sessions on the standby server to not see recent changes on the primary, if it delays application of WAL records.

Once the delay specified by `max_standby_archive_delay` or `max_standby_streaming_delay` has been exceeded, conflicting queries will be canceled. This usually results just in a cancellation error, although in the case of replaying a `DROP DATABASE` the entire conflicting session will be terminated. Also, if the conflict is over a lock held by an idle transaction, the conflicting session is terminated (this behavior might change in the future).

Canceled queries may be retried immediately (after beginning a new transaction, of course). Since query cancellation depends on the nature of the WAL records being replayed, a query that was canceled may well succeed if it is executed again.

Keep in mind that the delay parameters are compared to the elapsed time since the WAL data was received by the standby server. Thus, the grace period allowed to any one query on the standby is never more than the delay parameter, and could be considerably less if the standby has already fallen behind as a result of waiting for previous queries to complete, or as a result of being unable to keep up with a heavy update load.

The most common reason for conflict between standby queries and WAL replay is “early cleanup”. Normally, Postgres Pro allows cleanup of old row versions when there are no transactions that need to see them to ensure correct visibility of data according to MVCC rules. However, this rule can only be applied for transactions executing on the primary. So it is possible that cleanup on the primary will remove row versions that are still visible to a transaction on the standby.

Experienced users should note that both row version cleanup and row version freezing will potentially conflict with standby queries. Running a manual `VACUUM FREEZE` is likely to cause conflicts even on tables with no updated or deleted rows.

Users should be clear that tables that are regularly and heavily updated on the primary server will quickly cause cancellation of longer running queries on the standby. In such cases the setting of a finite value for `max_standby_archive_delay` or `max_standby_streaming_delay` can be considered similar to setting `statement_timeout`.

Remedial possibilities exist if the number of standby-query cancellations is found to be unacceptable. The first option is to set the parameter `hot_standby_feedback`, which prevents `VACUUM` from removing recently-dead rows and so cleanup conflicts do not occur. If you do this, you should note that this will delay cleanup of dead rows on the primary, which may result in undesirable table bloat. However, the cleanup situation will be no worse than if the standby queries were running directly on the primary server, and you are still getting the benefit of off-loading execution onto the standby. If standby servers connect and disconnect frequently, you might want to make adjustments to handle the period when `hot_standby_feedback` feedback is not being provided. For example, consider increasing `max_standby_archive_delay` so that queries are not rapidly canceled by conflicts in WAL archive files during disconnected periods. You should also consider increasing `max_standby_streaming_delay` to avoid rapid cancellations by newly-arrived streaming WAL entries after reconnection.

Another option is to increase vacuum_defer_cleanup_age on the primary server, so that dead rows will not be cleaned up as quickly as they normally would be. This will allow more time for queries to execute before they are canceled on the standby, without having to set a high `max_standby_streaming_delay`. However it is difficult to guarantee any specific execution-time window with this approach, since `vacuum_defer_cleanup_age` is measured in transactions executed on the primary server.

The number of query cancels and the reason for them can be viewed using the `pg_stat_database_conflicts` system view on the standby server. The `pg_stat_database` system view also contains summary information.

Users can control whether a log message is produced when WAL replay is waiting longer than `deadlock_timeout` for conflicts. This is controlled by the log_recovery_conflict_waits parameter.

26.4.3. Administrator's Overview

If `hot_standby` is `on` in `postgresql.conf` (the default value) and there is a `standby.signal`file present, the server will run in Hot Standby mode. However, it may take some time for Hot Standby connections to be allowed, because the server will not accept connections until it has completed sufficient recovery to provide a consistent state against which queries can run. During this period, clients that attempt to connect will be refused with an error message. To confirm the server has come up, either loop trying to connect from the application, or look for these messages in the server logs:

```
LOG:  entering standby mode

... then some time later ...

LOG:  consistent recovery state reached
LOG:  database system is ready to accept read-only connections
```

Consistency information is recorded once per checkpoint on the primary. It is not possible to enable hot standby when reading WAL written during a period when `wal_level` was not set to `replica` or `logical` on the primary. Reaching a consistent state can also be delayed in the presence of both of these conditions:

- A write transaction has more than 64 subtransactions
- Very long-lived write transactions

If you are running file-based log shipping ("warm standby"), you might need to wait until the next WAL file arrives, which could be as long as the `archive_timeout` setting on the primary.

The settings of some parameters determine the size of shared memory for tracking transaction IDs, locks, and prepared transactions. These shared memory structures must be no smaller on a standby than on the primary in order to ensure that the standby does not run out of shared memory during recovery.

For example, if the primary had used a prepared transaction but the standby had not allocated any shared memory for tracking prepared transactions, then recovery could not continue until the standby's configuration is changed. The parameters affected are:

- `max_connections`
- `max_prepared_transactions`
- `max_locks_per_transaction`
- `max_wal_senders`
- `max_worker_processes`

The easiest way to ensure this does not become a problem is to have these parameters set on the standbys to values equal to or greater than on the primary. Therefore, if you want to increase these values, you should do so on all standby servers first, before applying the changes to the primary server. Conversely, if you want to decrease these values, you should do so on the primary server first, before applying the changes to all standby servers. Keep in mind that when a standby is promoted, it becomes the new reference for the required parameter settings for the standbys that follow it. Therefore, to avoid this becoming a problem during a switchover or failover, it is recommended to keep these settings the same on all standby servers.

The WAL tracks changes to these parameters on the primary. If a hot standby processes WAL that indicates that the current value on the primary is higher than its own value, it will log a warning and pause recovery, for example:

```
WARNING:  hot standby is not possible because of insufficient parameter settings
DETAIL:  max_connections = 80 is a lower setting than on the primary server, where its
 value was 100.
LOG:  recovery has paused
DETAIL:  If recovery is unpaused, the server will shut down.
HINT:  You can then restart the server after making the necessary configuration
 changes.
```

At that point, the settings on the standby need to be updated and the instance restarted before recovery can continue. If the standby is not a hot standby, then when it encounters the incompatible parameter change, it will shut down immediately without pausing, since there is then no value in keeping it up.

It is important that the administrator select appropriate settings for max_standby_archive_delay and max_standby_streaming_delay. The best choices vary depending on business priorities. For example if the server is primarily tasked as a High Availability server, then you will want low delay settings, perhaps even zero, though that is a very aggressive setting. If the standby server is tasked as an additional server for decision support queries then it might be acceptable to set the maximum delay values to many hours, or even -1 which means wait forever for queries to complete.

Transaction status "hint bits" written on the primary are not WAL-logged, so data on the standby will likely re-write the hints again on the standby. Thus, the standby server will still perform disk writes even though all users are read-only; no changes occur to the data values themselves. Users will still write large sort temporary files and re-generate relcache info files, so no part of the database is truly read-only during hot standby mode. Note also that writes to remote databases using dblink module, and other operations outside the database using PL functions will still be possible, even though the transaction is read-only locally.

The following types of administration commands are not accepted during recovery mode:

- Data Definition Language (DDL): e.g., `CREATE INDEX`
- Privilege and Ownership: `GRANT`, `REVOKE`, `REASSIGN`
- Maintenance commands: `ANALYZE`, `VACUUM`, `CLUSTER`, `REINDEX`

Again, note that some of these commands are actually allowed during "read only" mode transactions on the primary.

As a result, you cannot create additional indexes that exist solely on the standby, nor statistics that exist solely on the standby. If these administration commands are needed, they should be executed on the primary, and eventually those changes will propagate to the standby.

`pg_cancel_backend()` and `pg_terminate_backend()` will work on user backends, but not the Startup process, which performs recovery. `pg_stat_activity` does not show recovering transactions as active. As a result, `pg_prepared_xacts` is always empty during recovery. If you wish to resolve in-doubt prepared transactions, view `pg_prepared_xacts` on the primary and issue commands to resolve transactions there or resolve them after the end of recovery.

`pg_locks` will show locks held by backends, as normal. `pg_locks` also shows a virtual transaction managed by the Startup process that owns all `AccessExclusiveLocks` held by transactions being replayed by recovery. Note that the Startup process does not acquire locks to make database changes, and thus locks other than `AccessExclusiveLocks` do not show in `pg_locks` for the Startup process; they are just presumed to exist.

The Nagios plugin check_pgsql will work, because the simple information it checks for exists. The check_postgres monitoring script will also work, though some reported values could give different or confusing results. For example, last vacuum time will not be maintained, since no vacuum occurs on the standby. Vacuums running on the primary do still send their changes to the standby.

WAL file control commands will not work during recovery, e.g., `pg_start_backup`, `pg_switch_wal` etc.

Dynamically loadable modules work, including `pg_stat_statements`.

Advisory locks work normally in recovery, including deadlock detection. Note that advisory locks are never WAL logged, so it is impossible for an advisory lock on either the primary or the standby to conflict with WAL replay. Nor is it possible to acquire an advisory lock on the primary and have it initiate a similar advisory lock on the standby. Advisory locks relate only to the server on which they are acquired.

Trigger-based replication systems such as Slony, Londiste and Bucardo won't run on the standby at all, though they will run happily on the primary server as long as the changes are not sent to standby servers to be applied. WAL replay is not trigger-based so you cannot relay from the standby to any system that requires additional database writes or relies on the use of triggers.

New OIDs cannot be assigned, though some UUID generators may still work as long as they do not rely on writing new status to the database.

Currently, temporary table creation is not allowed during read-only transactions, so in some cases existing scripts will not run correctly. This restriction might be relaxed in a later release. This is both an SQL standard compliance issue and a technical issue.

`DROP TABLESPACE` can only succeed if the tablespace is empty. Some standby users may be actively using the tablespace via their `temp_tablespaces` parameter. If there are temporary files in the tablespace, all active queries are canceled to ensure that temporary files are removed, so the tablespace can be removed and WAL replay can continue.

Running `DROP DATABASE` or `ALTER DATABASE ... SET TABLESPACE` on the primary will generate a WAL entry that will cause all users connected to that database on the standby to be forcibly disconnected. This action occurs immediately, whatever the setting of `max_standby_streaming_delay`. Note that `ALTER DATABASE ... RENAME` does not disconnect users, which in most cases will go unnoticed, though might in some cases cause a program confusion if it depends in some way upon database name.

In normal (non-recovery) mode, if you issue `DROP USER` or `DROP ROLE` for a role with login capability while that user is still connected then nothing happens to the connected user — they remain connected. The user cannot reconnect however. This behavior applies in recovery also, so a `DROP USER` on the primary does not disconnect that user on the standby.

The statistics collector is active during recovery. All scans, reads, blocks, index usage, etc., will be recorded normally on the standby. Replayed actions will not duplicate their effects on primary, so re-

playing an insert will not increment the Inserts column of pg_stat_user_tables. The stats file is deleted at the start of recovery, so stats from primary and standby will differ; this is considered a feature, not a bug.

Autovacuum is not active during recovery. It will start normally at the end of recovery.

The checkpointer process and the background writer process are active during recovery. The checkpointer process will perform restartpoints (similar to checkpoints on the primary) and the background writer process will perform normal block cleaning activities. This can include updates of the hint bit information stored on the standby server. The `CHECKPOINT` command is accepted during recovery, though it performs a restartpoint rather than a new checkpoint.

26.4.4. Hot Standby Parameter Reference

Various parameters have been mentioned above in Section 26.4.2 and Section 26.4.3.

On the primary, parameters wal_level and vacuum_defer_cleanup_age can be used. max_standby_archive_delay and max_standby_streaming_delay have no effect if set on the primary.

On the standby, parameters hot_standby, max_standby_archive_delay and max_standby_streaming_delay can be used. vacuum_defer_cleanup_age has no effect as long as the server remains in standby mode, though it will become relevant if the standby becomes primary.

26.4.5. Caveats

There are several limitations of Hot Standby. These can and probably will be fixed in future releases:

- Full knowledge of running transactions is required before snapshots can be taken. Transactions that use large numbers of subtransactions (currently greater than 64) will delay the start of read-only connections until the completion of the longest running write transaction. If this situation occurs, explanatory messages will be sent to the server log.
- Valid starting points for standby queries are generated at each checkpoint on the primary. If the standby is shut down while the primary is in a shutdown state, it might not be possible to re-enter Hot Standby until the primary is started up, so that it generates further starting points in the WAL logs. This situation isn't a problem in the most common situations where it might happen. Generally, if the primary is shut down and not available anymore, that's likely due to a serious failure that requires the standby being converted to operate as the new primary anyway. And in situations where the primary is being intentionally taken down, coordinating to make sure the standby becomes the new primary smoothly is also standard procedure.
- At the end of recovery, `AccessExclusiveLocks` held by prepared transactions will require twice the normal number of lock table entries. If you plan on running either a large number of concurrent prepared transactions that normally take `AccessExclusiveLocks`, or you plan on having one large transaction that takes many `AccessExclusiveLocks`, you are advised to select a larger value of `max_locks_per_transaction`, perhaps as much as twice the value of the parameter on the primary server. You need not consider this at all if your setting of `max_prepared_transactions` is 0.
- The Serializable transaction isolation level is not yet available in hot standby. (See Section 13.2.3 and Section 13.4.1 for details.) An attempt to set a transaction to the serializable isolation level in hot standby mode will generate an error.

Chapter 27. Monitoring Database Activity

A database administrator frequently wonders, “What is the system doing right now?” This chapter discusses how to find that out.

Several tools are available for monitoring database activity and analyzing performance. Most of this chapter is devoted to describing Postgres Pro's statistics collector, but one should not neglect regular Unix monitoring programs such as `ps`, `top`, `iostat`, and `vmstat`. Also, once one has identified a poorly-performing query, further investigation might be needed using Postgres Pro's `EXPLAIN` command. Section 14.1 discusses `EXPLAIN` and other methods for understanding the behavior of an individual query.

27.1. Standard Unix Tools

On most Unix platforms, Postgres Pro modifies its command title as reported by `ps`, so that individual server processes can readily be identified. A sample display is

```
$ ps auxww | grep ^postgres
postgres  15551  0.0  0.1  57536  7132 pts/0    S    18:02   0:00 postgres -i
postgres  15554  0.0  0.0  57536  1184 ?        Ss   18:02   0:00 postgres: background
 writer
postgres  15555  0.0  0.0  57536   916 ?        Ss   18:02   0:00 postgres:
 checkpointer
postgres  15556  0.0  0.0  57536   916 ?        Ss   18:02   0:00 postgres: walwriter
postgres  15557  0.0  0.0  58504  2244 ?        Ss   18:02   0:00 postgres: autovacuum
 launcher
postgres  15558  0.0  0.0  17512  1068 ?        Ss   18:02   0:00 postgres: stats
 collector
postgres  15582  0.0  0.0  58772  3080 ?        Ss   18:04   0:00 postgres: joe runbug
 127.0.0.1 idle
postgres  15606  0.0  0.0  58772  3052 ?        Ss   18:07   0:00 postgres: tgl
 regression [local] SELECT waiting
postgres  15610  0.0  0.0  58772  3056 ?        Ss   18:07   0:00 postgres: tgl
 regression [local] idle in transaction
```

(The appropriate invocation of `ps` varies across different platforms, as do the details of what is shown. This example is from a recent Linux system.) The first process listed here is the primary server process. The command arguments shown for it are the same ones used when it was launched. The next five processes are background worker processes automatically launched by the primary process. (The “stats collector” process will not be present if you have set the system not to start the statistics collector; likewise the “autovacuum launcher” process can be disabled.) Each of the remaining processes is a server process handling one client connection. Each such process sets its command line display in the form

`postgres: *user database host activity*`

The user, database, and (client) host items remain the same for the life of the client connection, but the activity indicator changes. The activity can be `idle` (i.e., waiting for a client command), `idle in transaction` (waiting for client inside a `BEGIN` block), or a command type name such as `SELECT`. Also, `waiting` is appended if the server process is presently waiting on a lock held by another session. In the above example we can infer that process 15606 is waiting for process 15610 to complete its transaction and thereby release some lock. (Process 15610 must be the blocker, because there is no other active session. In more complicated cases it would be necessary to look into the `pg_locks` system view to determine who is blocking whom.)

If cluster_name has been configured the cluster name will also be shown in `ps` output:

```
$ psql -c 'SHOW cluster_name'
 cluster_name
--------------
 server1
```

```
(1 row)

$ ps aux|grep server1
postgres   27093  0.0  0.0  30096  2752 ?        Ss   11:34   0:00 postgres: server1:
 background writer
...
```

If you have turned off update_process_title then the activity indicator is not updated; the process title is set only once when a new process is launched. On some platforms this saves a measurable amount of per-command overhead; on others it's insignificant.

> **Tip**
>
> Solaris requires special handling. You must use `/usr/ucb/ps`, rather than `/bin/ps`. You also must use two `w` flags, not just one. In addition, your original invocation of the `postgres` command must have a shorter `ps` status display than that provided by each server process. If you fail to do all three things, the `ps` output for each server process will be the original `postgres` command line.

27.2. The Statistics Collector

Postgres Pro's *statistics collector* is a subsystem that supports collection and reporting of information about server activity. Presently, the collector can count accesses to tables and indexes in both disk-block and individual-row terms. It also tracks the total number of rows in each table, and information about vacuum and analyze actions for each table. It can also count calls to user-defined functions and the total time spent in each one.

Postgres Pro also supports reporting dynamic information about exactly what is going on in the system right now, such as the exact command currently being executed by other server processes, and which other connections exist in the system. This facility is independent of the collector process.

27.2.1. Statistics Collection Configuration

Since collection of statistics adds some overhead to query execution, the system can be configured to collect or not collect information. This is controlled by configuration parameters that are normally set in `postgresql.conf`. (See Chapter 19 for details about setting configuration parameters.)

The parameter track_activities enables monitoring of the current command being executed by any server process.

The parameter track_counts controls whether statistics are collected about table and index accesses.

The parameter track_functions enables tracking of usage of user-defined functions.

The parameter track_io_timing enables monitoring of block read and write times.

The parameter track_wal_io_timing enables monitoring of WAL write times.

Normally these parameters are set in `postgresql.conf` so that they apply to all server processes, but it is possible to turn them on or off in individual sessions using the SET command. (To prevent ordinary users from hiding their activity from the administrator, only superusers are allowed to change these parameters with `SET`.)

The statistics collector transmits the collected information to other Postgres Pro processes through temporary files. These files are stored in the directory named by the stats_temp_directory parameter, `pg_stat_tmp` by default. For better performance, `stats_temp_directory` can be pointed at a RAM-based file system, decreasing physical I/O requirements. When the server shuts down cleanly, a permanent copy of the statistics data is stored in the `pg_stat` subdirectory, so that statistics can be retained across server restarts. When recovery is performed at server start (e.g., after immediate shutdown, server crash, and point-in-time recovery), all statistics counters are reset.

27.2.2. Viewing Statistics

Several predefined views, listed in Table 27.1, are available to show the current state of the system. There are also several other views, listed in Table 27.2, available to show the results of statistics collection. Alternatively, one can build custom views using the underlying statistics functions, as discussed in Section 27.2.25.

When using the statistics to monitor collected data, it is important to realize that the information does not update instantaneously. Each individual server process transmits new statistical counts to the collector just before going idle; so a query or transaction still in progress does not affect the displayed totals. Also, the collector itself emits a new report at most once per `PGSTAT_STAT_INTERVAL` milliseconds (500 ms unless altered while building the server). So the displayed information lags behind actual activity. However, current-query information collected by `track_activities` is always up-to-date.

Another important point is that when a server process is asked to display any of these statistics, it first fetches the most recent report emitted by the collector process and then continues to use this snapshot for all statistical views and functions until the end of its current transaction. So the statistics will show static information as long as you continue the current transaction. Similarly, information about the current queries of all sessions is collected when any such information is first requested within a transaction, and the same information will be displayed throughout the transaction. This is a feature, not a bug, because it allows you to perform several queries on the statistics and correlate the results without worrying that the numbers are changing underneath you. But if you want to see new results with each query, be sure to do the queries outside any transaction block. Alternatively, you can invoke `pg_stat_clear_snapshot()`, which will discard the current transaction's statistics snapshot (if any). The next use of statistical information will cause a new snapshot to be fetched.

A transaction can also see its own statistics (as yet untransmitted to the collector) in the views `pg_stat_xact_all_tables`, `pg_stat_xact_sys_tables`, `pg_stat_xact_user_tables`, and `pg_stat_xact_user_functions`. These numbers do not act as stated above; instead they update continuously throughout the transaction.

Some of the information in the dynamic statistics views shown in Table 27.1 is security restricted. Ordinary users can only see all the information about their own sessions (sessions belonging to a role that they are a member of). In rows about other sessions, many columns will be null. Note, however, that the existence of a session and its general properties such as its sessions user and database are visible to all users. Superusers and members of the built-in role `pg_read_all_stats` (see also Section 21.5) can see all the information about all sessions.

Table 27.1. Dynamic Statistics Views

View Name	Description
`pg_stat_activity`	One row per server process, showing information related to the current activity of that process, such as state and current query. See `pg_stat_activity` for details.
`pg_pool_backends`	One row per pooler backend, showing information on the workload of that backend. See `pg_pool_backends` for details.
`pg_client_session_info`	One row per client session in the built-in connection pooler, showing information on that session. See `pg_client_session_info` for details.
`pgpro_stat_wal_activity`	One row per server process, showing the size of WAL files generated by this process, as well as all the data provided in the `pg_stat_activity` view. See `pgpro_stat_wal_activity` for details.
`pg_stat_replication`	One row per WAL sender process, showing statistics about replication to that sender's connected

View Name	Description
	standby server. See pg_stat_replication for details.
pg_stat_wal_receiver	Only one row, showing statistics about the WAL receiver from that receiver's connected server. See pg_stat_wal_receiver for details.
pg_stat_subscription	At least one row per subscription, showing information about the subscription workers. See pg_stat_subscription for details.
pg_stat_ssl	One row per connection (regular and replication), showing information about SSL used on this connection. See pg_stat_ssl for details.
pg_stat_gssapi	One row per connection (regular and replication), showing information about GSSAPI authentication and encryption used on this connection. See pg_stat_gssapi for details.
pg_stat_progress_analyze	One row for each backend (including autovacuum worker processes) running ANALYZE, showing current progress. See Section 27.4.1.
pg_stat_progress_create_index	One row for each backend running CREATE INDEX or REINDEX, showing current progress. See Section 27.4.2.
pg_stat_progress_vacuum	One row for each backend (including autovacuum worker processes) running VACUUM, showing current progress. See Section 27.4.3.
pg_stat_progress_cluster	One row for each backend running CLUSTER or VACUUM FULL, showing current progress. See Section 27.4.4.
pg_stat_progress_basebackup	One row for each WAL sender process streaming a base backup, showing current progress. See Section 27.4.5.
pg_stat_progress_copy	One row for each backend running COPY, showing current progress. See Section 27.4.6.

Table 27.2. Collected Statistics Views

View Name	Description
pg_stat_archiver	One row only, showing statistics about the WAL archiver process's activity. See pg_stat_archiver for details.
pg_stat_bgwriter	One row only, showing statistics about the background writer process's activity. See pg_stat_bgwriter for details.
pg_stat_wal	One row only, showing statistics about WAL activity. See pg_stat_wal for details.
pg_stat_database	One row per database, showing database-wide statistics. See pg_stat_database for details.
pg_stat_database_conflicts	One row per database, showing database-wide statistics about query cancels due to conflict with recovery on standby servers. See pg_stat_database_conflicts for details.

View Name	Description
pg_stat_all_tables	One row for each table in the current database, showing statistics about accesses to that specific table. See pg_stat_all_tables for details.
pg_stat_sys_tables	Same as pg_stat_all_tables, except that only system tables are shown.
pg_stat_user_tables	Same as pg_stat_all_tables, except that only user tables are shown.
pg_stat_xact_all_tables	Similar to pg_stat_all_tables, but counts actions taken so far within the current transaction (which are *not* yet included in pg_stat_all_tables and related views). The columns for numbers of live and dead rows and vacuum and analyze actions are not present in this view.
pg_stat_xact_sys_tables	Same as pg_stat_xact_all_tables, except that only system tables are shown.
pg_stat_xact_user_tables	Same as pg_stat_xact_all_tables, except that only user tables are shown.
pg_stat_all_indexes	One row for each index in the current database, showing statistics about accesses to that specific index. See pg_stat_all_indexes for details.
pg_stat_sys_indexes	Same as pg_stat_all_indexes, except that only indexes on system tables are shown.
pg_stat_user_indexes	Same as pg_stat_all_indexes, except that only indexes on user tables are shown.
pg_statio_all_tables	One row for each table in the current database, showing statistics about I/O on that specific table. See pg_statio_all_tables for details.
pg_statio_sys_tables	Same as pg_statio_all_tables, except that only system tables are shown.
pg_statio_user_tables	Same as pg_statio_all_tables, except that only user tables are shown.
pg_statio_all_indexes	One row for each index in the current database, showing statistics about I/O on that specific index. See pg_statio_all_indexes for details.
pg_statio_sys_indexes	Same as pg_statio_all_indexes, except that only indexes on system tables are shown.
pg_statio_user_indexes	Same as pg_statio_all_indexes, except that only indexes on user tables are shown.
pg_statio_all_sequences	One row for each sequence in the current database, showing statistics about I/O on that specific sequence. See pg_statio_all_sequences for details.
pg_statio_sys_sequences	Same as pg_statio_all_sequences, except that only system sequences are shown. (Presently, no system sequences are defined, so this view is always empty.)
pg_statio_user_sequences	Same as pg_statio_all_sequences, except that only user sequences are shown.

View Name	Description
pg_stat_user_functions	One row for each tracked function, showing statistics about executions of that function. See pg_stat_user_functions for details.
pg_stat_xact_user_functions	Similar to pg_stat_user_functions, but counts only calls during the current transaction (which are *not* yet included in pg_stat_user_functions).
pg_stat_slru	One row per SLRU, showing statistics of operations. See pg_stat_slru for details.
pg_stat_replication_slots	One row per replication slot, showing statistics about the replication slot's usage. See pg_stat_replication_slots for details.

The per-index statistics are particularly useful to determine which indexes are being used and how effective they are.

The pg_statio_ views are primarily useful to determine the effectiveness of the buffer cache. When the number of actual disk reads is much smaller than the number of buffer hits, then the cache is satisfying most read requests without invoking a kernel call. However, these statistics do not give the entire story: due to the way in which Postgres Pro handles disk I/O, data that is not in the Postgres Pro buffer cache might still reside in the kernel's I/O cache, and might therefore still be fetched without requiring a physical read. Users interested in obtaining more detailed information on Postgres Pro I/O behavior are advised to use the Postgres Pro statistics collector in combination with operating system utilities that allow insight into the kernel's handling of I/O.

27.2.3. pg_stat_activity

The pg_stat_activity view will have one row per server process, showing information related to the current activity of that process.

Table 27.3. pg_stat_activity View

Column Type Description
datid oid OID of the database this backend is connected to
datname name Name of the database this backend is connected to
pid integer Process ID of this backend
leader_pid integer Process ID of the parallel group leader, if this process is a parallel query worker. NULL if this process is a parallel group leader or does not participate in parallel query.
usesysid oid OID of the user logged into this backend
usename name Name of the user logged into this backend
application_name text Name of the application that is connected to this backend
client_addr inet IP address of the client connected to this backend. If this field is null, it indicates either that the client is connected via a Unix socket on the server machine or that this is an internal process such as autovacuum.

Column Type Description
`client_hostname text` Host name of the connected client, as reported by a reverse DNS lookup of `client_addr` . This field will only be non-null for IP connections, and only when log_hostname is enabled.
`client_port integer` TCP port number that the client is using for communication with this backend, or `-1` if a Unix socket is used. If this field is null, it indicates that this is an internal server process.
`backend_start timestamp with time zone` Time when this process was started. For client backends, this is the time the client connected to the server.
`xact_start timestamp with time zone` Time when this process' current transaction was started, or null if no transaction is active. If the current query is the first of its transaction, this column is equal to the `query_start` column.
`query_start timestamp with time zone` Time when the currently active query was started, or if `state` is not `active`, when the last query was started
`state_change timestamp with time zone` Time when the `state` was last changed
`wait_event_type text` The type of event for which the backend is waiting, if any; otherwise NULL. See Table 27.4.
`wait_event text` Wait event name if backend is currently waiting, otherwise NULL. See Table 27.5 through Table 27.13.
`wait_state_id bigint` Internal identifier of a wait state instance. It can be used by monitoring modules to differentiate between distinct waits.
`state text` Current overall state of this backend. Possible values are: • `active`: The backend is executing a query. • `idle`: The backend is waiting for a new client command. • `idle in transaction`: The backend is in a transaction, but is not currently executing a query. • `idle in transaction (aborted)` : This state is similar to `idle in transaction`, except one of the statements in the transaction caused an error. • `fastpath function call`: The backend is executing a fast-path function. • `disabled`: This state is reported if track_activities is disabled in this backend.
`backend_xid xid` Top-level transaction identifier of this backend, if any.
`backend_xmin xid` The current backend's `xmin` horizon.
`query_id bigint` Identifier of this backend's most recent query. If `state` is `active` this field shows the identifier of the currently executing query. In all other states, it shows the identifier of last query that was executed. Query identifiers are not computed by default so this field will be null unless compute_query_id parameter is enabled or a third-party module that computes query identifiers is configured.

Column Type Description	
`query` `text` Text of this backend's most recent query. If `state` is `active` this field shows the currently executing query. In all other states, it shows the last query that was executed. By default the query text is truncated at 1024 bytes; this value can be changed via the parameter track_activity_query_size.	
`backend_type` `text` Type of current backend. Possible types are `autovacuum launcher`, `autovacuum worker`, `logical replication launcher`, `logical replication worker`, `parallel worker`, `background writer`, `client backend`, `checkpointer`, `archiver`, `startup`, `walreceiver`, `walsender` and `walwriter`. In addition, background workers registered by extensions may have additional types.	

> **Note**
>
> The `wait_event` and `state` columns are independent. If a backend is in the `active` state, it may or may not be `waiting` on some event. If the state is `active` and `wait_event` is non-null, it means that a query is being executed, but is being blocked somewhere in the system.

Table 27.4. Wait Event Types

Wait Event Type	Description
`Activity`	The server process is idle. This event type indicates a process waiting for activity in its main processing loop. `wait_event` will identify the specific wait point; see Table 27.5.
`BufferPin`	The server process is waiting for exclusive access to a data buffer. Buffer pin waits can be protracted if another process holds an open cursor that last read data from the buffer in question. See Table 27.6.
`Client`	The server process is waiting for activity on a socket connected to a user application. Thus, the server expects something to happen that is independent of its internal processes. `wait_event` will identify the specific wait point; see Table 27.7.
`Extension`	The server process is waiting for some condition defined by an extension module. See Table 27.8.
`IO`	The server process is waiting for an I/O operation to complete. `wait_event` will identify the specific wait point; see Table 27.9.
`IPC`	The server process is waiting for some interaction with another server process. `wait_event` will identify the specific wait point; see Table 27.10.
`Lock`	The server process is waiting for a heavyweight lock. Heavyweight locks, also known as lock manager locks or simply locks, primarily protect SQL-visible objects such as tables. However, they are also used to ensure mutual exclusion for certain internal operations such as relation extension.

Wait Event Type	Description
	`wait_event` will identify the type of lock awaited; see Table 27.11.
`LWLock`	The server process is waiting for a lightweight lock. Most such locks protect a particular data structure in shared memory. `wait_event` will contain a name identifying the purpose of the lightweight lock. (Some locks have specific names; others are part of a group of locks each with a similar purpose.) See Table 27.12.
`Timeout`	The server process is waiting for a timeout to expire. `wait_event` will identify the specific wait point; see Table 27.13.

Table 27.5. Wait Events of Type `Activity`

`Activity` Wait Event	Description
`ArchiverMain`	Waiting in main loop of archiver process.
`AutoVacuumMain`	Waiting in main loop of autovacuum launcher process.
`BgWriterHibernate`	Waiting in background writer process, hibernating.
`BgWriterMain`	Waiting in main loop of background writer process.
`CheckpointerMain`	Waiting in main loop of checkpointer process.
`LogicalApplyMain`	Waiting in main loop of logical replication apply process.
`LogicalLauncherMain`	Waiting in main loop of logical replication launcher process.
`PgStatMain`	Waiting in main loop of statistics collector process.
`RecoveryWalStream`	Waiting in main loop of startup process for WAL to arrive, during streaming recovery.
`ReplicationRepairMain`	Waiting in main loop of replication repair background worker.
`SysLoggerMain`	Waiting in main loop of syslogger process.
`WalReceiverMain`	Waiting in main loop of WAL receiver process.
`WalSenderMain`	Waiting in main loop of WAL sender process.
`WalWriterMain`	Waiting in main loop of WAL writer process.

Table 27.6. Wait Events of Type `BufferPin`

`BufferPin` Wait Event	Description
`BufferPin`	Waiting to acquire an exclusive pin on a buffer.

Table 27.7. Wait Events of Type `Client`

`Client` Wait Event	Description
`ClientRead`	Waiting to read data from the client.
`ClientWrite`	Waiting to write data to the client.
`GSSOpenServer`	Waiting to read data from the client while establishing a GSSAPI session.

Client **Wait Event**	**Description**
LibPQWalReceiverConnect	Waiting in WAL receiver to establish connection to remote server.
LibPQWalReceiverReceive	Waiting in WAL receiver to receive data from remote server.
SSLOpenServer	Waiting for SSL while attempting connection.
WalSenderWaitForWAL	Waiting for WAL to be flushed in WAL sender process.
WalSenderWriteData	Waiting for any activity when processing replies from WAL receiver in WAL sender process.

Table 27.8. Wait Events of Type Extension

Extension **Wait Event**	**Description**
Extension	Waiting in an extension.

Table 27.9. Wait Events of Type IO

IO **Wait Event**	**Description**
BaseBackupRead	Waiting for base backup to read from a file.
BufFileRead	Waiting for a read from a buffered file.
BufFileWrite	Waiting for a write to a buffered file.
BufFileTruncate	Waiting for a buffered file to be truncated.
BufBlockRepair	Waiting for a repair block from a standby.
ControlFileRead	Waiting for a read from the pg_control file.
ControlFileSync	Waiting for the pg_control file to reach durable storage.
ControlFileSyncUpdate	Waiting for an update to the pg_control file to reach durable storage.
ControlFileWrite	Waiting for a write to the pg_control file.
ControlFileWriteUpdate	Waiting for a write to update the pg_control file.
CopyFileRead	Waiting for a read during a file copy operation.
CopyFileWrite	Waiting for a write during a file copy operation.
DSMFillZeroWrite	Waiting to fill a dynamic shared memory backing file with zeroes.
DataFileExtend	Waiting for a relation data file to be extended.
DataFileFlush	Waiting for a relation data file to reach durable storage.
DataFileImmediateSync	Waiting for an immediate synchronization of a relation data file to durable storage.
DataFilePrefetch	Waiting for an asynchronous prefetch from a relation data file.
DataFileRead	Waiting for a read from a relation data file.
DataFileSync	Waiting for changes to a relation data file to reach durable storage.
DataFileTruncate	Waiting for a relation data file to be truncated.
DataFileWrite	Waiting for a write to a relation data file.

IO **Wait Event**	**Description**
LockFileAddToDataDirRead	Waiting for a read while adding a line to the data directory lock file.
LockFileAddToDataDirSync	Waiting for data to reach durable storage while adding a line to the data directory lock file.
LockFileAddToDataDirWrite	Waiting for a write while adding a line to the data directory lock file.
LockFileCreateRead	Waiting to read while creating the data directory lock file.
LockFileCreateSync	Waiting for data to reach durable storage while creating the data directory lock file.
LockFileCreateWrite	Waiting for a write while creating the data directory lock file.
LockFileReCheckDataDirRead	Waiting for a read during recheck of the data directory lock file.
LogicalRewriteCheckpointSync	Waiting for logical rewrite mappings to reach durable storage during a checkpoint.
LogicalRewriteMappingSync	Waiting for mapping data to reach durable storage during a logical rewrite.
LogicalRewriteMappingWrite	Waiting for a write of mapping data during a logical rewrite.
LogicalRewriteSync	Waiting for logical rewrite mappings to reach durable storage.
LogicalRewriteTruncate	Waiting for truncate of mapping data during a logical rewrite.
LogicalRewriteWrite	Waiting for a write of logical rewrite mappings.
RelationMapRead	Waiting for a read of the relation map file.
RelationMapSync	Waiting for the relation map file to reach durable storage.
RelationMapWrite	Waiting for a write to the relation map file.
ReorderBufferRead	Waiting for a read during reorder buffer management.
ReorderBufferWrite	Waiting for a write during reorder buffer management.
ReorderLogicalMappingRead	Waiting for a read of a logical mapping during reorder buffer management.
ReplicationSlotRead	Waiting for a read from a replication slot control file.
ReplicationSlotRestoreSync	Waiting for a replication slot control file to reach durable storage while restoring it to memory.
ReplicationSlotSync	Waiting for a replication slot control file to reach durable storage.
ReplicationSlotWrite	Waiting for a write to a replication slot control file.
SLRUFlushSync	Waiting for SLRU data to reach durable storage during a checkpoint or database shutdown.
SLRURead	Waiting for a read of an SLRU page.

IO **Wait Event**	**Description**
SLRUSync	Waiting for SLRU data to reach durable storage following a page write.
SLRUWrite	Waiting for a write of an SLRU page.
SnapbuildRead	Waiting for a read of a serialized historical catalog snapshot.
SnapbuildSync	Waiting for a serialized historical catalog snapshot to reach durable storage.
SnapbuildWrite	Waiting for a write of a serialized historical catalog snapshot.
TimelineHistoryFileSync	Waiting for a timeline history file received via streaming replication to reach durable storage.
TimelineHistoryFileWrite	Waiting for a write of a timeline history file received via streaming replication.
TimelineHistoryRead	Waiting for a read of a timeline history file.
TimelineHistorySync	Waiting for a newly created timeline history file to reach durable storage.
TimelineHistoryWrite	Waiting for a write of a newly created timeline history file.
TwophaseFileRead	Waiting for a read of a two phase state file.
TwophaseFileSync	Waiting for a two phase state file to reach durable storage.
TwophaseFileWrite	Waiting for a write of a two phase state file.
WALBootstrapSync	Waiting for WAL to reach durable storage during bootstrapping.
WALBootstrapWrite	Waiting for a write of a WAL page during bootstrapping.
WALCopyRead	Waiting for a read when creating a new WAL segment by copying an existing one.
WALCopySync	Waiting for a new WAL segment created by copying an existing one to reach durable storage.
WALCopyWrite	Waiting for a write when creating a new WAL segment by copying an existing one.
WALInitSync	Waiting for a newly initialized WAL file to reach durable storage.
WALInitWrite	Waiting for a write while initializing a new WAL file.
WALRead	Waiting for a read from a WAL file.
WALSenderTimelineHistoryRead	Waiting for a read from a timeline history file during a walsender timeline command.
WALSync	Waiting for a WAL file to reach durable storage.
WALSyncMethodAssign	Waiting for data to reach durable storage while assigning a new WAL sync method.
WALWrite	Waiting for a write to a WAL file.
LogicalChangesRead	Waiting for a read from a logical changes file.
LogicalChangesWrite	Waiting for a write to a logical changes file.

IO **Wait Event**	**Description**
LogicalSubxactRead	Waiting for a read from a logical subxact file.
LogicalSubxactWrite	Waiting for a write to a logical subxact file.

Table 27.10. Wait Events of Type IPC

IPC **Wait Event**	**Description**
AppendReady	Waiting for subplan nodes of an Append plan node to be ready.
BackendTermination	Waiting for the termination of another backend.
BackupWaitWalArchive	Waiting for WAL files required for a backup to be successfully archived.
BgWorkerShutdown	Waiting for background worker to shut down.
BgWorkerStartup	Waiting for background worker to start up.
BtreePage	Waiting for the page number needed to continue a parallel B-tree scan to become available.
BufferIO	Waiting for buffer I/O to complete.
CheckpointDone	Waiting for a checkpoint to complete.
CheckpointStart	Waiting for a checkpoint to start.
ExecuteGather	Waiting for activity from a child process while executing a Gather plan node.
HashBatchAllocate	Waiting for an elected Parallel Hash participant to allocate a hash table.
HashBatchElect	Waiting to elect a Parallel Hash participant to allocate a hash table.
HashBatchLoad	Waiting for other Parallel Hash participants to finish loading a hash table.
HashBuildAllocate	Waiting for an elected Parallel Hash participant to allocate the initial hash table.
HashBuildElect	Waiting to elect a Parallel Hash participant to allocate the initial hash table.
HashBuildHashInner	Waiting for other Parallel Hash participants to finish hashing the inner relation.
HashBuildHashOuter	Waiting for other Parallel Hash participants to finish partitioning the outer relation.
HashGrowBatchesAllocate	Waiting for an elected Parallel Hash participant to allocate more batches.
HashGrowBatchesDecide	Waiting to elect a Parallel Hash participant to decide on future batch growth.
HashGrowBatchesElect	Waiting to elect a Parallel Hash participant to allocate more batches.
HashGrowBatchesFinish	Waiting for an elected Parallel Hash participant to decide on future batch growth.
HashGrowBatchesRepartition	Waiting for other Parallel Hash participants to finish repartitioning.
HashGrowBucketsAllocate	Waiting for an elected Parallel Hash participant to finish allocating more buckets.

IPC **Wait Event**	**Description**
HashGrowBucketsElect	Waiting to elect a Parallel Hash participant to allocate more buckets.
HashGrowBucketsReinsert	Waiting for other Parallel Hash participants to finish inserting tuples into new buckets.
LogicalSyncData	Waiting for a logical replication remote server to send data for initial table synchronization.
LogicalSyncStateChange	Waiting for a logical replication remote server to change state.
MessageQueueInternal	Waiting for another process to be attached to a shared message queue.
MessageQueuePutMessage	Waiting to write a protocol message to a shared message queue.
MessageQueueReceive	Waiting to receive bytes from a shared message queue.
MessageQueueSend	Waiting to send bytes to a shared message queue.
ParallelBitmapScan	Waiting for parallel bitmap scan to become initialized.
ParallelCreateIndexScan	Waiting for parallel CREATE INDEX workers to finish heap scan.
ParallelFinish	Waiting for parallel workers to finish computing.
ProcArrayGroupUpdate	Waiting for the group leader to clear the transaction ID at transaction end.
ProcSignalBarrier	Waiting for a barrier event to be processed by all backends.
Promote	Waiting for standby promotion.
RecoveryConflictSnapshot	Waiting for recovery conflict resolution for a vacuum cleanup.
RecoveryConflictTablespace	Waiting for recovery conflict resolution for dropping a tablespace.
RecoveryPause	Waiting for recovery to be resumed.
ReplicationOriginDrop	Waiting for a replication origin to become inactive so it can be dropped.
ReplicationSlotDrop	Waiting for a replication slot to become inactive so it can be dropped.
SafeSnapshot	Waiting to obtain a valid snapshot for a READ ONLY DEFERRABLE transaction.
SyncRep	Waiting for confirmation from a remote server during synchronous replication.
WalReceiverExit	Waiting for the WAL receiver to exit.
WalReceiverWaitStart	Waiting for startup process to send initial data for streaming replication.
XactGroupUpdate	Waiting for the group leader to update transaction status at transaction end.

Table 27.11. Wait Events of Type `Lock`

`Lock` **Wait Event**	**Description**
`advisory`	Waiting to acquire an advisory user lock.
`extend`	Waiting to extend a relation.
`frozenid`	Waiting to update `pg_database .datfrozenxid` and `pg_database .datminmxid`.
`object`	Waiting to acquire a lock on a non-relation database object.
`page`	Waiting to acquire a lock on a page of a relation.
`relation`	Waiting to acquire a lock on a relation.
`spectoken`	Waiting to acquire a speculative insertion lock.
`transactionid`	Waiting for a transaction to finish.
`tuple`	Waiting to acquire a lock on a tuple.
`userlock`	Waiting to acquire a user lock.
`virtualxid`	Waiting to acquire a virtual transaction ID lock.

Table 27.12. Wait Events of Type `LWLock`

`LWLock` **Wait Event**	**Description**
`AddinShmemInit`	Waiting to manage an extension's space allocation in shared memory.
`AutoFile`	Waiting to update the `postgresql.auto.conf` file.
`Autovacuum`	Waiting to read or update the current state of autovacuum workers.
`AutovacuumSchedule`	Waiting to ensure that a table selected for autovacuum still needs vacuuming.
`BackgroundWorker`	Waiting to read or update background worker state.
`BtreeVacuum`	Waiting to read or update vacuum-related information for a B-tree index.
`BufferContent`	Waiting to access a data page in memory.
`BufferMapping`	Waiting to associate a data block with a buffer in the buffer pool.
`CfsGc`	Waiting on CFS GC control lock.
`CheckpointerComm`	Waiting to manage fsync requests.
`ClientSessionInfo`	Waiting to read or update client session information of the built-in connection pooler.
`CommitTs`	Waiting to read or update the last value set for a transaction commit timestamp.
`CommitTsBuffer`	Waiting for I/O on a commit timestamp SLRU buffer.
`CommitTsSLRU`	Waiting to access the commit timestamp SLRU cache.
`ControlFile`	Waiting to read or update the `pg_control` file or create a new WAL file.
`DynamicSharedMemoryControl`	Waiting to read or update dynamic shared memory allocation information.

LWLock **Wait Event**	**Description**
LockFastPath	Waiting to read or update a process' fast-path lock information.
LockManager	Waiting to read or update information about “heavyweight” locks.
LogicalRepWorker	Waiting to read or update the state of logical replication workers.
MultiXactGen	Waiting to read or update shared multixact state.
MultiXactMemberBuffer	Waiting for I/O on a multixact member SLRU buffer.
MultiXactMemberSLRU	Waiting to access the multixact member SLRU cache.
MultiXactOffsetBuffer	Waiting for I/O on a multixact offset SLRU buffer.
MultiXactOffsetSLRU	Waiting to access the multixact offset SLRU cache.
MultiXactTruncation	Waiting to read or truncate multixact information.
NotifyBuffer	Waiting for I/O on a NOTIFY message SLRU buffer.
NotifyQueue	Waiting to read or update NOTIFY messages.
NotifyQueueTail	Waiting to update limit on NOTIFY message storage.
NotifySLRU	Waiting to access the NOTIFY message SLRU cache.
OidGen	Waiting to allocate a new OID.
OldSnapshotTimeMap	Waiting to read or update old snapshot control information.
ParallelAppend	Waiting to choose the next subplan during Parallel Append plan execution.
ParallelHashJoin	Waiting to synchronize workers during Parallel Hash Join plan execution.
ParallelQueryDSA	Waiting for parallel query dynamic shared memory allocation.
PerSessionDSA	Waiting for parallel query dynamic shared memory allocation.
PerSessionRecordType	Waiting to access a parallel query's information about composite types.
PerSessionRecordTypmod	Waiting to access a parallel query's information about type modifiers that identify anonymous record types.
PerXactPredicateList	Waiting to access the list of predicate locks held by the current serializable transaction during a parallel query.
PredicateLockManager	Waiting to access predicate lock information used by serializable transactions.
ProcArray	Waiting to access the shared per-process data structures (typically, to get a snapshot or report a session's transaction ID).

LWLock **Wait Event**	**Description**
RelationMapping	Waiting to read or update a pg_filenode.map file (used to track the filenode assignments of certain system catalogs).
RelCacheInit	Waiting to read or update a pg_internal.init relation cache initialization file.
ReplicationOrigin	Waiting to create, drop or use a replication origin.
ReplicationOriginState	Waiting to read or update the progress of one replication origin.
ReplicationSlotAllocation	Waiting to allocate or free a replication slot.
ReplicationSlotControl	Waiting to read or update replication slot state.
ReplicationSlotIO	Waiting for I/O on a replication slot.
SerialBuffer	Waiting for I/O on a serializable transaction conflict SLRU buffer.
SerializableFinishedList	Waiting to access the list of finished serializable transactions.
SerializablePredicateList	Waiting to access the list of predicate locks held by serializable transactions.
SerializableXactHash	Waiting to read or update information about serializable transactions.
SerialSLRU	Waiting to access the serializable transaction conflict SLRU cache.
SharedTidBitmap	Waiting to access a shared TID bitmap during a parallel bitmap index scan.
SharedTupleStore	Waiting to access a shared tuple store during parallel query.
ShmemIndex	Waiting to find or allocate space in shared memory.
SInvalRead	Waiting to retrieve messages from the shared catalog invalidation queue.
SInvalWrite	Waiting to add a message to the shared catalog invalidation queue.
SubtransBuffer	Waiting for I/O on a sub-transaction SLRU buffer.
SubtransSLRU	Waiting to access the sub-transaction SLRU cache.
SyncRep	Waiting to read or update information about the state of synchronous replication.
SyncScan	Waiting to select the starting location of a synchronized table scan.
TablespaceCreate	Waiting to create or drop a tablespace.
TwoPhaseState	Waiting to read or update the state of prepared transactions.
WALBufMapping	Waiting to replace a page in WAL buffers.
WALInsert	Waiting to insert WAL data into a memory buffer.
WALWrite	Waiting for WAL buffers to be written to disk.
WrapLimitsVacuum	Waiting to update limits on transaction id and multixact consumption.

LWLock **Wait Event**	**Description**
XactBuffer	Waiting for I/O on a transaction status SLRU buffer.
XactSLRU	Waiting to access the transaction status SLRU cache.
XactTruncation	Waiting to execute pg_xact_status or update the oldest transaction ID available to it.
XidGen	Waiting to allocate a new transaction ID.

> **Note**
>
> Extensions can add LWLock types to the list shown in Table 27.12. In some cases, the name assigned by an extension will not be available in all server processes; so an LWLock wait event might be reported as just "extension" rather than the extension-assigned name.

Table 27.13. Wait Events of Type Timeout

Timeout **Wait Event**	**Description**
BaseBackupThrottle	Waiting during base backup when throttling activity.
CheckpointWriteDelay	Waiting between writes while performing a checkpoint.
PgSleep	Waiting due to a call to pg_sleep or a sibling function.
RecoveryApplyDelay	Waiting to apply WAL during recovery because of a delay setting.
RecoveryRetrieveRetryInterval	Waiting during recovery when WAL data is not available from any source (pg_wal , archive or stream).
RegisterSyncRequest	Waiting while sending synchronization requests to the checkpointer, because the request queue is full.
VacuumDelay	Waiting in a cost-based vacuum delay point.

Here is an example of how wait events can be viewed:

```
SELECT pid, wait_event_type, wait_event FROM pg_stat_activity WHERE wait_event is NOT
 NULL;
 pid  | wait_event_type | wait_event
------+-----------------+------------
 2540 | Lock            | relation
 6644 | LWLock          | ProcArray
(2 rows)
```

27.2.4. pg_pool_backends

The pg_pool_backends view will contain one row per pooler backend, showing information on the workload of that backend.

Table 27.14. pg_pool_backends View

Column Type **Description**
pid integer Process ID of a backend.

Column Type Description
`active_sessions integer` Number of user sessions currently served by this backend, as returned by the `pg_backend_active_sessions` (*pid*) function. See Table 27.36 for details.
`max_sessions integer` Maximal number of user sessions served by this backend since its start, as returned by the `pg_backend_max_sessions` (*pid*) function. See Table 27.36 for details.
`finished_sessions integer` Number of user sessions that this backend already served, as returned by the `pg_backend_finished_sessions` (*pid*) function. See Table 27.36 for details. This column shows the distribution of the workload among the pooler backends.
`load_average integer` Number of user sessions waiting in a queue for this backend, including the active session, as returned by the `pg_backend_load_average` (*pid*) function. See Table 27.36 for details.
`datname integer` Name of the database this backend is connected to.
`usename integer` Name of the user logged into this backend.

Here is an example of how information on pooler backends can be viewed:

```
SELECT * FROM pg_pool_backends;
  pid  | active_sessions | max_sessions | finished_sessions | load_average | datname |
 usename
-------+-----------------+--------------+-------------------+--------------+---------
+---------
 11262 |               1 |            1 |                 0 |            1 | test    |
 user1
 11229 |               0 |            1 |                 1 |            1 | test    |
 user1
(2 rows)
```

27.2.5. `pg_client_session_info`

The `pg_client_session_info` view will contain one row per client session in the built-in connection pooler, showing information on that session.

Table 27.15. `pg_client_session_info` View

Column Type Description
`backend_pid integer` Process ID of the backend that serves this client session
`session_id integer` Session ID
`user_id oid` OID of the user who established the connection. Remains unchanged if the user executes the command `SET ROLE/RESET ROLE`.
`client_addr integer` IP address of this client. If this field is null, it indicates either that the client is connected via a Unix socket on the server machine or that this is an internal process such as autovacuum.
`client_port integer` TCP port number that this client is using for communication with the backend, or -1 if a Unix socket is used

Column Type Description
elapsed_time interval Total time spent by the backend in this session
last_activation timestamp with time zone Time of the last execution of a query in this session
context_switches integer Number of times the backend switched to other sessions

Here is an example of how information on client sessions in the pooler can be viewed:

```
SELECT * FROM pg_client_session_info;
 backend_pid | session_id | user_id | client_addr | client_port | elapsed_time |
 last_activation       | context_switches
-------------+------------+---------+-------------+-------------+--------------
+-----------------------------+------------------
        6709 |          1 |      10 |             |          -1 | 00:00:00     |
 2020-05-08 06:28:31.742675 |                0
(1 row)
```

27.2.6. pgpro_stat_wal_activity

The pgpro_stat_wal_activity view will have one row per server process, showing information related to the current activity of that process. It inherits all columns from the pg_stat_activity view and adds the wal_written column to display the size of WAL files generated by each process.

Table 27.16. pgpro_stat_wal_activity View

Column	Type	Description
wal_written	bigint	The size of WAL files generated by a process.

27.2.7. pg_stat_replication

The pg_stat_replication view will contain one row per WAL sender process, showing statistics about replication to that sender's connected standby server. Only directly connected standbys are listed; no information is available about downstream standby servers.

Table 27.17. pg_stat_replication View

Column Type Description
pid integer Process ID of a WAL sender process
usesysid oid OID of the user logged into this WAL sender process
usename name Name of the user logged into this WAL sender process
application_name text Name of the application that is connected to this WAL sender
client_addr inet IP address of the client connected to this WAL sender. If this field is null, it indicates that the client is connected via a Unix socket on the server machine.
client_hostname text Host name of the connected client, as reported by a reverse DNS lookup of client_addr . This field will only be non-null for IP connections, and only when log_hostname is enabled.
client_port integer

Column Type **Description**
TCP port number that the client is using for communication with this WAL sender, or `-1` if a Unix socket is used
`backend_start timestamp with time zone` Time when this process was started, i.e., when the client connected to this WAL sender
`backend_xmin xid` This standby's `xmin` horizon reported by hot_standby_feedback.
`state text` Current WAL sender state. Possible values are: • `startup`: This WAL sender is starting up. • `catchup`: This WAL sender's connected standby is catching up with the primary. • `streaming`: This WAL sender is streaming changes after its connected standby server has caught up with the primary. • `backup`: This WAL sender is sending a backup. • `stopping`: This WAL sender is stopping.
`sent_lsn pg_lsn` Last write-ahead log location sent on this connection
`write_lsn pg_lsn` Last write-ahead log location written to disk by this standby server
`flush_lsn pg_lsn` Last write-ahead log location flushed to disk by this standby server
`replay_lsn pg_lsn` Last write-ahead log location replayed into the database on this standby server
`write_lag interval` Time elapsed between flushing recent WAL locally and receiving notification that this standby server has written it (but not yet flushed it or applied it). This can be used to gauge the delay that `synchronous_commit` level `remote_write` incurred while committing if this server was configured as a synchronous standby.
`flush_lag interval` Time elapsed between flushing recent WAL locally and receiving notification that this standby server has written and flushed it (but not yet applied it). This can be used to gauge the delay that `synchronous_commit` level `on` incurred while committing if this server was configured as a synchronous standby.
`replay_lag interval` Time elapsed between flushing recent WAL locally and receiving notification that this standby server has written, flushed and applied it. This can be used to gauge the delay that `synchronous_commit` level `remote_apply` incurred while committing if this server was configured as a synchronous standby.
`sync_priority integer` Priority of this standby server for being chosen as the synchronous standby in a priority-based synchronous replication. This has no effect in a quorum-based synchronous replication.
`sync_state text` Synchronous state of this standby server. Possible values are: • `async`: This standby server is asynchronous. • `potential`: This standby server is now asynchronous, but can potentially become synchronous if one of current synchronous ones fails.

Column Type Description
• `sync`: This standby server is synchronous. • `quorum`: This standby server is considered as a candidate for quorum standbys.
`reply_time timestamp with time zone` Send time of last reply message received from standby server

The lag times reported in the `pg_stat_replication` view are measurements of the time taken for recent WAL to be written, flushed and replayed and for the sender to know about it. These times represent the commit delay that was (or would have been) introduced by each synchronous commit level, if the remote server was configured as a synchronous standby. For an asynchronous standby, the `replay_lag` column approximates the delay before recent transactions became visible to queries. If the standby server has entirely caught up with the sending server and there is no more WAL activity, the most recently measured lag times will continue to be displayed for a short time and then show NULL.

Lag times work automatically for physical replication. Logical decoding plugins may optionally emit tracking messages; if they do not, the tracking mechanism will simply display NULL lag.

> **Note**
>
> The reported lag times are not predictions of how long it will take for the standby to catch up with the sending server assuming the current rate of replay. Such a system would show similar times while new WAL is being generated, but would differ when the sender becomes idle. In particular, when the standby has caught up completely, `pg_stat_replication` shows the time taken to write, flush and replay the most recent reported WAL location rather than zero as some users might expect. This is consistent with the goal of measuring synchronous commit and transaction visibility delays for recent write transactions. To reduce confusion for users expecting a different model of lag, the lag columns revert to NULL after a short time on a fully replayed idle system. Monitoring systems should choose whether to represent this as missing data, zero or continue to display the last known value.

27.2.8. `pg_stat_replication_slots`

The `pg_stat_replication_slots` view will contain one row per logical replication slot, showing statistics about its usage.

Table 27.18. `pg_stat_replication_slots` View

Column Type Description
`slot_name text` A unique, cluster-wide identifier for the replication slot
`spill_txns bigint` Number of transactions spilled to disk once the memory used by logical decoding to decode changes from WAL has exceeded `logical_decoding_work_mem`. The counter gets incremented for both top-level transactions and subtransactions.
`spill_count bigint` Number of times transactions were spilled to disk while decoding changes from WAL for this slot. This counter is incremented each time a transaction is spilled, and the same transaction may be spilled multiple times.
`spill_bytes bigint` Amount of decoded transaction data spilled to disk while performing decoding of changes from WAL for this slot. This and other spill counters can be used to gauge the I/O which occurred during logical decoding and allow tuning `logical_decoding_work_mem`.

Column Type Description
`stream_txns bigint` Number of in-progress transactions streamed to the decoding output plugin after the memory used by logical decoding to decode changes from WAL for this slot has exceeded `logical_decoding_work_mem`. Streaming only works with top-level transactions (subtransactions can't be streamed independently), so the counter is not incremented for subtransactions.
`stream_count bigint` Number of times in-progress transactions were streamed to the decoding output plugin while decoding changes from WAL for this slot. This counter is incremented each time a transaction is streamed, and the same transaction may be streamed multiple times.
`stream_bytes bigint` Amount of transaction data decoded for streaming in-progress transactions to the decoding output plugin while decoding changes from WAL for this slot. This and other streaming counters for this slot can be used to tune `logical_decoding_work_mem`.
`total_txns bigint` Number of decoded transactions sent to the decoding output plugin for this slot. This counts top-level transactions only, and is not incremented for subtransactions. Note that this includes the transactions that are streamed and/or spilled.
`total_bytes bigint` Amount of transaction data decoded for sending transactions to the decoding output plugin while decoding changes from WAL for this slot. Note that this includes data that is streamed and/or spilled.
`stats_reset timestamp with time zone` Time at which these statistics were last reset

27.2.9. `pg_stat_wal_receiver`

The `pg_stat_wal_receiver` view will contain only one row, showing statistics about the WAL receiver from that receiver's connected server.

Table 27.19. `pg_stat_wal_receiver` View

Column Type Description
`pid integer` Process ID of the WAL receiver process
`status text` Activity status of the WAL receiver process
`receive_start_lsn pg_lsn` First write-ahead log location used when WAL receiver is started
`receive_start_tli integer` First timeline number used when WAL receiver is started
`written_lsn pg_lsn` Last write-ahead log location already received and written to disk, but not flushed. This should not be used for data integrity checks.
`flushed_lsn pg_lsn` Last write-ahead log location already received and flushed to disk, the initial value of this field being the first log location used when WAL receiver is started
`received_tli integer` Timeline number of last write-ahead log location received and flushed to disk, the initial value of this field being the timeline number of the first log location used when WAL receiver is started

Column Type Description
last_msg_send_time timestamp with time zone Send time of last message received from origin WAL sender
last_msg_receipt_time timestamp with time zone Receipt time of last message received from origin WAL sender
latest_end_lsn pg_lsn Last write-ahead log location reported to origin WAL sender
latest_end_time timestamp with time zone Time of last write-ahead log location reported to origin WAL sender
slot_name text Replication slot name used by this WAL receiver
sender_host text Host of the Postgres Pro instance this WAL receiver is connected to. This can be a host name, an IP address, or a directory path if the connection is via Unix socket. (The path case can be distinguished because it will always be an absolute path, beginning with /.)
sender_port integer Port number of the Postgres Pro instance this WAL receiver is connected to.
conninfo text Connection string used by this WAL receiver, with security-sensitive fields obfuscated.

27.2.10. pg_stat_subscription

The pg_stat_subscription view will contain one row per subscription for main worker (with null PID if the worker is not running), and additional rows for workers handling the initial data copy of the subscribed tables.

Table 27.20. pg_stat_subscription View

Column Type Description
subid oid OID of the subscription
subname name Name of the subscription
pid integer Process ID of the subscription worker process
relid oid OID of the relation that the worker is synchronizing; null for the main apply worker
received_lsn pg_lsn Last write-ahead log location received, the initial value of this field being 0
last_msg_send_time timestamp with time zone Send time of last message received from origin WAL sender
last_msg_receipt_time timestamp with time zone Receipt time of last message received from origin WAL sender
latest_end_lsn pg_lsn Last write-ahead log location reported to origin WAL sender
latest_end_time timestamp with time zone Time of last write-ahead log location reported to origin WAL sender

27.2.11. pg_stat_ssl

The pg_stat_ssl view will contain one row per backend or WAL sender process, showing statistics about SSL usage on this connection. It can be joined to pg_stat_activity or pg_stat_replication on the pid column to get more details about the connection.

Table 27.21. pg_stat_ssl View

Column Type Description
pid integer Process ID of a backend or WAL sender process
ssl boolean True if SSL is used on this connection
version text Version of SSL in use, or NULL if SSL is not in use on this connection
cipher text Name of SSL cipher in use, or NULL if SSL is not in use on this connection
bits integer Number of bits in the encryption algorithm used, or NULL if SSL is not used on this connection
client_dn text Distinguished Name (DN) field from the client certificate used, or NULL if no client certificate was supplied or if SSL is not in use on this connection. This field is truncated if the DN field is longer than NAMEDATALEN (64 characters in a standard build).
client_serial numeric Serial number of the client certificate, or NULL if no client certificate was supplied or if SSL is not in use on this connection. The combination of certificate serial number and certificate issuer uniquely identifies a certificate (unless the issuer erroneously reuses serial numbers).
issuer_dn text DN of the issuer of the client certificate, or NULL if no client certificate was supplied or if SSL is not in use on this connection. This field is truncated like client_dn .

27.2.12. pg_stat_gssapi

The pg_stat_gssapi view will contain one row per backend, showing information about GSSAPI usage on this connection. It can be joined to pg_stat_activity or pg_stat_replication on the pid column to get more details about the connection.

Table 27.22. pg_stat_gssapi View

Column Type Description
pid integer Process ID of a backend
gss_authenticated boolean True if GSSAPI authentication was used for this connection
principal text Principal used to authenticate this connection, or NULL if GSSAPI was not used to authenticate this connection. This field is truncated if the principal is longer than NAMEDATALEN (64 characters in a standard build).
encrypted boolean True if GSSAPI encryption is in use on this connection

27.2.13. pg_stat_archiver

The pg_stat_archiver view will always have a single row, containing data about the archiver process of the cluster.

Table 27.23. pg_stat_archiver View

Column Type Description
archived_count bigint Number of WAL files that have been successfully archived
last_archived_wal text Name of the last WAL file successfully archived
last_archived_time timestamp with time zone Time of the last successful archive operation
failed_count bigint Number of failed attempts for archiving WAL files
last_failed_wal text Name of the WAL file of the last failed archival operation
last_failed_time timestamp with time zone Time of the last failed archival operation
stats_reset timestamp with time zone Time at which these statistics were last reset

27.2.14. pg_stat_bgwriter

The pg_stat_bgwriter view will always have a single row, containing global data for the cluster.

Table 27.24. pg_stat_bgwriter View

Column Type Description
checkpoints_timed bigint Number of scheduled checkpoints that have been performed
checkpoints_req bigint Number of requested checkpoints that have been performed
checkpoint_write_time double precision Total amount of time that has been spent in the portion of checkpoint processing where files are written to disk, in milliseconds
checkpoint_sync_time double precision Total amount of time that has been spent in the portion of checkpoint processing where files are synchronized to disk, in milliseconds
buffers_checkpoint bigint Number of buffers written during checkpoints
buffers_clean bigint Number of buffers written by the background writer
maxwritten_clean bigint Number of times the background writer stopped a cleaning scan because it had written too many buffers
buffers_backend bigint Number of buffers written directly by a backend
buffers_backend_fsync bigint Number of times a backend had to execute its own fsync call (normally the background writer handles those even when the backend does its own write)
buffers_alloc bigint

Column Type Description
Number of buffers allocated
`stats_reset timestamp with time zone` Time at which these statistics were last reset

27.2.15. pg_stat_wal

The `pg_stat_wal` view will always have a single row, containing data about WAL activity of the cluster.

Table 27.25. `pg_stat_wal` View

Column Type Description
`wal_records bigint` Total number of WAL records generated
`wal_fpi bigint` Total number of WAL full page images generated
`wal_bytes numeric` Total amount of WAL generated in bytes
`wal_buffers_full bigint` Number of times WAL data was written to disk because WAL buffers became full
`wal_write bigint` Number of times WAL buffers were written out to disk via `XLogWrite` request. See Section 29.5 for more information about the internal WAL function `XLogWrite`.
`wal_sync bigint` Number of times WAL files were synced to disk via `issue_xlog_fsync` request (if fsync is `on` and wal_sync_method is either `fdatasync`, `fsync` or `fsync_writethrough`, otherwise zero). See Section 29.5 for more information about the internal WAL function `issue_xlog_fsync`.
`wal_write_time double precision` Total amount of time spent writing WAL buffers to disk via `XLogWrite` request, in milliseconds (if track_wal_io_timing is enabled, otherwise zero). This includes the sync time when `wal_sync_method` is either `open_datasync` or `open_sync`.
`wal_sync_time double precision` Total amount of time spent syncing WAL files to disk via `issue_xlog_fsync` request, in milliseconds (if `track_wal_io_timing` is enabled, `fsync` is `on`, and `wal_sync_method` is either `fdatasync`, `fsync` or `fsync_writethrough`, otherwise zero).
`stats_reset timestamp with time zone` Time at which these statistics were last reset

27.2.16. pg_stat_database

The `pg_stat_database` view will contain one row for each database in the cluster, plus one for shared objects, showing database-wide statistics.

Table 27.26. `pg_stat_database` View

Column Type Description
`datid oid` OID of this database, or 0 for objects belonging to a shared relation
`datname name` Name of this database, or `NULL` for shared objects.

Column Type Description
numbackends integer Number of backends currently connected to this database, or NULL for shared objects. This is the only column in this view that returns a value reflecting current state; all other columns return the accumulated values since the last reset.
xact_commit bigint Number of transactions in this database that have been committed
xact_rollback bigint Number of transactions in this database that have been rolled back
blks_read bigint Number of disk blocks read in this database
blks_hit bigint Number of times disk blocks were found already in the buffer cache, so that a read was not necessary (this only includes hits in the Postgres Pro buffer cache, not the operating system's file system cache)
tup_returned bigint Number of rows returned by queries in this database
tup_fetched bigint Number of rows fetched by queries in this database
tup_inserted bigint Number of rows inserted by queries in this database
tup_updated bigint Number of rows updated by queries in this database
tup_deleted bigint Number of rows deleted by queries in this database
conflicts bigint Number of queries canceled due to conflicts with recovery in this database. (Conflicts occur only on standby servers; see pg_stat_database_conflicts for details.)
temp_files bigint Number of temporary files created by queries in this database. All temporary files are counted, regardless of why the temporary file was created (e.g., sorting or hashing), and regardless of the log_temp_files setting.
temp_bytes bigint Total amount of data written to temporary files by queries in this database. All temporary files are counted, regardless of why the temporary file was created, and regardless of the log_temp_files setting.
deadlocks bigint Number of deadlocks detected in this database
checksum_failures bigint Number of data page checksum failures detected in this database (or on a shared object), or NULL if data checksums are not enabled.
checksum_last_failure timestamp with time zone Time at which the last data page checksum failure was detected in this database (or on a shared object), or NULL if data checksums are not enabled.
blk_read_time double precision Time spent reading data file blocks by backends in this database, in milliseconds (if track_io_timing is enabled, otherwise zero)
blk_write_time double precision

Column Type Description
Time spent writing data file blocks by backends in this database, in milliseconds (if track_io_timing is enabled, otherwise zero)
`session_time double precision` Time spent by database sessions in this database, in milliseconds (note that statistics are only updated when the state of a session changes, so if sessions have been idle for a long time, this idle time won't be included)
`active_time double precision` Time spent executing SQL statements in this database, in milliseconds (this corresponds to the states `active` and `fastpath function call` in `pg_stat_activity`)
`idle_in_transaction_time double precision` Time spent idling while in a transaction in this database, in milliseconds (this corresponds to the states `idle in transaction` and `idle in transaction (aborted)` in `pg_stat_activity`)
`sessions bigint` Total number of sessions established to this database
`sessions_abandoned bigint` Number of database sessions to this database that were terminated because connection to the client was lost
`sessions_fatal bigint` Number of database sessions to this database that were terminated by fatal errors
`sessions_killed bigint` Number of database sessions to this database that were terminated by operator intervention
`stats_reset timestamp with time zone` Time at which these statistics were last reset

27.2.17. `pg_stat_database_conflicts`

The `pg_stat_database_conflicts` view will contain one row per database, showing database-wide statistics about query cancels occurring due to conflicts with recovery on standby servers. This view will only contain information on standby servers, since conflicts do not occur on primary servers.

Table 27.27. `pg_stat_database_conflicts` View

Column Type Description
`datid oid` OID of a database
`datname name` Name of this database
`confl_tablespace bigint` Number of queries in this database that have been canceled due to dropped tablespaces
`confl_lock bigint` Number of queries in this database that have been canceled due to lock timeouts
`confl_snapshot bigint` Number of queries in this database that have been canceled due to old snapshots
`confl_bufferpin bigint` Number of queries in this database that have been canceled due to pinned buffers
`confl_deadlock bigint` Number of queries in this database that have been canceled due to deadlocks

27.2.18. pg_stat_all_tables

The pg_stat_all_tables view will contain one row for each table in the current database (including TOAST tables), showing statistics about accesses to that specific table. The pg_stat_user_tables and pg_stat_sys_tables views contain the same information, but filtered to only show user and system tables respectively.

Table 27.28. pg_stat_all_tables View

Column Type Description
relid oid OID of a table
schemaname name Name of the schema that this table is in
relname name Name of this table
seq_scan bigint Number of sequential scans initiated on this table
seq_tup_read bigint Number of live rows fetched by sequential scans
idx_scan bigint Number of index scans initiated on this table
idx_tup_fetch bigint Number of live rows fetched by index scans
n_tup_ins bigint Number of rows inserted
n_tup_upd bigint Number of rows updated (includes HOT updated rows)
n_tup_del bigint Number of rows deleted
n_tup_hot_upd bigint Number of rows HOT updated (i.e., with no separate index update required)
n_live_tup bigint Estimated number of live rows
n_dead_tup bigint Estimated number of dead rows
n_mod_since_analyze bigint Estimated number of rows modified since this table was last analyzed
n_ins_since_vacuum bigint Estimated number of rows inserted since this table was last vacuumed
last_vacuum timestamp with time zone Last time at which this table was manually vacuumed (not counting VACUUM FULL)
last_autovacuum timestamp with time zone Last time at which this table was vacuumed by the autovacuum daemon
last_analyze timestamp with time zone Last time at which this table was manually analyzed
last_autoanalyze timestamp with time zone Last time at which this table was analyzed by the autovacuum daemon
vacuum_count bigint

Column Type Description
Number of times this table has been manually vacuumed (not counting `VACUUM FULL`)
`autovacuum_count bigint` Number of times this table has been vacuumed by the autovacuum daemon
`analyze_count bigint` Number of times this table has been manually analyzed
`autoanalyze_count bigint` Number of times this table has been analyzed by the autovacuum daemon

27.2.19. `pg_stat_all_indexes`

The `pg_stat_all_indexes` view will contain one row for each index in the current database, showing statistics about accesses to that specific index. The `pg_stat_user_indexes` and `pg_stat_sys_indexes` views contain the same information, but filtered to only show user and system indexes respectively.

Table 27.29. `pg_stat_all_indexes` View

Column Type Description
`relid oid` OID of the table for this index
`indexrelid oid` OID of this index
`schemaname name` Name of the schema this index is in
`relname name` Name of the table for this index
`indexrelname name` Name of this index
`idx_scan bigint` Number of index scans initiated on this index
`idx_tup_read bigint` Number of index entries returned by scans on this index
`idx_tup_fetch bigint` Number of live table rows fetched by simple index scans using this index

Indexes can be used by simple index scans, “bitmap” index scans, and the optimizer. In a bitmap scan the output of several indexes can be combined via AND or OR rules, so it is difficult to associate individual heap row fetches with specific indexes when a bitmap scan is used. Therefore, a bitmap scan increments the `pg_stat_all_indexes.idx_tup_read` count(s) for the index(es) it uses, and it increments the `pg_stat_all_tables.idx_tup_fetch` count for the table, but it does not affect `pg_stat_all_indexes.idx_tup_fetch`. The optimizer also accesses indexes to check for supplied constants whose values are outside the recorded range of the optimizer statistics because the optimizer statistics might be stale.

> **Note**
>
> The `idx_tup_read` and `idx_tup_fetch` counts can be different even without any use of bitmap scans, because `idx_tup_read` counts index entries retrieved from the index while `idx_tup_fetch` counts live rows fetched from the table. The latter will be less if any dead or not-yet-committed rows are fetched using the index, or if any heap fetches are avoided by means of an index-only scan.

27.2.20. pg_statio_all_tables

The pg_statio_all_tables view will contain one row for each table in the current database (including TOAST tables), showing statistics about I/O on that specific table. The pg_statio_user_tables and pg_statio_sys_tables views contain the same information, but filtered to only show user and system tables respectively.

Table 27.30. pg_statio_all_tables View

Column Type Description
relid oid OID of a table
schemaname name Name of the schema that this table is in
relname name Name of this table
heap_blks_read bigint Number of disk blocks read from this table
heap_blks_hit bigint Number of buffer hits in this table
idx_blks_read bigint Number of disk blocks read from all indexes on this table
idx_blks_hit bigint Number of buffer hits in all indexes on this table
toast_blks_read bigint Number of disk blocks read from this table's TOAST table (if any)
toast_blks_hit bigint Number of buffer hits in this table's TOAST table (if any)
tidx_blks_read bigint Number of disk blocks read from this table's TOAST table indexes (if any)
tidx_blks_hit bigint Number of buffer hits in this table's TOAST table indexes (if any)

27.2.21. pg_statio_all_indexes

The pg_statio_all_indexes view will contain one row for each index in the current database, showing statistics about I/O on that specific index. The pg_statio_user_indexes and pg_statio_sys_indexes views contain the same information, but filtered to only show user and system indexes respectively.

Table 27.31. pg_statio_all_indexes View

Column Type Description
relid oid OID of the table for this index
indexrelid oid OID of this index
schemaname name Name of the schema this index is in
relname name Name of the table for this index
indexrelname name

Column Type Description
Name of this index
idx_blks_read bigint Number of disk blocks read from this index
idx_blks_hit bigint Number of buffer hits in this index

27.2.22. pg_statio_all_sequences

The pg_statio_all_sequences view will contain one row for each sequence in the current database, showing statistics about I/O on that specific sequence.

Table 27.32. pg_statio_all_sequences View

Column Type Description
relid oid OID of a sequence
schemaname name Name of the schema this sequence is in
relname name Name of this sequence
blks_read bigint Number of disk blocks read from this sequence
blks_hit bigint Number of buffer hits in this sequence

27.2.23. pg_stat_user_functions

The pg_stat_user_functions view will contain one row for each tracked function, showing statistics about executions of that function. The track_functions parameter controls exactly which functions are tracked.

Table 27.33. pg_stat_user_functions View

Column Type Description
funcid oid OID of a function
schemaname name Name of the schema this function is in
funcname name Name of this function
calls bigint Number of times this function has been called
total_time double precision Total time spent in this function and all other functions called by it, in milliseconds
self_time double precision Total time spent in this function itself, not including other functions called by it, in milliseconds

27.2.24. pg_stat_slru

Postgres Pro accesses certain on-disk information via *SLRU* (simple least-recently-used) caches. The `pg_stat_slru` view will contain one row for each tracked SLRU cache, showing statistics about access to cached pages.

Table 27.34. `pg_stat_slru` View

Column Type Description
`name text` Name of the SLRU
`blks_zeroed bigint` Number of blocks zeroed during initializations
`blks_hit bigint` Number of times disk blocks were found already in the SLRU, so that a read was not necessary (this only includes hits in the SLRU, not the operating system's file system cache)
`blks_read bigint` Number of disk blocks read for this SLRU
`blks_written bigint` Number of disk blocks written for this SLRU
`blks_exists bigint` Number of blocks checked for existence for this SLRU
`flushes bigint` Number of flushes of dirty data for this SLRU
`truncates bigint` Number of truncates for this SLRU
`stats_reset timestamp with time zone` Time at which these statistics were last reset

27.2.25. Statistics Functions

Other ways of looking at the statistics can be set up by writing queries that use the same underlying statistics access functions used by the standard views shown above. For details such as the functions' names, consult the definitions of the standard views. (For example, in psql you could issue `\d+ pg_stat_activity`.) The access functions for per-database statistics take a database OID as an argument to identify which database to report on. The per-table and per-index functions take a table or index OID. The functions for per-function statistics take a function OID. Note that only tables, indexes, and functions in the current database can be seen with these functions.

Additional functions related to statistics collection are listed in Table 27.35.

Table 27.35. Additional Statistics Functions

Function Description
`pg_backend_pid () → integer` Returns the process ID of the server process attached to the current session.
`pg_stat_get_activity ( integer ) → setof record` Returns a record of information about the backend with the specified process ID, or one record for each active backend in the system if `NULL` is specified. The fields returned are a subset of those in the `pg_stat_activity` view.
`pg_stat_get_snapshot_timestamp () → timestamp with time zone` Returns the timestamp of the current statistics snapshot.
`pg_stat_get_xact_blocks_fetched ( oid ) → bigint`

Function Description
Returns the number of block read requests for table or index, in the current transaction. This number minus pg_stat_get_xact_blocks_hit gives the number of kernel read() calls; the number of actual physical reads is usually lower due to kernel-level buffering.
pg_stat_get_xact_blocks_hit (oid) → bigint Returns the number of block read requests for table or index, in the current transaction, found in cache (not triggering kernel read() calls).
pg_stat_clear_snapshot () → void Discards the current statistics snapshot.
pg_stat_reset () → void Resets all statistics counters for the current database to zero. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_stat_reset_shared (text) → void Resets some cluster-wide statistics counters to zero, depending on the argument. The argument can be bgwriter to reset all the counters shown in the pg_stat_bgwriter view, archiver to reset all the counters shown in the pg_stat_archiver view or wal to reset all the counters shown in the pg_stat_wal view. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_stat_reset_single_table_counters (oid) → void Resets statistics for a single table or index in the current database to zero. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_stat_reset_single_function_counters (oid) → void Resets statistics for a single function in the current database to zero. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_stat_reset_slru (text) → void Resets statistics to zero for a single SLRU cache, or for all SLRUs in the cluster. If the argument is NULL, all counters shown in the pg_stat_slru view for all SLRU caches are reset. The argument can be one of CommitTs, MultiXactMember, MultiXactOffset, Notify, Serial, Subtrans, or Xact to reset the counters for only that entry. If the argument is other (or indeed, any unrecognized name), then the counters for all other SLRU caches, such as extension-defined caches, are reset. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.
pg_stat_reset_replication_slot (text) → void Resets statistics of the replication slot defined by the argument. If the argument is NULL, resets statistics for all the replication slots. This function is restricted to superusers by default, but other users can be granted EXECUTE to run the function.

Warning

Using pg_stat_reset() also resets counters that autovacuum uses to determine when to trigger a vacuum or an analyze. Resetting these counters can cause autovacuum to not perform necessary work, which can cause problems such as table bloat or out-dated table statistics. A database-wide ANALYZE is recommended after the statistics have been reset.

pg_stat_get_activity, the underlying function of the pg_stat_activity view, returns a set of records containing all the available information about each backend process. Sometimes it may be more convenient to obtain just a subset of this information. In such cases, an older set of per-backend statistics access functions can be used; these are shown in Table 27.36. These access functions use a backend ID number, which ranges from one to the number of currently active backends. The function pg_stat_get_backend_idset provides a convenient way to generate one row for each active backend for invoking these functions. For example, to show the PIDs and current queries of all backends:

```
SELECT pg_stat_get_backend_pid(s.backendid) AS pid,
       pg_stat_get_backend_activity(s.backendid) AS query
    FROM (SELECT pg_stat_get_backend_idset() AS backendid) AS s;
```

Table 27.36. Per-Backend Statistics Functions

Function Description
pg_stat_get_backend_idset() → setof integer Returns the set of currently active backend ID numbers (from 1 to the number of active backends).
pg_stat_get_backend_activity(integer) → text Returns the text of this backend's most recent query.
pg_stat_get_backend_activity_start(integer) → timestamp with time zone Returns the time when the backend's most recent query was started.
pg_stat_get_backend_client_addr(integer) → inet Returns the IP address of the client connected to this backend.
pg_stat_get_backend_client_port(integer) → integer Returns the TCP port number that the client is using for communication.
pg_stat_get_backend_dbid(integer) → oid Returns the OID of the database this backend is connected to.
pg_stat_get_backend_pid(integer) → integer Returns the process ID of this backend.
pg_stat_get_backend_start(integer) → timestamp with time zone Returns the time when this process was started.
pg_stat_get_backend_userid(integer) → oid Returns the OID of the user logged into this backend.
pg_stat_get_backend_wait_event_type(integer) → text Returns the wait event type name if this backend is currently waiting, otherwise NULL. See Table 27.4 for details.
pg_stat_get_backend_wait_event(integer) → text Returns the wait event name if this backend is currently waiting, otherwise NULL. See Table 27.5 through Table 27.13.
pg_stat_get_backend_xact_start(integer) → timestamp with time zone Returns the time when the backend's current transaction was started.
pg_backend_active_sessions(integer) → integer Returns the number of user sessions currently served by this backend. This value is an indicator of the current workload of the backend.
pg_backend_max_sessions(integer) → integer Returns the maximal number of user sessions served by this backend since its start. This value is an indicator of the peak workload of the backend.
pg_backend_finished_sessions(integer) → integer

Function Description
Returns the number of user sessions that this backend already served. This value is an indicator of the cumulative workload of the backend.
`pg_backend_load_average ( integer ) → integer` Returns the number of user sessions waiting in a queue for this backend, including the active session. This value shows the pure workload of the backend, which does not include idle user sessions. Possible values are: • 0: the backend is idle • 1: the backend is busy, but the queue is empty • > 1: the backend is busy, and the queue is non-empty
`pgpro_stat_get_wal_activity ( integer ) → bigint` Returns the size of WAL files generated by a backend.

27.3. Viewing Locks

Another useful tool for monitoring database activity is the `pg_locks` system table. It allows the database administrator to view information about the outstanding locks in the lock manager. For example, this capability can be used to:

- View all the locks currently outstanding, all the locks on relations in a particular database, all the locks on a particular relation, or all the locks held by a particular Postgres Pro session.
- Determine the relation in the current database with the most ungranted locks (which might be a source of contention among database clients).
- Determine the effect of lock contention on overall database performance, as well as the extent to which contention varies with overall database traffic.

Details of the `pg_locks` view appear in Section 54.76. For more information on locking and managing concurrency with Postgres Pro, refer to Chapter 13.

27.4. Progress Reporting

Postgres Pro has the ability to report the progress of certain commands during command execution. Currently, the only commands which support progress reporting are `ANALYZE`, `CLUSTER`, `CREATE INDEX`, `VACUUM`, `COPY`, and BASE_BACKUP (i.e., replication command that pg_basebackup issues to take a base backup). This may be expanded in the future.

27.4.1. ANALYZE Progress Reporting

Whenever `ANALYZE` is running, the `pg_stat_progress_analyze` view will contain a row for each backend that is currently running that command. The tables below describe the information that will be reported and provide information about how to interpret it.

Table 27.37. `pg_stat_progress_analyze` View

Column Type Description
`pid integer` Process ID of backend.
`datid oid` OID of the database to which this backend is connected.
`datname name` Name of the database to which this backend is connected.
`relid oid` OID of the table being analyzed.

Column Type Description
`phase` `text` Current processing phase. See Table 27.38.
`sample_blks_total` `bigint` Total number of heap blocks that will be sampled.
`sample_blks_scanned` `bigint` Number of heap blocks scanned.
`ext_stats_total` `bigint` Number of extended statistics.
`ext_stats_computed` `bigint` Number of extended statistics computed. This counter only advances when the phase is `computing extended statistics`.
`child_tables_total` `bigint` Number of child tables.
`child_tables_done` `bigint` Number of child tables scanned. This counter only advances when the phase is `acquiring inherited sample rows`.
`current_child_table_relid` `oid` OID of the child table currently being scanned. This field is only valid when the phase is `acquiring inherited sample rows`.

Table 27.38. ANALYZE Phases

Phase	Description
`initializing`	The command is preparing to begin scanning the heap. This phase is expected to be very brief.
`acquiring sample rows`	The command is currently scanning the table given by `relid` to obtain sample rows.
`acquiring inherited sample rows`	The command is currently scanning child tables to obtain sample rows. Columns `child_tables_total`, `child_tables_done`, and `current_child_table_relid` contain the progress information for this phase.
`computing statistics`	The command is computing statistics from the sample rows obtained during the table scan.
`computing extended statistics`	The command is computing extended statistics from the sample rows obtained during the table scan.
`finalizing analyze`	The command is updating `pg_class`. When this phase is completed, `ANALYZE` will end.

> **Note**
>
> Note that when `ANALYZE` is run on a partitioned table, all of its partitions are also recursively analyzed. In that case, `ANALYZE` progress is reported first for the parent table, whereby its inheritance statistics are collected, followed by that for each partition.

27.4.2. CREATE INDEX Progress Reporting

Whenever `CREATE INDEX` or `REINDEX` is running, the `pg_stat_progress_create_index` view will contain one row for each backend that is currently creating indexes. The tables below describe the information that will be reported and provide information about how to interpret it.

Table 27.39. `pg_stat_progress_create_index` View

Column Type Description
`pid` `integer` Process ID of backend.
`datid` `oid` OID of the database to which this backend is connected.
`datname` `name` Name of the database to which this backend is connected.
`relid` `oid` OID of the table on which the index is being created.
`index_relid` `oid` OID of the index being created or reindexed. During a non-concurrent `CREATE INDEX`, this is 0.
`command` `text` The command that is running: `CREATE INDEX`, `CREATE INDEX CONCURRENTLY`, `REINDEX`, or `REINDEX CONCURRENTLY`.
`phase` `text` Current processing phase of index creation. See Table 27.40.
`lockers_total` `bigint` Total number of lockers to wait for, when applicable.
`lockers_done` `bigint` Number of lockers already waited for.
`current_locker_pid` `bigint` Process ID of the locker currently being waited for.
`blocks_total` `bigint` Total number of blocks to be processed in the current phase.
`blocks_done` `bigint` Number of blocks already processed in the current phase.
`tuples_total` `bigint` Total number of tuples to be processed in the current phase.
`tuples_done` `bigint` Number of tuples already processed in the current phase.
`partitions_total` `bigint` When creating an index on a partitioned table, this column is set to the total number of partitions on which the index is to be created. This field is `0` during a `REINDEX`.
`partitions_done` `bigint` When creating an index on a partitioned table, this column is set to the number of partitions on which the index has been created. This field is `0` during a `REINDEX`.

Table 27.40. CREATE INDEX Phases

Phase	Description
`initializing`	`CREATE INDEX` or `REINDEX` is preparing to create the index. This phase is expected to be very brief.
`waiting for writers before build`	`CREATE INDEX CONCURRENTLY` or `REINDEX CONCURRENTLY` is waiting for transactions with write locks that can potentially see the table to finish. This phase is skipped when not in concurrent mode. Columns `lockers_total` , `lockers_done` and `current_locker_pid` contain the progress information for this phase.

Phase	Description
building index	The index is being built by the access method-specific code. In this phase, access methods that support progress reporting fill in their own progress data, and the subphase is indicated in this column. Typically, blocks_total and blocks_done will contain progress data, as well as potentially tuples_total and tuples_done .
waiting for writers before validation	CREATE INDEX CONCURRENTLY or REINDEX CONCURRENTLY is waiting for transactions with write locks that can potentially write into the table to finish. This phase is skipped when not in concurrent mode. Columns lockers_total , lockers_done and current_locker_pid contain the progress information for this phase.
index validation: scanning index	CREATE INDEX CONCURRENTLY is scanning the index searching for tuples that need to be validated. This phase is skipped when not in concurrent mode. Columns blocks_total (set to the total size of the index) and blocks_done contain the progress information for this phase.
index validation: sorting tuples	CREATE INDEX CONCURRENTLY is sorting the output of the index scanning phase.
index validation: scanning table	CREATE INDEX CONCURRENTLY is scanning the table to validate the index tuples collected in the previous two phases. This phase is skipped when not in concurrent mode. Columns blocks_total (set to the total size of the table) and blocks_done contain the progress information for this phase.
waiting for old snapshots	CREATE INDEX CONCURRENTLY or REINDEX CONCURRENTLY is waiting for transactions that can potentially see the table to release their snapshots. This phase is skipped when not in concurrent mode. Columns lockers_total , lockers_done and current_locker_pid contain the progress information for this phase.
waiting for readers before marking dead	REINDEX CONCURRENTLY is waiting for transactions with read locks on the table to finish, before marking the old index dead. This phase is skipped when not in concurrent mode. Columns lockers_total , lockers_done and current_locker_pid contain the progress information for this phase.
waiting for readers before dropping	REINDEX CONCURRENTLY is waiting for transactions with read locks on the table to finish, before dropping the old index. This phase is skipped when not in concurrent mode. Columns lockers_total , lockers_done and current_locker_pid contain the progress information for this phase.

27.4.3. VACUUM Progress Reporting

Whenever VACUUM is running, the pg_stat_progress_vacuum view will contain one row for each backend (including autovacuum worker processes) that is currently vacuuming. The tables below describe the information that will be reported and provide information about how to interpret it. Progress for VACUUM FULL commands is reported via pg_stat_progress_cluster because both VACUUM FULL and CLUSTER rewrite the table, while regular VACUUM only modifies it in place. See Section 27.4.4.

Table 27.41. pg_stat_progress_vacuum View

Column Type Description
pid integer Process ID of backend.
datid oid

Column Type Description
OID of the database to which this backend is connected.
`datname` `name` Name of the database to which this backend is connected.
`relid` `oid` OID of the table being vacuumed.
`phase` `text` Current processing phase of vacuum. See Table 27.42.
`heap_blks_total` `bigint` Total number of heap blocks in the table. This number is reported as of the beginning of the scan; blocks added later will not be (and need not be) visited by this `VACUUM`.
`heap_blks_scanned` `bigint` Number of heap blocks scanned. Because the visibility map is used to optimize scans, some blocks will be skipped without inspection; skipped blocks are included in this total, so that this number will eventually become equal to `heap_blks_total` when the vacuum is complete. This counter only advances when the phase is `scanning heap`.
`heap_blks_vacuumed` `bigint` Number of heap blocks vacuumed. Unless the table has no indexes, this counter only advances when the phase is `vacuuming heap`. Blocks that contain no dead tuples are skipped, so the counter may sometimes skip forward in large increments.
`index_vacuum_count` `bigint` Number of completed index vacuum cycles.
`max_dead_tuples` `bigint` Number of dead tuples that we can store before needing to perform an index vacuum cycle, based on maintenance_work_mem.
`num_dead_tuples` `bigint` Number of dead tuples collected since the last index vacuum cycle.

Table 27.42. VACUUM Phases

Phase	Description
`initializing`	`VACUUM` is preparing to begin scanning the heap. This phase is expected to be very brief.
`scanning heap`	`VACUUM` is currently scanning the heap. It will prune and defragment each page if required, and possibly perform freezing activity. The `heap_blks_scanned` column can be used to monitor the progress of the scan.
`vacuuming indexes`	`VACUUM` is currently vacuuming the indexes. If a table has any indexes, this will happen at least once per vacuum, after the heap has been completely scanned. It may happen multiple times per vacuum if maintenance_work_mem (or, in the case of autovacuum, autovacuum_work_mem if set) is insufficient to store the number of dead tuples found.
`vacuuming heap`	`VACUUM` is currently vacuuming the heap. Vacuuming the heap is distinct from scanning the heap, and occurs after each instance of vacuuming indexes. If `heap_blks_scanned` is less than `heap_blks_total`, the system will return to scanning the heap after this phase is completed; otherwise, it will begin cleaning up indexes after this phase is completed.

Phase	Description
cleaning up indexes	VACUUM is currently cleaning up indexes. This occurs after the heap has been completely scanned and all vacuuming of the indexes and the heap has been completed.
truncating heap	VACUUM is currently truncating the heap so as to return empty pages at the end of the relation to the operating system. This occurs after cleaning up indexes.
performing final cleanup	VACUUM is performing final cleanup. During this phase, VACUUM will vacuum the free space map, update statistics in pg_class , and report statistics to the statistics collector. When this phase is completed, VACUUM will end.

27.4.4. CLUSTER Progress Reporting

Whenever CLUSTER or VACUUM FULL is running, the pg_stat_progress_cluster view will contain a row for each backend that is currently running either command. The tables below describe the information that will be reported and provide information about how to interpret it.

Table 27.43. pg_stat_progress_cluster View

Column Type Description
pid integer Process ID of backend.
datid oid OID of the database to which this backend is connected.
datname name Name of the database to which this backend is connected.
relid oid OID of the table being clustered.
command text The command that is running. Either CLUSTER or VACUUM FULL.
phase text Current processing phase. See Table 27.44.
cluster_index_relid oid If the table is being scanned using an index, this is the OID of the index being used; otherwise, it is zero.
heap_tuples_scanned bigint Number of heap tuples scanned. This counter only advances when the phase is seq scanning heap, index scanning heap or writing new heap.
heap_tuples_written bigint Number of heap tuples written. This counter only advances when the phase is seq scanning heap, index scanning heap or writing new heap.
heap_blks_total bigint Total number of heap blocks in the table. This number is reported as of the beginning of seq scanning heap.
heap_blks_scanned bigint Number of heap blocks scanned. This counter only advances when the phase is seq scanning heap.
index_rebuild_count bigint Number of indexes rebuilt. This counter only advances when the phase is rebuilding index.

Table 27.44. CLUSTER and VACUUM FULL Phases

Phase	Description
`initializing`	The command is preparing to begin scanning the heap. This phase is expected to be very brief.
`seq scanning heap`	The command is currently scanning the table using a sequential scan.
`index scanning heap`	`CLUSTER` is currently scanning the table using an index scan.
`sorting tuples`	`CLUSTER` is currently sorting tuples.
`writing new heap`	`CLUSTER` is currently writing the new heap.
`swapping relation files`	The command is currently swapping newly-built files into place.
`rebuilding index`	The command is currently rebuilding an index.
`performing final cleanup`	The command is performing final cleanup. When this phase is completed, `CLUSTER` or `VACUUM FULL` will end.

27.4.5. Base Backup Progress Reporting

Whenever an application like pg_basebackup is taking a base backup, the `pg_stat_progress_basebackup` view will contain a row for each WAL sender process that is currently running the `BASE_BACKUP` replication command and streaming the backup. The tables below describe the information that will be reported and provide information about how to interpret it.

Table 27.45. `pg_stat_progress_basebackup` View

Column Type Description
`pid integer` Process ID of a WAL sender process.
`phase text` Current processing phase. See Table 27.46.
`backup_total bigint` Total amount of data that will be streamed. This is estimated and reported as of the beginning of `streaming database files` phase. Note that this is only an approximation since the database may change during `streaming database files` phase and WAL log may be included in the backup later. This is always the same value as `backup_streamed` once the amount of data streamed exceeds the estimated total size. If the estimation is disabled in pg_basebackup (i.e., `--no-estimate-size` option is specified), this is `NULL`.
`backup_streamed bigint` Amount of data streamed. This counter only advances when the phase is `streaming database files` or `transferring wal files`.
`tablespaces_total bigint` Total number of tablespaces that will be streamed.
`tablespaces_streamed bigint` Number of tablespaces streamed. This counter only advances when the phase is `streaming database files`.

Table 27.46. Base Backup Phases

Phase	Description
`initializing`	The WAL sender process is preparing to begin the backup. This phase is expected to be very brief.

Phase	Description
waiting for checkpoint to finish	The WAL sender process is currently performing pg_start_backup to prepare to take a base backup, and waiting for the start-of-backup checkpoint to finish.
estimating backup size	The WAL sender process is currently estimating the total amount of database files that will be streamed as a base backup.
streaming database files	The WAL sender process is currently streaming database files as a base backup.
waiting for wal archiving to finish	The WAL sender process is currently performing pg_stop_backup to finish the backup, and waiting for all the WAL files required for the base backup to be successfully archived. If either --wal-method=none or --wal-method=stream is specified in pg_basebackup, the backup will end when this phase is completed.
transferring wal files	The WAL sender process is currently transferring all WAL logs generated during the backup. This phase occurs after waiting for wal archiving to finish phase if --wal-method=fetch is specified in pg_basebackup. The backup will end when this phase is completed.

27.4.6. COPY Progress Reporting

Whenever COPY is running, the pg_stat_progress_copy view will contain one row for each backend that is currently running a COPY command. The table below describes the information that will be reported and provides information about how to interpret it.

Table 27.47. pg_stat_progress_copy View

Column Type Description
pid integer Process ID of backend.
datid oid OID of the database to which this backend is connected.
datname name Name of the database to which this backend is connected.
relid oid OID of the table on which the COPY command is executed. It is set to 0 if copying from a SELECT query.
command text The command that is running: COPY FROM, or COPY TO.
type text The io type that the data is read from or written to: FILE, PROGRAM, PIPE (for COPY FROM STDIN and COPY TO STDOUT), or CALLBACK (used for example during the initial table synchronization in logical replication).
bytes_processed bigint Number of bytes already processed by COPY command.
bytes_total bigint Size of source file for COPY FROM command in bytes. It is set to 0 if not available.
tuples_processed bigint Number of tuples already processed by COPY command.
tuples_excluded bigint

Column Type Description
Number of tuples not processed because they were excluded by the `WHERE` clause of the `COPY` command.

Chapter 28. Monitoring Disk Usage

This chapter discusses how to monitor the disk usage of a Postgres Pro database system.

28.1. Determining Disk Usage

Each table has a primary heap disk file where most of the data is stored. If the table has any columns with potentially-wide values, there also might be a TOAST file associated with the table, which is used to store values too wide to fit comfortably in the main table (see Section 70.2). There will be one valid index on the TOAST table, if present. There also might be indexes associated with the base table. Each table and index is stored in a separate disk file — possibly more than one file, if the file would exceed one gigabyte. Naming conventions for these files are described in Section 70.1.

You can monitor disk space in three ways: using the SQL functions listed in Table 9.92, using the oid2name module, or using manual inspection of the system catalogs. The SQL functions are the easiest to use and are generally recommended. The remainder of this section shows how to do it by inspection of the system catalogs.

Using psql on a recently vacuumed or analyzed database, you can issue queries to see the disk usage of any table:

```
SELECT pg_relation_filepath(oid), relpages FROM pg_class WHERE relname = 'customer';

 pg_relation_filepath | relpages
----------------------+----------
 base/16384/16806     |       60
(1 row)
```

Each page is typically 8 kilobytes. (Remember, `relpages` is only updated by `VACUUM`, `ANALYZE`, and a few DDL commands such as `CREATE INDEX`.) The file path name is of interest if you want to examine the table's disk file directly.

To show the space used by TOAST tables, use a query like the following:

```
SELECT relname, relpages
FROM pg_class,
     (SELECT reltoastrelid
      FROM pg_class
      WHERE relname = 'customer') AS ss
WHERE oid = ss.reltoastrelid OR
      oid = (SELECT indexrelid
             FROM pg_index
             WHERE indrelid = ss.reltoastrelid)
ORDER BY relname;

       relname        | relpages
----------------------+----------
 pg_toast_16806       |        0
 pg_toast_16806_index |        1
```

You can easily display index sizes, too:

```
SELECT c2.relname, c2.relpages
FROM pg_class c, pg_class c2, pg_index i
WHERE c.relname = 'customer' AND
      c.oid = i.indrelid AND
      c2.oid = i.indexrelid
ORDER BY c2.relname;

      relname      | relpages
```

```
-------------------+----------
 customer_id_index |       26
```

It is easy to find your largest tables and indexes using this information:

```
SELECT relname, relpages
FROM pg_class
ORDER BY relpages DESC;

       relname        | relpages
----------------------+----------
 bigtable             |     3290
 customer             |     3144
```

28.2. Disk Full Failure

The most important disk monitoring task of a database administrator is to make sure the disk doesn't become full. A filled data disk will not result in data corruption, but it might prevent useful activity from occurring. If the disk holding the WAL files grows full, database server panic and consequent shutdown might occur.

If you cannot free up additional space on the disk by deleting other things, you can move some of the database files to other file systems by making use of tablespaces. See Section 22.6 for more information about that.

> **Tip**
>
> Some file systems perform badly when they are almost full, so do not wait until the disk is completely full to take action.

If your system supports per-user disk quotas, then the database will naturally be subject to whatever quota is placed on the user the server runs as. Exceeding the quota will have the same bad effects as running out of disk space entirely.

Chapter 29. Reliability and the Write-Ahead Log

This chapter explains how the Write-Ahead Log is used to obtain efficient, reliable operation.

29.1. Reliability

Reliability is an important property of any serious database system, and Postgres Pro does everything possible to guarantee reliable operation. One aspect of reliable operation is that all data recorded by a committed transaction should be stored in a nonvolatile area that is safe from power loss, operating system failure, and hardware failure (except failure of the nonvolatile area itself, of course). Successfully writing the data to the computer's permanent storage (disk drive or equivalent) ordinarily meets this requirement. In fact, even if a computer is fatally damaged, if the disk drives survive they can be moved to another computer with similar hardware and all committed transactions will remain intact.

While forcing data to the disk platters periodically might seem like a simple operation, it is not. Because disk drives are dramatically slower than main memory and CPUs, several layers of caching exist between the computer's main memory and the disk platters. First, there is the operating system's buffer cache, which caches frequently requested disk blocks and combines disk writes. Fortunately, all operating systems give applications a way to force writes from the buffer cache to disk, and Postgres Pro uses those features. (See the wal_sync_method parameter to adjust how this is done.)

Next, there might be a cache in the disk drive controller; this is particularly common on RAID controller cards. Some of these caches are *write-through*, meaning writes are sent to the drive as soon as they arrive. Others are *write-back*, meaning data is sent to the drive at some later time. Such caches can be a reliability hazard because the memory in the disk controller cache is volatile, and will lose its contents in a power failure. Better controller cards have *battery-backup units* (BBUs), meaning the card has a battery that maintains power to the cache in case of system power loss. After power is restored the data will be written to the disk drives.

And finally, most disk drives have caches. Some are write-through while some are write-back, and the same concerns about data loss exist for write-back drive caches as for disk controller caches. Consumer-grade IDE and SATA drives are particularly likely to have write-back caches that will not survive a power failure. Many solid-state drives (SSD) also have volatile write-back caches.

These caches can typically be disabled; however, the method for doing this varies by operating system and drive type:

- On Linux, IDE and SATA drives can be queried using `hdparm -I`; write caching is enabled if there is a `*` next to `Write cache`. `hdparm -W 0` can be used to turn off write caching. SCSI drives can be queried using *sdparm*. Use `sdparm --get=WCE` to check whether the write cache is enabled and `sdparm --clear=WCE` to disable it.
- On FreeBSD, IDE drives can be queried using `camcontrol identify` and write caching turned off using `hw.ata.wc=0` in `/boot/loader.conf`; SCSI drives can be queried using `camcontrol identify`, and the write cache both queried and changed using `sdparm` when available.
- On Solaris, the disk write cache is controlled by `format -e`. (The Solaris ZFS file system is safe with disk write-cache enabled because it issues its own disk cache flush commands.)
- On Windows, if `wal_sync_method` is `open_datasync` (the default), write caching can be disabled by unchecking `My Computer\Open\`*`disk drive`*`\Properties\Hardware\Properties\Policies\Enable write caching on the disk`. Alternatively, set `wal_sync_method` to `fsync` or `fsync_writethrough`, which prevent write caching.
- On macOS, write caching can be prevented by setting `wal_sync_method` to `fsync_writethrough`.

Recent SATA drives (those following ATAPI-6 or later) offer a drive cache flush command (`FLUSH CACHE EXT`), while SCSI drives have long supported a similar command `SYNCHRONIZE CACHE`. These commands

are not directly accessible to Postgres Pro, but some file systems (e.g., ZFS, ext4) can use them to flush data to the platters on write-back-enabled drives. Unfortunately, such file systems behave suboptimally when combined with battery-backup unit (BBU) disk controllers. In such setups, the synchronize command forces all data from the controller cache to the disks, eliminating much of the benefit of the BBU. You can run the pg_test_fsync program to see if you are affected. If you are affected, the performance benefits of the BBU can be regained by turning off write barriers in the file system or reconfiguring the disk controller, if that is an option. If write barriers are turned off, make sure the battery remains functional; a faulty battery can potentially lead to data loss. Hopefully file system and disk controller designers will eventually address this suboptimal behavior.

When the operating system sends a write request to the storage hardware, there is little it can do to make sure the data has arrived at a truly non-volatile storage area. Rather, it is the administrator's responsibility to make certain that all storage components ensure integrity for both data and file-system metadata. Avoid disk controllers that have non-battery-backed write caches. At the drive level, disable write-back caching if the drive cannot guarantee the data will be written before shutdown. If you use SSDs, be aware that many of these do not honor cache flush commands by default. You can test for reliable I/O subsystem behavior using *diskchecker.pl*.

Another risk of data loss is posed by the disk platter write operations themselves. Disk platters are divided into sectors, commonly 512 bytes each. Every physical read or write operation processes a whole sector. When a write request arrives at the drive, it might be for some multiple of 512 bytes (Postgres Pro typically writes 8192 bytes, or 16 sectors, at a time), and the process of writing could fail due to power loss at any time, meaning some of the 512-byte sectors were written while others were not. To guard against such failures, Postgres Pro periodically writes full page images to permanent WAL storage *before* modifying the actual page on disk. By doing this, during crash recovery Postgres Pro can restore partially-written pages from WAL. If you have file-system software that prevents partial page writes (e.g., ZFS), you can turn off this page imaging by turning off the full_page_writes parameter. Battery-Backed Unit (BBU) disk controllers do not prevent partial page writes unless they guarantee that data is written to the BBU as full (8kB) pages.

Postgres Pro also protects against some kinds of data corruption on storage devices that may occur because of hardware errors or media failure over time, such as reading/writing garbage data.

- Each individual record in a WAL file is protected by a CRC-32C (32-bit) check that allows us to tell if record contents are correct. The CRC value is set when we write each WAL record and checked during crash recovery, archive recovery and replication.
- Data pages are not currently checksummed by default, though full page images recorded in WAL records will be protected; see initdb for details about enabling data checksums.
- Internal data structures such as `pg_xact`, `pg_subtrans`, `pg_multixact`, `pg_serial`, `pg_notify`, `pg_stat`, `pg_snapshots` are not directly checksummed, nor are pages protected by full page writes. However, where such data structures are persistent, WAL records are written that allow recent changes to be accurately rebuilt at crash recovery and those WAL records are protected as discussed above.
- Individual state files in `pg_twophase` are protected by CRC-32C.
- Temporary data files used in larger SQL queries for sorts, materializations and intermediate results are not currently checksummed, nor will WAL records be written for changes to those files.

Postgres Pro does not protect against correctable memory errors and it is assumed you will operate using RAM that uses industry standard Error Correcting Codes (ECC) or better protection.

29.2. Data Checksums

By default, data pages are not protected by checksums, but this can optionally be enabled for a cluster. When enabled, each data page includes a checksum that is updated when the page is written and verified each time the page is read. Only data pages are protected by checksums; internal data structures and temporary files are not.

Checksums can be enabled when the cluster is initialized using initdb. They can also be enabled or disabled at a later time as an offline operation. Data checksums are enabled or disabled at the full cluster level, and cannot be specified individually for databases or tables.

The current state of checksums in the cluster can be verified by viewing the value of the read-only configuration variable data_checksums by issuing the command `SHOW data_checksums`.

When attempting to recover from page corruptions, it may be necessary to bypass the checksum protection. To do this, temporarily set the configuration parameter ignore_checksum_failure.

29.2.1. Off-line Enabling of Checksums

The pg_checksums application can be used to enable or disable data checksums, as well as verify checksums, on an offline cluster.

29.3. Write-Ahead Logging (WAL)

Write-Ahead Logging (WAL) is a standard method for ensuring data integrity. A detailed description can be found in most (if not all) books about transaction processing. Briefly, WAL's central concept is that changes to data files (where tables and indexes reside) must be written only after those changes have been logged, that is, after log records describing the changes have been flushed to permanent storage. If we follow this procedure, we do not need to flush data pages to disk on every transaction commit, because we know that in the event of a crash we will be able to recover the database using the log: any changes that have not been applied to the data pages can be redone from the log records. (This is roll-forward recovery, also known as REDO.)

> **Tip**
>
> Because WAL restores database file contents after a crash, journaled file systems are not necessary for reliable storage of the data files or WAL files. In fact, journaling overhead can reduce performance, especially if journaling causes file system *data* to be flushed to disk. Fortunately, data flushing during journaling can often be disabled with a file system mount option, e.g., `data=writeback` on a Linux ext3 file system. Journaled file systems do improve boot speed after a crash.

Using WAL results in a significantly reduced number of disk writes, because only the log file needs to be flushed to disk to guarantee that a transaction is committed, rather than every data file changed by the transaction. The log file is written sequentially, and so the cost of syncing the log is much less than the cost of flushing the data pages. This is especially true for servers handling many small transactions touching different parts of the data store. Furthermore, when the server is processing many small concurrent transactions, one `fsync` of the log file may suffice to commit many transactions.

WAL also makes it possible to support on-line backup and point-in-time recovery, as described in Section 25.3. By archiving the WAL data we can support reverting to any time instant covered by the available WAL data: we simply install a prior physical backup of the database, and replay the WAL log just as far as the desired time. What's more, the physical backup doesn't have to be an instantaneous snapshot of the database state — if it is made over some period of time, then replaying the WAL log for that period will fix any internal inconsistencies.

29.4. Asynchronous Commit

Asynchronous commit is an option that allows transactions to complete more quickly, at the cost that the most recent transactions may be lost if the database should crash. In many applications this is an acceptable trade-off.

As described in the previous section, transaction commit is normally *synchronous*: the server waits for the transaction's WAL records to be flushed to permanent storage before returning a success indication

to the client. The client is therefore guaranteed that a transaction reported to be committed will be preserved, even in the event of a server crash immediately after. However, for short transactions this delay is a major component of the total transaction time. Selecting asynchronous commit mode means that the server returns success as soon as the transaction is logically completed, before the WAL records it generated have actually made their way to disk. This can provide a significant boost in throughput for small transactions.

Asynchronous commit introduces the risk of data loss. There is a short time window between the report of transaction completion to the client and the time that the transaction is truly committed (that is, it is guaranteed not to be lost if the server crashes). Thus asynchronous commit should not be used if the client will take external actions relying on the assumption that the transaction will be remembered. As an example, a bank would certainly not use asynchronous commit for a transaction recording an ATM's dispensing of cash. But in many scenarios, such as event logging, there is no need for a strong guarantee of this kind.

The risk that is taken by using asynchronous commit is of data loss, not data corruption. If the database should crash, it will recover by replaying WAL up to the last record that was flushed. The database will therefore be restored to a self-consistent state, but any transactions that were not yet flushed to disk will not be reflected in that state. The net effect is therefore loss of the last few transactions. Because the transactions are replayed in commit order, no inconsistency can be introduced — for example, if transaction B made changes relying on the effects of a previous transaction A, it is not possible for A's effects to be lost while B's effects are preserved.

The user can select the commit mode of each transaction, so that it is possible to have both synchronous and asynchronous commit transactions running concurrently. This allows flexible trade-offs between performance and certainty of transaction durability. The commit mode is controlled by the user-settable parameter synchronous_commit, which can be changed in any of the ways that a configuration parameter can be set. The mode used for any one transaction depends on the value of `synchronous_commit` when transaction commit begins.

Certain utility commands, for instance `DROP TABLE`, are forced to commit synchronously regardless of the setting of `synchronous_commit`. This is to ensure consistency between the server's file system and the logical state of the database. The commands supporting two-phase commit, such as `PREPARE TRANSACTION`, are also always synchronous.

If the database crashes during the risk window between an asynchronous commit and the writing of the transaction's WAL records, then changes made during that transaction *will* be lost. The duration of the risk window is limited because a background process (the “WAL writer”) flushes unwritten WAL records to disk every wal_writer_delay milliseconds. The actual maximum duration of the risk window is three times `wal_writer_delay` because the WAL writer is designed to favor writing whole pages at a time during busy periods.

> **Caution**
>
> An immediate-mode shutdown is equivalent to a server crash, and will therefore cause loss of any unflushed asynchronous commits.

Asynchronous commit provides behavior different from setting fsync = off. `fsync` is a server-wide setting that will alter the behavior of all transactions. It disables all logic within Postgres Pro that attempts to synchronize writes to different portions of the database, and therefore a system crash (that is, a hardware or operating system crash, not a failure of Postgres Pro itself) could result in arbitrarily bad corruption of the database state. In many scenarios, asynchronous commit provides most of the performance improvement that could be obtained by turning off `fsync`, but without the risk of data corruption.

commit_delay also sounds very similar to asynchronous commit, but it is actually a synchronous commit method (in fact, `commit_delay` is ignored during an asynchronous commit). `commit_delay` causes a delay just before a transaction flushes WAL to disk, in the hope that a single flush executed by one such transaction can also serve other transactions committing at about the same time. The setting can be

thought of as a way of increasing the time window in which transactions can join a group about to participate in a single flush, to amortize the cost of the flush among multiple transactions.

29.5. WAL Configuration

There are several WAL-related configuration parameters that affect database performance. This section explains their use. Consult Chapter 19 for general information about setting server configuration parameters.

*Checkpoints*are points in the sequence of transactions at which it is guaranteed that the heap and index data files have been updated with all information written before that checkpoint. At checkpoint time, all dirty data pages are flushed to disk and a special checkpoint record is written to the log file. (The change records were previously flushed to the WAL files.) In the event of a crash, the crash recovery procedure looks at the latest checkpoint record to determine the point in the log (known as the redo record) from which it should start the REDO operation. Any changes made to data files before that point are guaranteed to be already on disk. Hence, after a checkpoint, log segments preceding the one containing the redo record are no longer needed and can be recycled or removed. (When WAL archiving is being done, the log segments must be archived before being recycled or removed.)

The checkpoint requirement of flushing all dirty data pages to disk can cause a significant I/O load. For this reason, checkpoint activity is throttled so that I/O begins at checkpoint start and completes before the next checkpoint is due to start; this minimizes performance degradation during checkpoints.

The server's checkpointer process automatically performs a checkpoint every so often. A checkpoint is begun every checkpoint_timeout seconds, or if max_wal_size is about to be exceeded, whichever comes first. The default settings are 5 minutes and 1 GB, respectively. If no WAL has been written since the previous checkpoint, new checkpoints will be skipped even if `checkpoint_timeout` has passed. (If WAL archiving is being used and you want to put a lower limit on how often files are archived in order to bound potential data loss, you should adjust the archive_timeout parameter rather than the checkpoint parameters.) It is also possible to force a checkpoint by using the SQL command `CHECKPOINT`.

Reducing `checkpoint_timeout` and/or `max_wal_size` causes checkpoints to occur more often. This allows faster after-crash recovery, since less work will need to be redone. However, one must balance this against the increased cost of flushing dirty data pages more often. If full_page_writes is set (as is the default), there is another factor to consider. To ensure data page consistency, the first modification of a data page after each checkpoint results in logging the entire page content. In that case, a smaller checkpoint interval increases the volume of output to the WAL log, partially negating the goal of using a smaller interval, and in any case causing more disk I/O.

Checkpoints are fairly expensive, first because they require writing out all currently dirty buffers, and second because they result in extra subsequent WAL traffic as discussed above. It is therefore wise to set the checkpointing parameters high enough so that checkpoints don't happen too often. As a simple sanity check on your checkpointing parameters, you can set the checkpoint_warning parameter. If checkpoints happen closer together than `checkpoint_warning` seconds, a message will be output to the server log recommending increasing `max_wal_size`. Occasional appearance of such a message is not cause for alarm, but if it appears often then the checkpoint control parameters should be increased. Bulk operations such as large `COPY` transfers might cause a number of such warnings to appear if you have not set `max_wal_size` high enough.

To avoid flooding the I/O system with a burst of page writes, writing dirty buffers during a checkpoint is spread over a period of time. That period is controlled by checkpoint_completion_target, which is given as a fraction of the checkpoint interval (configured by using `checkpoint_timeout`). The I/O rate is adjusted so that the checkpoint finishes when the given fraction of `checkpoint_timeout` seconds have elapsed, or before `max_wal_size` is exceeded, whichever is sooner. With the default value of 0.9, Postgres Pro can be expected to complete each checkpoint a bit before the next scheduled checkpoint (at around 90% of the last checkpoint's duration). This spreads out the I/O as much as possible so that the checkpoint I/O load is consistent throughout the checkpoint interval. The disadvantage of this is that prolonging checkpoints affects recovery time, because more WAL segments will need to be kept around for possible use in recovery. A user concerned about the amount of time required to recover

might wish to reduce checkpoint_timeout so that checkpoints occur more frequently but still spread the I/O across the checkpoint interval. Alternatively, checkpoint_completion_target could be reduced, but this would result in times of more intense I/O (during the checkpoint) and times of less I/O (after the checkpoint completed but before the next scheduled checkpoint) and therefore is not recommended. Although checkpoint_completion_target could be set as high as 1.0, it is typically recommended to set it to no higher than 0.9 (the default) since checkpoints include some other activities besides writing dirty buffers. A setting of 1.0 is quite likely to result in checkpoints not being completed on time, which would result in performance loss due to unexpected variation in the number of WAL segments needed.

On Linux and POSIX platforms checkpoint_flush_after allows to force the OS that pages written by the checkpoint should be flushed to disk after a configurable number of bytes. Otherwise, these pages may be kept in the OS's page cache, inducing a stall when fsync is issued at the end of a checkpoint. This setting will often help to reduce transaction latency, but it also can have an adverse effect on performance; particularly for workloads that are bigger than shared_buffers, but smaller than the OS's page cache.

The number of WAL segment files in pg_wal directory depends on min_wal_size, max_wal_size and the amount of WAL generated in previous checkpoint cycles. When old log segment files are no longer needed, they are removed or recycled (that is, renamed to become future segments in the numbered sequence). If, due to a short-term peak of log output rate, max_wal_size is exceeded, the unneeded segment files will be removed until the system gets back under this limit. Below that limit, the system recycles enough WAL files to cover the estimated need until the next checkpoint, and removes the rest. The estimate is based on a moving average of the number of WAL files used in previous checkpoint cycles. The moving average is increased immediately if the actual usage exceeds the estimate, so it accommodates peak usage rather than average usage to some extent. min_wal_size puts a minimum on the amount of WAL files recycled for future usage; that much WAL is always recycled for future use, even if the system is idle and the WAL usage estimate suggests that little WAL is needed.

Independently of max_wal_size, the most recent wal_keep_size megabytes of WAL files plus one additional WAL file are kept at all times. Also, if WAL archiving is used, old segments cannot be removed or recycled until they are archived. If WAL archiving cannot keep up with the pace that WAL is generated, or if archive_command fails repeatedly, old WAL files will accumulate in pg_wal until the situation is resolved. A slow or failed standby server that uses a replication slot will have the same effect (see Section 26.2.6).

In archive recovery or standby mode, the server periodically performs *restartpoints*, which are similar to checkpoints in normal operation: the server forces all its state to disk, updates the pg_control file to indicate that the already-processed WAL data need not be scanned again, and then recycles any old log segment files in the pg_wal directory. Restartpoints can't be performed more frequently than checkpoints on the primary because restartpoints can only be performed at checkpoint records. A restartpoint is triggered when a checkpoint record is reached if at least checkpoint_timeout seconds have passed since the last restartpoint, or if WAL size is about to exceed max_wal_size. However, because of limitations on when a restartpoint can be performed, max_wal_size is often exceeded during recovery, by up to one checkpoint cycle's worth of WAL. (max_wal_size is never a hard limit anyway, so you should always leave plenty of headroom to avoid running out of disk space.)

There are two commonly used internal WAL functions: XLogInsertRecord and XLogFlush. XLogInsertRecord is used to place a new record into the WAL buffers in shared memory. If there is no space for the new record, XLogInsertRecord will have to write (move to kernel cache) a few filled WAL buffers. This is undesirable because XLogInsertRecord is used on every database low level modification (for example, row insertion) at a time when an exclusive lock is held on affected data pages, so the operation needs to be as fast as possible. What is worse, writing WAL buffers might also force the creation of a new log segment, which takes even more time. Normally, WAL buffers should be written and flushed by an XLogFlush request, which is made, for the most part, at transaction commit time to ensure that transaction records are flushed to permanent storage. On systems with high log output, XLogFlush requests might not occur often enough to prevent XLogInsertRecord from having to do writes. On such systems one should increase the number of WAL buffers by modifying the wal_buffers parameter. When full_page_writes is set and the system is very busy, setting wal_buffers higher will help smooth response times during the period immediately following each checkpoint.

The commit_delay parameter defines for how many microseconds a group commit leader process will sleep after acquiring a lock within XLogFlush, while group commit followers queue up behind the leader. This delay allows other server processes to add their commit records to the WAL buffers so that all of them will be flushed by the leader's eventual sync operation. No sleep will occur if fsync is not enabled, or if fewer than commit_siblings other sessions are currently in active transactions; this avoids sleeping when it's unlikely that any other session will commit soon. Note that on some platforms, the resolution of a sleep request is ten milliseconds, so that any nonzero commit_delay setting between 1 and 10000 microseconds would have the same effect. Note also that on some platforms, sleep operations may take slightly longer than requested by the parameter.

Since the purpose of commit_delay is to allow the cost of each flush operation to be amortized across concurrently committing transactions (potentially at the expense of transaction latency), it is necessary to quantify that cost before the setting can be chosen intelligently. The higher that cost is, the more effective commit_delay is expected to be in increasing transaction throughput, up to a point. The pg_test_fsync program can be used to measure the average time in microseconds that a single WAL flush operation takes. A value of half of the average time the program reports it takes to flush after a single 8kB write operation is often the most effective setting for commit_delay, so this value is recommended as the starting point to use when optimizing for a particular workload. While tuning commit_delay is particularly useful when the WAL log is stored on high-latency rotating disks, benefits can be significant even on storage media with very fast sync times, such as solid-state drives or RAID arrays with a battery-backed write cache; but this should definitely be tested against a representative workload. Higher values of commit_siblings should be used in such cases, whereas smaller commit_siblings values are often helpful on higher latency media. Note that it is quite possible that a setting of commit_delay that is too high can increase transaction latency by so much that total transaction throughput suffers.

When commit_delay is set to zero (the default), it is still possible for a form of group commit to occur, but each group will consist only of sessions that reach the point where they need to flush their commit records during the window in which the previous flush operation (if any) is occurring. At higher client counts a “gangway effect” tends to occur, so that the effects of group commit become significant even when commit_delay is zero, and thus explicitly setting commit_delay tends to help less. Setting commit_delay can only help when (1) there are some concurrently committing transactions, and (2) throughput is limited to some degree by commit rate; but with high rotational latency this setting can be effective in increasing transaction throughput with as few as two clients (that is, a single committing client with one sibling transaction).

The wal_sync_method parameter determines how Postgres Pro will ask the kernel to force WAL updates out to disk. All the options should be the same in terms of reliability, with the exception of fsync_writethrough, which can sometimes force a flush of the disk cache even when other options do not do so. However, it's quite platform-specific which one will be the fastest. You can test the speeds of different options using the pg_test_fsync program. Note that this parameter is irrelevant if fsync has been turned off.

Enabling the wal_debug configuration parameter (provided that Postgres Pro has been compiled with support for it) will result in each XLogInsertRecord and XLogFlush WAL call being logged to the server log. This option might be replaced by a more general mechanism in the future.

There are two internal functions to write WAL data to disk: XLogWrite and issue_xlog_fsync. When track_wal_io_timing is enabled, the total amounts of time XLogWrite writes and issue_xlog_fsync syncs WAL data to disk are counted as wal_write_time and wal_sync_time in pg_stat_wal, respectively. XLogWrite is normally called by XLogInsertRecord (when there is no space for the new record in WAL buffers), XLogFlush and the WAL writer, to write WAL buffers to disk and call issue_xlog_fsync. issue_xlog_fsync is normally called by XLogWrite to sync WAL files to disk. If wal_sync_method is either open_datasync or open_sync, a write operation in XLogWrite guarantees to sync written WAL data to disk and issue_xlog_fsync does nothing. If wal_sync_method is either fdatasync, fsync, or fsync_writethrough, the write operation moves WAL buffers to kernel cache and issue_xlog_fsync syncs them to disk. Regardless of the setting of track_wal_io_timing, the number of times XLogWrite writes and issue_xlog_fsync syncs WAL data to disk are also counted as wal_write and wal_sync in pg_stat_wal, respectively.

29.6. WAL Restoration

Postgres Pro uses WAL to provide protection against some types of data corruption that may occur because of hardware faults. To validate data integrity, all the WAL records are protected by a CRC check.

However, some uncommon transient faults that can be attributed to hardware may cause checksum errors when moving WAL records. As a result, WAL changes would not apply to a replica, and the physical replication would terminate due to a fatal error accompanied by an error message about an incorrect data checksum.

Postgres Pro offers a solution to this type of issues by restoring corrupted WAL data from in-memory WAL buffers. The amount of WAL data kept in memory is specified by the wal_buffers parameter. The WAL sender process checks CRC values of WAL records before sending them to a replica. If a corrupted record is detected, the WAL sender process tries to restore it from the buffers. For extra protection, there are two copies of the buffers. If the corrupted record could not be restored, the WAL sender process aborts replication with an error. The level of error depends on the value of the wal_sender_panic_on_crc_error configuration parameter. So if you already have, or suspect you have, such hardware problems, it is recommended to enable additional WAL restoration from WAL buffers by modifying the wal_sender_check_crc parameter.

29.7. WAL Internals

WAL is automatically enabled; no action is required from the administrator except ensuring that the disk-space requirements for the WAL logs are met, and that any necessary tuning is done (see Section 29.5).

WAL records are appended to the WAL logs as each new record is written. The insert position is described by a Log Sequence Number (LSN) that is a byte offset into the logs, increasing monotonically with each new record. LSN values are returned as the datatype `pg_lsn`. Values can be compared to calculate the volume of WAL data that separates them, so they are used to measure the progress of replication and recovery.

WAL logs are stored in the directory `pg_wal` under the data directory, as a set of segment files, normally each 16 MB in size (but the size can be changed by altering the `--wal-segsize` initdb option). Each segment is divided into pages, normally 8 kB each. The log record content is dependent on the type of event that is being logged. Segment files are given ever-increasing numbers as names, starting at `000000010000000000000001`. The numbers do not wrap, but it will take a very, very long time to exhaust the available stock of numbers.

It is advantageous if the log is located on a different disk from the main database files. This can be achieved by moving the `pg_wal` directory to another location (while the server is shut down, of course) and creating a symbolic link from the original location in the main data directory to the new location.

The aim of WAL is to ensure that the log is written before database records are altered, but this can be subverted by disk drives that falsely report a successful write to the kernel, when in fact they have only cached the data and not yet stored it on the disk. A power failure in such a situation might lead to irrecoverable data corruption. Administrators should try to ensure that disks holding Postgres Pro's WAL log files do not make such false reports. (See Section 29.1.)

After a checkpoint has been made and the log flushed, the checkpoint's position is saved in the file `pg_control`. Therefore, at the start of recovery, the server first reads `pg_control` and then the checkpoint record; then it performs the REDO operation by scanning forward from the log location indicated in the checkpoint record. Because the entire content of data pages is saved in the log on the first page modification after a checkpoint (assuming full_page_writes is not disabled), all pages changed since the checkpoint will be restored to a consistent state.

To deal with the case where `pg_control` is corrupt, we should support the possibility of scanning existing log segments in reverse order — newest to oldest — in order to find the latest checkpoint. This has not been implemented yet. `pg_control` is small enough (less than one disk page) that it is not subject to partial-write problems, and as of this writing there have been no reports of database failures due solely

to the inability to read `pg_control` itself. So while it is theoretically a weak spot, `pg_control` does not seem to be a problem in practice.

Chapter 30. Logical Replication

Logical replication is a method of replicating data objects and their changes, based upon their replication identity (usually a primary key). We use the term logical in contrast to physical replication, which uses exact block addresses and byte-by-byte replication. Postgres Pro supports both mechanisms concurrently, see Chapter 26. Logical replication allows fine-grained control over both data replication and security.

Logical replication uses a *publish* and *subscribe* model with one or more *subscribers* subscribing to one or more *publications* on a *publisher* node. Subscribers pull data from the publications they subscribe to and may subsequently re-publish data to allow cascading replication or more complex configurations.

Logical replication of a table typically starts with taking a snapshot of the data on the publisher database and copying that to the subscriber. Once that is done, the changes on the publisher are sent to the subscriber as they occur in real-time. The subscriber applies the data in the same order as the publisher so that transactional consistency is guaranteed for publications within a single subscription. This method of data replication is sometimes referred to as transactional replication.

The typical use-cases for logical replication are:

- Sending incremental changes in a single database or a subset of a database to subscribers as they occur.
- Firing triggers for individual changes as they arrive on the subscriber.
- Consolidating multiple databases into a single one (for example for analytical purposes).
- Replicating between different major versions of Postgres Pro.
- Replicating between Postgres Pro instances on different platforms (for example Linux to Windows)
- Giving access to replicated data to different groups of users.
- Sharing a subset of the database between multiple databases.

The subscriber database behaves in the same way as any other Postgres Pro instance and can be used as a publisher for other databases by defining its own publications. When the subscriber is treated as read-only by application, there will be no conflicts from a single subscription. On the other hand, if there are other writes done either by an application or by other subscribers to the same set of tables, conflicts can arise.

> **Note**
>
> Postgres Pro supports logical replication to a Postgres Pro Enterprise server from servers of different editions: PostgreSQL or Postgres Pro Standard of the same or a previous version.

30.1. Publication

A *publication* can be defined on any physical replication primary. The node where a publication is defined is referred to as *publisher*. A publication is a set of changes generated from a table or a group of tables, and might also be described as a change set or replication set. Each publication exists in only one database.

Publications are different from schemas and do not affect how the table is accessed. Each table can be added to multiple publications if needed. Publications may currently only contain tables. Objects must be added explicitly, except when a publication is created for `ALL TABLES`.

Publications can choose to limit the changes they produce to any combination of `INSERT`, `UPDATE`, `DELETE`, and `TRUNCATE`, similar to how triggers are fired by particular event types. By default, all operation types are replicated.

A published table must have a “replica identity” configured in order to be able to replicate UPDATE and DELETE operations, so that appropriate rows to update or delete can be identified on the subscriber side. By default, this is the primary key, if there is one. Another unique index (with certain additional requirements) can also be set to be the replica identity. If the table does not have any suitable key, then it can be set to replica identity “full”, which means the entire row becomes the key. This, however, is very inefficient and should only be used as a fallback if no other solution is possible. If a replica identity other than “full” is set on the publisher side, a replica identity comprising the same or fewer columns must also be set on the subscriber side. See REPLICA IDENTITY for details on how to set the replica identity. If a table without a replica identity is added to a publication that replicates UPDATE or DELETE operations then subsequent UPDATE or DELETE operations will cause an error on the publisher. INSERT operations can proceed regardless of any replica identity.

Every publication can have multiple subscribers.

A publication is created using the CREATE PUBLICATION command and may later be altered or dropped using corresponding commands.

The individual tables can be added and removed dynamically using ALTER PUBLICATION. Both the ADD TABLE and DROP TABLE operations are transactional; so the table will start or stop replicating at the correct snapshot once the transaction has committed.

30.2. Subscription

A *subscription* is the downstream side of logical replication. The node where a subscription is defined is referred to as the *subscriber*. A subscription defines the connection to another database and set of publications (one or more) to which it wants to subscribe.

The subscriber database behaves in the same way as any other Postgres Pro instance and can be used as a publisher for other databases by defining its own publications.

A subscriber node may have multiple subscriptions if desired. It is possible to define multiple subscriptions between a single publisher-subscriber pair, in which case care must be taken to ensure that the subscribed publication objects don't overlap.

Each subscription will receive changes via one replication slot (see Section 26.2.6). Additional replication slots may be required for the initial data synchronization of pre-existing table data and those will be dropped at the end of data synchronization.

A logical replication subscription can be a standby for synchronous replication (see Section 26.2.8). The standby name is by default the subscription name. An alternative name can be specified as application_name in the connection information of the subscription.

Subscriptions are dumped by pg_dump if the current user is a superuser. Otherwise a warning is written and subscriptions are skipped, because non-superusers cannot read all subscription information from the pg_subscription catalog.

The subscription is added using CREATE SUBSCRIPTION and can be stopped/resumed at any time using the ALTER SUBSCRIPTION command and removed using DROP SUBSCRIPTION.

When a subscription is dropped and recreated, the synchronization information is lost. This means that the data has to be resynchronized afterwards.

The schema definitions are not replicated, and the published tables must exist on the subscriber. Only regular tables may be the target of replication. For example, you can't replicate to a view.

The tables are matched between the publisher and the subscriber using the fully qualified table name. Replication to differently-named tables on the subscriber is not supported.

Columns of a table are also matched by name. The order of columns in the subscriber table does not need to match that of the publisher. The data types of the columns do not need to match, as long as

the text representation of the data can be converted to the target type. For example, you can replicate from a column of type `integer` to a column of type `bigint`. The target table can also have additional columns not provided by the published table. Any such columns will be filled with the default value as specified in the definition of the target table.

30.2.1. Replication Slot Management

As mentioned earlier, each (active) subscription receives changes from a replication slot on the remote (publishing) side.

Additional table synchronization slots are normally transient, created internally to perform initial table synchronization and dropped automatically when they are no longer needed. These table synchronization slots have generated names: "`pg_%u_sync_%u_%llu`" (parameters: Subscription *`oid`*, Table *`relid`*, system identifier *`sysid`*)

Normally, the remote replication slot is created automatically when the subscription is created using `CREATE SUBSCRIPTION` and it is dropped automatically when the subscription is dropped using `DROP SUBSCRIPTION`. In some situations, however, it can be useful or necessary to manipulate the subscription and the underlying replication slot separately. Here are some scenarios:

- When creating a subscription, the replication slot already exists. In that case, the subscription can be created using the `create_slot = false` option to associate with the existing slot.
- When creating a subscription, the remote host is not reachable or in an unclear state. In that case, the subscription can be created using the `connect = false` option. The remote host will then not be contacted at all. This is what pg_dump uses. The remote replication slot will then have to be created manually before the subscription can be activated.
- When dropping a subscription, the replication slot should be kept. This could be useful when the subscriber database is being moved to a different host and will be activated from there. In that case, disassociate the slot from the subscription using `ALTER SUBSCRIPTION` before attempting to drop the subscription.
- When dropping a subscription, the remote host is not reachable. In that case, disassociate the slot from the subscription using `ALTER SUBSCRIPTION` before attempting to drop the subscription. If the remote database instance no longer exists, no further action is then necessary. If, however, the remote database instance is just unreachable, the replication slot (and any still remaining table synchronization slots) should then be dropped manually; otherwise it/they would continue to reserve WAL and might eventually cause the disk to fill up. Such cases should be carefully investigated.

30.3. Conflicts

Logical replication behaves similarly to normal DML operations in that the data will be updated even if it was changed locally on the subscriber node. If incoming data violates any constraints the replication will stop. This is referred to as a *conflict*. When replicating `UPDATE` or `DELETE` operations, missing data will not produce a conflict and such operations will simply be skipped.

A conflict will produce an error and will stop the replication; it must be resolved manually by the user. Details about the conflict can be found in the subscriber's server log.

The resolution can be done either by changing data on the subscriber so that it does not conflict with the incoming change or by skipping the transaction that conflicts with the existing data. The transaction can be skipped by calling the `pg_replication_origin_advance()` function with a *`node_name`* corresponding to the subscription name, and a position. The current position of origins can be seen in the `pg_replication_origin_status` system view.

30.4. Restrictions

Logical replication currently has the following restrictions or missing functionality. These might be addressed in future releases.

- The database schema and DDL commands are not replicated. The initial schema can be copied by hand using `pg_dump --schema-only`. Subsequent schema changes would need to be kept in sync manually. (Note, however, that there is no need for the schemas to be absolutely the same on both sides.) Logical replication is robust when schema definitions change in a live database: When the schema is changed on the publisher and replicated data starts arriving at the subscriber but does not fit into the table schema, replication will error until the schema is updated. In many cases, intermittent errors can be avoided by applying additive schema changes to the subscriber first.
- Sequence data is not replicated. The data in serial or identity columns backed by sequences will of course be replicated as part of the table, but the sequence itself would still show the start value on the subscriber. If the subscriber is used as a read-only database, then this should typically not be a problem. If, however, some kind of switchover or failover to the subscriber database is intended, then the sequences would need to be updated to the latest values, either by copying the current data from the publisher (perhaps using `pg_dump`) or by determining a sufficiently high value from the tables themselves.
- Replication of `TRUNCATE` commands is supported, but some care must be taken when truncating groups of tables connected by foreign keys. When replicating a truncate action, the subscriber will truncate the same group of tables that was truncated on the publisher, either explicitly specified or implicitly collected via `CASCADE`, minus tables that are not part of the subscription. This will work correctly if all affected tables are part of the same subscription. But if some tables to be truncated on the subscriber have foreign-key links to tables that are not part of the same (or any) subscription, then the application of the truncate action on the subscriber will fail.
- Large objects (see Chapter 37) are not replicated. There is no workaround for that, other than storing data in normal tables.
- Replication is only supported by tables, including partitioned tables. Attempts to replicate other types of relations, such as views, materialized views, or foreign tables, will result in an error.
- When replicating between partitioned tables, the actual replication originates, by default, from the leaf partitions on the publisher, so partitions on the publisher must also exist on the subscriber as valid target tables. (They could either be leaf partitions themselves, or they could be further subpartitioned, or they could even be independent tables.) Publications can also specify that changes are to be replicated using the identity and schema of the partitioned root table instead of that of the individual leaf partitions in which the changes actually originate (see `CREATE PUBLICATION`).

30.5. Architecture

Logical replication starts by copying a snapshot of the data on the publisher database. Once that is done, changes on the publisher are sent to the subscriber as they occur in real time. The subscriber applies data in the order in which commits were made on the publisher so that transactional consistency is guaranteed for the publications within any single subscription.

Logical replication is built with an architecture similar to physical streaming replication (see Section 26.2.5). It is implemented by "walsender" and "apply" processes. The walsender process starts logical decoding (described in Chapter 51) of the WAL and loads the standard logical decoding output plugin (`pgoutput`). The plugin transforms the changes read from WAL to the logical replication protocol (see Section 55.5) and filters the data according to the publication specification. The data is then continuously transferred using the streaming replication protocol to the apply worker, which maps the data to local tables and applies the individual changes as they are received, in correct transactional order.

The apply process on the subscriber database always runs with `session_replication_role` set to `replica`. This means that, by default, triggers and rules will not fire on a subscriber. Users can optionally choose to enable triggers and rules on a table using the `ALTER TABLE` command and the `ENABLE TRIGGER` and `ENABLE RULE` clauses.

The logical replication apply process currently only fires row triggers, not statement triggers. The initial table synchronization, however, is implemented like a `COPY` command and thus fires both row and statement triggers for `INSERT`.

30.5.1. Initial Snapshot

The initial data in existing subscribed tables are snapshotted and copied in a parallel instance of a special kind of apply process. This process will create its own replication slot and copy the existing data. As soon as the copy is finished the table contents will become visible to other backends. Once existing data is copied, the worker enters synchronization mode, which ensures that the table is brought up to a synchronized state with the main apply process by streaming any changes that happened during the initial data copy using standard logical replication. During this synchronization phase, the changes are applied and committed in the same order as they happened on the publisher. Once synchronization is done, control of the replication of the table is given back to the main apply process where replication continues as normal.

30.6. Monitoring

Because logical replication is based on a similar architecture as physical streaming replication, the monitoring on a publication node is similar to monitoring of a physical replication primary (see Section 26.2.5.2).

The monitoring information about subscription is visible in `pg_stat_subscription`. This view contains one row for every subscription worker. A subscription can have zero or more active subscription workers depending on its state.

Normally, there is a single apply process running for an enabled subscription. A disabled subscription or a crashed subscription will have zero rows in this view. If the initial data synchronization of any table is in progress, there will be additional workers for the tables being synchronized.

30.7. Security

A user able to modify the schema of subscriber-side tables can execute arbitrary code as a superuser. Limit ownership and `TRIGGER` privilege on such tables to roles that superusers trust. Moreover, if untrusted users can create tables, use only publications that list tables explicitly. That is to say, create a subscription `FOR ALL TABLES` only when superusers trust every user permitted to create a non-temp table on the publisher or the subscriber.

The role used for the replication connection must have the `REPLICATION` attribute (or be a superuser). If the role lacks `SUPERUSER` and `BYPASSRLS`, publisher row security policies can execute. If the role does not trust all table owners, include `options=-crow_security=off` in the connection string; if a table owner then adds a row security policy, that setting will cause replication to halt rather than execute the policy. Access for the role must be configured in `pg_hba.conf` and it must have the `LOGIN` attribute.

In order to be able to copy the initial table data, the role used for the replication connection must have the `SELECT` privilege on a published table (or be a superuser).

To create a publication, the user must have the `CREATE` privilege in the database.

To add tables to a publication, the user must have ownership rights on the table. To create a publication that publishes all tables automatically, the user must be a superuser.

To create a subscription, the user must be a superuser.

The subscription apply process will run in the local database with the privileges of a superuser.

Privileges are only checked once at the start of a replication connection. They are not re-checked as each change record is read from the publisher, nor are they re-checked for each change when applied.

30.8. Configuration Settings

Logical replication requires several configuration options to be set.

On the publisher side, `wal_level` must be set to `logical`, and `max_replication_slots` must be set to at least the number of subscriptions expected to connect, plus some reserve for table synchronization.

And max_wal_senders should be set to at least the same as max_replication_slots plus the number of physical replicas that are connected at the same time.

max_replication_slots must also be set on the subscriber. It should be set to at least the number of subscriptions that will be added to the subscriber, plus some reserve for table synchronization. max_logical_replication_workers must be set to at least the number of subscriptions, again plus some reserve for the table synchronization. Additionally the max_worker_processes may need to be adjusted to accommodate for replication workers, at least (max_logical_replication_workers + 1). Note that some extensions and parallel queries also take worker slots from max_worker_processes.

30.9. Quick Setup

First set the configuration options in postgresql.conf:

```
wal_level = logical
```

The other required settings have default values that are sufficient for a basic setup.

pg_hba.conf needs to be adjusted to allow replication (the values here depend on your actual network configuration and user you want to use for connecting):

```
host     all     repuser     0.0.0.0/0     md5
```

Then on the publisher database:

```
CREATE PUBLICATION mypub FOR TABLE users, departments;
```

And on the subscriber database:

```
CREATE SUBSCRIPTION mysub CONNECTION 'dbname=foo host=bar user=repuser' PUBLICATION
 mypub;
```

The above will start the replication process, which synchronizes the initial table contents of the tables users and departments and then starts replicating incremental changes to those tables.

Chapter 31. Just-in-Time Compilation (JIT)

This chapter explains what just-in-time compilation is, and how it can be configured in Postgres Pro.

31.1. What Is JIT compilation?

Just-in-Time (JIT) compilation is the process of turning some form of interpreted program evaluation into a native program, and doing so at run time. For example, instead of using general-purpose code that can evaluate arbitrary SQL expressions to evaluate a particular SQL predicate like `WHERE a.col = 3`, it is possible to generate a function that is specific to that expression and can be natively executed by the CPU, yielding a speedup.

Postgres Pro has builtin support to perform JIT compilation using *LLVM* when Postgres Pro is built with `--with-llvm`.

31.1.1. JIT Accelerated Operations

Currently Postgres Pro's JIT implementation has support for accelerating expression evaluation and tuple deforming. Several other operations could be accelerated in the future.

Expression evaluation is used to evaluate `WHERE` clauses, target lists, aggregates and projections. It can be accelerated by generating code specific to each case.

Tuple deforming is the process of transforming an on-disk tuple (see Section 70.6.1) into its in-memory representation. It can be accelerated by creating a function specific to the table layout and the number of columns to be extracted.

31.1.2. Inlining

Postgres Pro is very extensible and allows new data types, functions, operators and other database objects to be defined; see Chapter 40. In fact the built-in objects are implemented using nearly the same mechanisms. This extensibility implies some overhead, for example due to function calls (see Section 40.3). To reduce that overhead, JIT compilation can inline the bodies of small functions into the expressions using them. That allows a significant percentage of the overhead to be optimized away.

31.1.3. Optimization

LLVM has support for optimizing generated code. Some of the optimizations are cheap enough to be performed whenever JIT is used, while others are only beneficial for longer-running queries. See *https://llvm.org/docs/Passes.html#transform-passes* for more details about optimizations.

31.2. When to JIT?

JIT compilation is beneficial primarily for long-running CPU-bound queries. Frequently these will be analytical queries. For short queries the added overhead of performing JIT compilation will often be higher than the time it can save.

To determine whether JIT compilation should be used, the total estimated cost of a query (see Chapter 71 and Section 19.7.2) is used. The estimated cost of the query will be compared with the setting of jit_above_cost. If the cost is higher, JIT compilation will be performed. Two further decisions are then needed. Firstly, if the estimated cost is more than the setting of jit_inline_above_cost, short functions and operators used in the query will be inlined. Secondly, if the estimated cost is more than the setting of jit_optimize_above_cost, expensive optimizations are applied to improve the generated code. Each of these options increases the JIT compilation overhead, but can reduce query execution time considerably.

These cost-based decisions will be made at plan time, not execution time. This means that when prepared statements are in use, and a generic plan is used (see PREPARE), the values of the configuration parameters in effect at prepare time control the decisions, not the settings at execution time.

> **Note**
>
> If jit is set to `off`, or if no JIT implementation is available (for example because the server was compiled without `--with-llvm`), JIT will not be performed, even if it would be beneficial based on the above criteria. Setting jit to `off` has effects at both plan and execution time.

EXPLAIN can be used to see whether JIT is used or not. As an example, here is a query that is not using JIT:

```
=# EXPLAIN ANALYZE SELECT SUM(relpages) FROM pg_class;
                                                     QUERY PLAN
---------------------------------------------------------------------------
----------------------------------------
 Aggregate  (cost=16.27..16.29 rows=1 width=8) (actual time=0.303..0.303 rows=1
 loops=1)
   ->  Seq Scan on pg_class  (cost=0.00..15.42 rows=342 width=4) (actual
 time=0.017..0.111 rows=356 loops=1)
 Planning Time: 0.116 ms
 Execution Time: 0.365 ms
(4 rows)
```

Given the cost of the plan, it is entirely reasonable that no JIT was used; the cost of JIT would have been bigger than the potential savings. Adjusting the cost limits will lead to JIT use:

```
=# SET jit_above_cost = 10;
SET
=# EXPLAIN ANALYZE SELECT SUM(relpages) FROM pg_class;
                                                     QUERY PLAN
---------------------------------------------------------------------------
----------------------------------------
 Aggregate  (cost=16.27..16.29 rows=1 width=8) (actual time=6.049..6.049 rows=1
 loops=1)
   ->  Seq Scan on pg_class  (cost=0.00..15.42 rows=342 width=4) (actual
 time=0.019..0.052 rows=356 loops=1)
 Planning Time: 0.133 ms
 JIT:
   Functions: 3
   Options: Inlining false, Optimization false, Expressions true, Deforming true
   Timing: Generation 1.259 ms, Inlining 0.000 ms, Optimization 0.797 ms, Emission
 5.048 ms, Total 7.104 ms
 Execution Time: 7.416 ms
```

As visible here, JIT was used, but inlining and expensive optimization were not. If jit_inline_above_cost or jit_optimize_above_cost were also lowered, that would change.

31.3. Configuration

The configuration variable jit determines whether JIT compilation is enabled or disabled. If it is enabled, the configuration variables jit_above_cost, jit_inline_above_cost, and jit_optimize_above_cost determine whether JIT compilation is performed for a query, and how much effort is spent doing so.

jit_provider determines which JIT implementation is used. It is rarely required to be changed. See Section 31.4.2.

For development and debugging purposes a few additional configuration parameters exist, as described in Section 19.19.

31.4. Extensibility

31.4.1. Inlining Support for Extensions

If you would like to build Postgres Pro extensions that support JIT inlining, make sure to set up your development environment as explained in Section 17.1.5.

Postgres Pro's JIT implementation can inline the bodies of functions of types `C` and `internal`, as well as operators based on such functions. To do so for functions in extensions, the definitions of those functions need to be made available. When using PGXS to build an extension against a server that has been compiled with LLVM JIT support, the relevant files will be built and installed automatically.

The relevant files have to be installed into `$pkglibdir/bitcode/$extension/` and a summary of them into `$pkglibdir/bitcode/$extension.index.bc`, where `$pkglibdir` is the directory returned by `pg_config --pkglibdir` and `$extension` is the base name of the extension's shared library.

> **Note**
>
> For functions built into Postgres Pro itself, the bitcode is installed into `$pkglibdir/bitcode/postgres`.

31.4.2. Pluggable JIT Providers

Postgres Pro provides a JIT implementation based on LLVM. The interface to the JIT provider is pluggable and the provider can be changed without recompiling (although currently, the build process only provides inlining support data for LLVM). The active provider is chosen via the setting jit_provider.

31.4.2.1. JIT Provider Interface

A JIT provider is loaded by dynamically loading the named shared library. The normal library search path is used to locate the library. To provide the required JIT provider callbacks and to indicate that the library is actually a JIT provider, it needs to provide a C function named `_PG_jit_provider_init`. This function is passed a struct that needs to be filled with the callback function pointers for individual actions:

```
struct JitProviderCallbacks
{
    JitProviderResetAfterErrorCB reset_after_error;
    JitProviderReleaseContextCB release_context;
    JitProviderCompileExprCB compile_expr;
};

extern void _PG_jit_provider_init(JitProviderCallbacks *cb);
```

Chapter 32. Enhanced Security

This chapter describes enhanced security mechanisms available in the certified edition of Postgres Pro Enterprise. Moreover, Postgres Pro Enterprise provides the following native security tools:

- The pg_proaudit extension enables detailed logging of various security events.
- Advanced authentication policies allow you to restrict database usage and enforce password requirements by assigning profiles to roles. For details on profiles, see CREATE PROFILE. The catalog `pg_profile` lists all profiles available for your cluster.

32.1. Memory Purge

Using memory purge configuration parameters, Postgres Pro Enterprise can automatically replace data with zero bytes before it is deleted. This section describes how different types of data are handled. By default, all the memory purge parameters are switched on.

32.1.1. Deleting Files from External Memory

When you run some SQL commands that delete files, the corresponding disk space is returned to the operating system. Such commands include:

- Commands that delete database objects:
  - `DROP TABLE`
  - `DROP TEMPORARY TABLE`
  - `DROP MATERIALIZED VIEW`
  - `DROP INDEX`
  - `TRUNCATE`
  - `DROP DATABASE`
  - `DROP SCHEMA`
- Commands that re-create objects:
  - `VACUUM FULL`
  - `REINDEX`
  - `ALTER TABLE ADD COLUMN` (with the default value)
  - `ALTER TABLE ALTER COLUMN TYPE`

If the wipe_file_on_delete configuration parameter is switched on, the files to be deleted are first filled with zero bytes.

> **Note**
>
> The `ALTER TABLE DROP COLUMN` command does not re-create the file. All the data contained in the deleted column remains inside the pages, although you cannot access this data using SQL commands. To physically remove this data from the file, run `VACUUM FULL` after deleting the column.

32.1.2. Page Cleanup

In accordance with the Multiversion Concurrency Control (MVCC) model, when rows are deleted (with the `DELETE` command) the data stored in these rows is marked as deleted, but is not physically removed. In the case of row updates (with the `UPDATE` command), the old version of the row is deleted, and then a new version is inserted, so the previous value is not removed from the page either.

To ensure that MVCC mechanism is working correctly, Postgres Pro keeps the deleted data in the page while the saved version of the row can be accessed by at least one active snapshot. If the row is refer-

enced from indexes, index pages also keep references to the row versions that are deleted but not yet freed. When the row version is not referenced from any snapshot anymore, this version can be deleted with the VACUUM process. At the same time, all references to this row version are deleted from indexes. However, deleting does not mean physical removal: in normal operation, the corresponding space in the page is marked as free and can be used to store another row.

To prevent access to the deleted row versions, make sure that the wipe_heaptuple_on_delete parameter is switched on in the postgresql.conf configuration file. In this case, the VACUUM process not only marks the page spaces as free, but also fills them with zero bytes.

32.1.3. Clearing Random-Access Memory

While the server is running, random-access memory (RAM) is constantly allocated and released. Postgres Pro uses its own context-based system of memory allocation, in which memory is always allocated in one of the nested contexts. Deleting a context frees all the memory allocated in this context and the corresponding nested contexts. This approach helps to avoid memory leaks. Nevertheless, memory allocation and release are ultimately performed by the operating system. In normal operation, the released part of RAM is returned to the operating system and can be allocated to another process.

To remove all the data from the released part of RAM, make sure that the following parameters are switched on in the postgresql.conf configuration file:

- wipe_memctx_on_free — this parameter fills the released memory with zero bytes if the released memory belongs to a context.
- wipe_mem_on_free — this parameter fills the released memory with zero bytes if the released memory does not belong to any context. Although Postgres Pro always allocates memory within a particular context, you can still use this parameter to be on the safe side.

32.1.4. Cleaning up WAL Files

Write-Ahead Log (WAL) is a standard method for ensuring data integrity, which enables database backups, point-in-time recovery, and data replication between servers. WAL's central concept is that changes to data files (where tables and indexes reside) must be written only after those changes have been logged, that is, after log records describing the changes have been flushed to permanent storage. Thus, WAL can contain sensitive data that must be secured.

Postgres Pro server always stores a certain number of WAL segments in the $PGDATA/pg_wal directory. The minimum amount of WAL segments to store is defined by the min_wal_size parameter. In case of heavy load, the size of WAL segments can increase up to the max_wal_size value, or even exceed this value a little. As long as WAL disk usage stays above the min_wal_size threshold, old WAL segment files are deleted when they are released. Otherwise, WAL segments get overwritten.

To prevent unauthorized access to the released WAL segments, make sure that the wipe_xlog_on_free parameter is switched on in the postgresql.conf configuration file. In this case, the WAL segment will be filled with zero bytes before it is deleted or overwritten.

For details on WAL configuration and usage, see Chapter 29.

32.2. Integrity Checks

32.2.1. Overview

Postgres Pro Enterprise includes the pg_integrity_check utility that provides the following features for integrity checks:

- On-demand checksum calculation and validation
- Built-in checksum validation at the server startup

pg_integrity_check can control read-only files, additional files, and system catalog tables.

32.2.1.1. Read-Only Files

Controlled read-only files include executable files, libraries, and other files that must never be modified. Checksums for read-only files are managed by the `/opt/pgpro/ent-14/share/security/system.conf` configuration file.

The `system.conf` file is included into the Postgres Pro Enterprise distribution. Each Postgres Pro Enterprise instance has a single `system.conf` file. Each line in `system.conf` corresponds to a single controlled object and includes two fields: the checksum, consisting of 40 hexadecimal digits, and a relative path to the controlled object. These fields are separated by three symbols: space, dash, space. Checksums are calculated and written into this file at the time of Postgres Pro Enterprise installation. They control both contents and attributes of read-only files. For example, if access rights to the file have been modified, the checksum will change.

32.2.1.2. Additional Files

Additional files are controlled files that can be modified by a database administrator. Checksums for additional files are managed by configuration files stored in the `share/security` directory. Each cluster must have a separate configuration file for additional files. The naming convention is as follows: the path to the data directory of the cluster (`PGDATA`), with forward slashes replaced by underscores, followed by the `.user.conf` postfix. For example, for a cluster with `/var/lib/pgpro/ent-14/data` data directory, the configuration file is called `_var_lib_pgpro_ent-14_data.user.conf`.

Each line in the configuration file corresponds to a single controlled object and includes two fields: the checksum, consisting of 40 hexadecimal digits, and a relative path to the controlled object. The fields are separated by three symbols: space, dash, space.

Checksums control both contents and attributes of additional files. For example, if access rights to the file have been modified, the checksum will change.

To set up checksum validation for additional files, database administrator needs to do the following:

1. Create a configuration file for each cluster, following the naming convention specified above.
2. In the created configuration file, specify all the additional files to be controlled. As a checksum, any 40 hexadecimal digits can be entered, for example, zeros.
3. Run the following command to recalculate the checksums, specifying the path to the data directory of your cluster:

```
pg_integrity_check -u -o -D /var/lib/pgpro/ent-14/data
```

> **Note**
>
> Alternatively, administrator can run the above command to generate a sample configuration file, and then edit this file as needed.

32.2.1.3. System Catalog Tables

System catalog tables represent a controlled data selection related to Postgres Pro Enterprise instance. Checksums for system catalog tables are managed by respective configuration files for each database in a cluster. You can setup integrity checks of system catalog tables for several databases by providing separate configuration files with specific checksum values.

Each line in the configuration file corresponds to a single controlled object and includes two fields: the checksum, consisting of 40 hexadecimal digits, and a relative path to the controlled object. The fields are separated by three symbols: space, dash, space.

To set up checksum validation for data selection, database administrator needs to do the following for each database in a cluster:

1. Create a configuration file for the selected database. For example, *database-name*-catalog.conf.
2. In the created configuration file, specify SQL queries that return the controlled data. As a checksum, any 40 hexadecimal digits can be entered, for example, zeros.
3. Run the following command to recalculate checksums, specifying connection parameters for your database:

```
pg_integrity_check -c -o -C configuration-file-full-path -d postgres -h localhost -p
 5432 -U postgres
```

To check system catalog tables, run pg_integrity_check for each database subject to integrity checks.

> **Note**
>
> Alternatively, administrator can run the above command to generate a sample configuration file, and then edit this file as needed.

32.2.2. Checking Integrity at Server Startup

Checksums for read-only files are always validated at the Postgres Pro Enterprise server startup. If the server start is blocked because of a checksum mismatch, administrator must troubleshoot and resolve the issue to restart the server.

System catalog tables and additional files are not validated at the server startup. You can validate them by running pg_integrity_check manually once the server is started.

32.2.3. Scheduling Integrity Checks

If you are using a Linux-based system, you can schedule recurrent integrity checks using the cron daemon. To schedule integrity checks, modify the /etc/crontab file by adding the lines that define the frequency of pg_integrity_check utility launches. The /etc/crontab is a system file that contains all instructions for the cron daemon. To get a detailed description of the crontab file format for your Linux-based operating system, run the command:

```
man 5 crontab
```

Examples

The following example illustrates integrity checks on a Rosa SX operating system:

```
# Data directory of the cluster
PGDATA = /var/lib/pgpro/ent-14/data
# pg_integrity_check log file
LOG = /opt/pgpro/ent-14/share/security/log
# Validate read-only files every day at 00:05
5 0 * * *       root   /opt/pgpro/ent-14/bin/pg_integrity_check -s >> $LOG
# Run integrity checks at 14:15 on the first day of the month
15 14 1 * *     root   /opt/pgpro/ent-14/bin/pg_integrity_check -s >> $LOG
# Run integrity checks at 22.00 on weekdays
0 22 * * 1-5    root   /opt/pgpro/ent-14/bin/pg_integrity_check -s >> $LOG
#  Run integrity checks at 00:23, 2:23, 4:23 ..., every day
23 0-23/2 * * * root   /opt/pgpro/ent-14/bin/pg_integrity_check -s >> $LOG
#  Run integrity checks at 4:05 each Sunday
5 4 * * sun     root   /opt/pgpro/ent-14/bin/pg_integrity_check -s >> $LOG
```

32.3. Separation of Duties between Privileged DBMS Users

The configuration of all PostgreSQL-based DBMS has the superuser role, which is needed at the initial database loading, but when later used for regular database operations, it carries information security

risks. As the `superuser` account has a wide range of system privileges, it can become a target for cyber-criminals and can cause adverse consequences, such as:

- Unauthorized access to sensitive data.
- Data leak.
- Dangerous changes to the DBMS configuration.
- DBMS failures.

Among the measures to resist such hazards, we can consider separation of duties, with reducing the number of operations that require superuser privileges. This is necessary to address risks both related to the trust in the superuser and to access of malicious users to the superuser account.

32.3.1. Overview

The Postgres Professional company has developed a model that separates superuser duties between two additional administrative roles — DBMS Administrator and Database Administrator (DB Administrator). Besides, mechanisms of protection against self-elevation of privileges and audit of all users' operations have been strengthened.

The DBMS Administrator is responsible for:

- The server management.
- Setup of the data replication and backups.
- Creation of databases.
- Setup of connections with the Postgres Pro database.
- Assignment of DB Administrators.

The DB Administrator is responsible for:

- Backup of the specific database.
- Creation of tables and other objects within the specific database.
- Creation of database users.
- Granting users with access rights.

Once most of the superuser's regular tasks are delegated to the new controlled administrators, the company can give up active use of this highly risky role. To do this, the infrastructure administrator must add rows that block superuser connections to the `pg_hba.conf` file and must also block updating this file by other administrators.

If superuser privileges must be temporarily returned to solve some rare complicated problem, this can be done in a single mode involving the infrastructure administrator. To switch the DBMS to a single mode, it should be stopped and then restarted as follows:

```
postgres --single -D DBMS_data_directory  other_options DB_name
```

See Section 17.3 for how to install additional supplied modules and extensions without superuser permissions.

The pg_proaudit extension, which enables logging various security events, is described in Section F.42.

32.3.2. Creation of Additional Administrators

32.3.2.1. Creating the DBMS Administrator Role

This section describes creation of the `PGPRO_DBMS_ADMIN` role with the appropriate permissions.

The following script creates the PGPRO_DBMS_ADMIN role and the user with this role. It is run by the superuser postgres. Note that the script uses these predefined roles:

- pg_create_tablespace allows executing the CREATE TABLESPACE command without superuser rights.
- pg_manage_profiles allows executing the CREATE PROFILE, ALTER PROFILE, and DROP PROFILE commands without superuser rights.

```
$ psql postgres
CREATE ROLE PGPRO_DBMS_ADMIN WITH CREATEDB CREATEROLE INHERIT LOGIN REPLICATION;
REVOKE ALL ON DATABASE postgres FROM PUBLIC;
GRANT CONNECT ON DATABASE postgres TO PGPRO_DBMS_ADMIN;
CREATE USER dbms_admin WITH CREATEDB CREATEROLE INHERIT LOGIN REPLICATION; -- Do not
 forget to set initial password
GRANT PGPRO_DBMS_ADMIN TO dbms_admin;
GRANT pg_read_all_settings TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
GRANT pg_read_all_stats TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
GRANT pg_stat_scan_tables TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
GRANT pg_monitor TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
GRANT pg_signal_backend TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
GRANT pg_checkpoint TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
GRANT pg_create_tablespace TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
GRANT pg_manage_profiles TO PGPRO_DBMS_ADMIN WITH ADMIN OPTION;
EXIT;
```

The following commands grant permissions to manage the configuration and to perform logging and backup/restore operations to the PGPRO_DBMS_ADMIN role. It is run by the superuser postgres.

```
$ psql postgres
GRANT EXECUTE ON FUNCTION pg_reload_conf TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_rotate_logfile TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_create_restore_point TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_start_backup TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_stop_backup(boolean,boolean) TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_switch_wal TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_promote TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_wal_replay_pause TO PGPRO_DBMS_ADMIN;
GRANT EXECUTE ON FUNCTION pg_wal_replay_resume TO PGPRO_DBMS_ADMIN;
EXIT;
```

32.3.2.2. Creating the DB Administrator Role

The PGPRO_DB_DBNAME_ADMIN role can include several users for one database. One user can also be included in several different PGPRO_DB_DBNAME_ADMIN roles if the user's job description includes management of several different databases.

This section describes creation of a database by example of the DB1 database, its DB Administrator role and the DB1_ADMIN user granted appropriate rights. At this point, rights of the user with the PGPRO_DBMS_ADMIN role, which was created earlier, are sufficient for all the involved operations.

The following script creates the DB1 database, the PGPRO_DB_1_ADMIN role and the user with this role. It is run by the DBMS Administrator:

```
$ psql postgres -U dbms_admin
SET ROLE PGPRO_DBMS_ADMIN;
CREATE ROLE PGPRO_DB_1_ADMIN WITH CREATEROLE INHERIT;
CREATE USER db1_admin WITH CREATEROLE INHERIT; -- Do not forget to set initial password
GRANT PGPRO_DB_1_ADMIN TO db1_admin;
GRANT PGPRO_DB_1_ADMIN TO PGPRO_DBMS_ADMIN;
GRANT pg_read_all_settings TO PGPRO_DB_1_ADMIN;
```

```
GRANT pg_read_all_stats TO PGPRO_DB_1_ADMIN;
GRANT pg_stat_scan_tables TO PGPRO_DB_1_ADMIN;
GRANT pg_monitor TO PGPRO_DB_1_ADMIN;
CREATE DATABASE db1 OWNER PGPRO_DB_1_ADMIN;
REVOKE CONNECT, TEMPORARY ON DATABASE db1 FROM PUBLIC;
```

32.3.3. Revoking Superuser Access

To block superuser connections, the infrastructure administrator adds these lines to `pg_hba.conf`:

```
TYPE     DATABASE  USER       ADDRESS       METHOD
local    all       postgres                 reject
host     all       postgres   127.0.0.1/32  reject
host     all       postgres   ::1/128       reject
```

The `root` infrastructure administrator disallows the `postgres` user to change `pg_hba.conf`:

```
# chown root pg_hba.conf
# chmod 640 pg_hba.conf
```

As a result, the `postgres` superuser cannot solely regain the possibility to connect to the DBMS:

```
# ls -lh pg_hba.conf
-rw-r----- 1 root postgres .......... pg_hba.conf
```

Restart of the DBMS server is needed for the new restrictions to take effect:

```
# pg_ctl restart
```

Chapter 33. Compressed File System (CFS)

This chapter describes the Compressed File System (CFS) feature, which enables page level compression in Postgres Pro Enterprise.

33.1. Why database compression may be useful

Databases are used to store larger number of text and duplicated information. This is why compression of most of databases can be quite efficient and reduce used storage size 3..5 times. Postgres Pro Enterprise performs compression of TOAST data, but small text fields which fits in the page are not compressed. Also not only heap pages can be compressed, indexes on text keys or indexes with larger number of duplicate values are also good candidates for compression.

Postgres Pro Enterprise is working with disk data through buffer pool which accumulates most frequently used buffers. Interface between buffer manager and file system is the most natural place for performing compression. Buffers are stored on the disk in compressed form for reducing disk usage and minimizing amount of data to be read. And in-memory buffer pool contains uncompressed buffers, providing access to the records at the same speed as without compression. As far as modern server have large enough size of RAM, substantial part of the database can be cached in memory and accessed without any compression overhead penalty.

Except obvious advantage: saving disk space, compression can also improve system performance. There are two main reasons for it:

Reducing amount of disk IO

Compression helps to reduce size of data which should be written to the disk or read from it. Compression ratio 3 actually means that you need to read 3 times less data or same number of records can be fetched 3 times faster.

Improving locality

When modified buffers are flushed from buffer pool to the disk, they are written to the random locations on the disk. Postgres Pro Enterprise cache replacement algorithm makes a decision about throwing away buffer from the pool based on its access frequency and ignoring its location on the disk. So two subsequently written buffers can be located in completely different parts of the disk. For HDD seek time is quite large - about 10msec, which corresponds to 100 random writes per second. And speed of sequential write can be about 100Mb/sec, which corresponds to 10000 buffers per second (100 times faster). For SSD gap between sequential and random write speed is smaller, but still sequential writers are more efficient. How it relates to data compression? Size of buffer in Postgres Pro Enterprise is fixed (8kb by default). Size of compressed buffer depends on the content of the buffer. So updated buffer can not always fit in its old location on the disk. This is why we can not access pages directly by its address. Instead of it we have to use map which translates logical address of the page to its physical location on the disk. Definitely this extra level of indirection adds overhead. But in most cases this map can fit in memory, so page lookup is nothing more than just accessing array element. But presence of this map also have positive effect: we can now write updated pages sequentially, just updating their map entries. Postgres Pro Enterprise is doing much to avoid "write storm" intensive flushing of data to the disk when buffer pool space is exhausted. Compression allows you to significantly reduce disk load.

33.2. How compression is integrated in Postgres Pro Enterprise

To improve efficiency of disk IO, Postgres Pro Enterprise is working with files through buffer manager, which pins in memory most frequently used pages. Each page is fixed size (8kb by default). But if we compress page, then its size will depend on its content. So updated page can require more (or less) space than original page. So we may not always perform in-place update of the page. Instead of it we have to locate new space for the page and somehow release old space. There are two main approaches to solving this problem:

Memory allocator

We should implement our own allocator of file space. Usually, to reduce fragmentation, fixed size block allocator is used. It means that we allocates place using some fixed quantum. For example if compressed page size is 932 bytes, then we will allocate 1024 bytes for it in the file.

Garbage collector

We can always allocate space for the pages sequentially at the end of the file and periodically do compactification (defragmentation) of the file, moving all used pages to the beginning of the file. Such garbage collection process can be performed in background. As it was explained in the previous section, sequential write of the flushed pages can significantly increase IO speed and some increase performance. This is why we have used this approach in CFS.

As far as page location is not fixed and page can be moved, we can not anymore access the page directly by its address and need to use extra level of indirection to map logical address of the page to it's physical location on the disk. It is done using mapping files. In most cases the mapping will be kept in memory (size of the map is 1000 times smaller size of the file) and address translation adds almost no overhead to page access time. But we need to maintain these extra files: flush them during checkpoint, remove when table is dropped, include them in backup and so on...

Postgres Pro Enterprise stores relation in a set of files, size of each file is not exceeding 2Gb. Separate page map is constructed for each file. Garbage collection in CFS is done by several background workers. Number of this workers and pauses in their work can be configured by database administrator. These workers are splitting work based on inode hash, so them do not conflict with each other. Each file is proceeded separately. The file is blocked for access at the time of garbage collection but complete relation is not blocked. To ensure data consistency GC creates copies of original data and map files. Once them are flushed to the disk, new version of data file is atomically renamed to original file name. And then new page map data is copied to memory-mapped file and backup file for page map is removed. In case of recovery after crash we first inspect if there is backup of data file. If such file exists, then original file is not yet updated and we can safely remove backup files. If such file doesn't exist, then we check for presence of map file backup. If it is present, then defragmentation of this file was not completed because of crash and we complete this operation by copying map from backup file.

CFS supports zstd, zlib, and pglz compression libraries. On modern operating systems, lz4 compression is also supported. By default, zstd is used. For safety reasons, CFS checks that the compression algorithm used in a tablespace corresponds to this library.

33.3. Using Compression

Compression can only be enabled for separate tablespaces. To compress a tablespace, you should enable the `compression` option when creating this tablespace. For example:

```
postgres=# CREATE TABLESPACE tcfs LOCATION '/var/data/cfs' WITH (compression=true);
```

All tables created in this tablespace will be compressed using zstd, which is the default compression library.

Aside from the boolean value of the option, you can explicitly specify the library to use for compression. Possible values are `zstd`, `default` (the same as `zstd`), `pglz`, `zlib`, and `lz4`. For example, to use `zlib`, create the tablespace as follows:

```
postgres=# CREATE TABLESPACE tcfs1 LOCATION '/var/data/cfs1' WITH
(compression='zlib');
```

Once set, the tablespace compression option cannot be altered, so you cannot compress or decompress an already existing tablespace. While user relations are always compressed in CFS, system relations are not compressed if the numeric part of the filename, such as, for example, `pg_relation_filenode()`, is less than 16384 (see Table 9.93 for more details).

If you would like to compress all tables created within the current session, you can make the compressed tablespace your default tablespace, as explained in Section 22.6.

> **Note**
>
> For compressed tablespaces, pg_checksums and pg_basebackup will not verify checksums even if they are enabled.

To configure CFS, use configuration parameters listed in Section 19.15. By default, CFS launches one background worker performing garbage collection. Garbage collector traverses tablespace directory, locating map files in it and checking percent of garbage in this file. When ratio of used and allocated spaces exceeds `cfs_gc_threshold` threshold, this file is defragmented. The file is locked at the period of defragmentation, preventing any access to this part of relation. To avoid getting stuck during any file defragmentation failure, CFS waits `cfs_gc_respond_time` seconds before the file is released from the lock. If it is not, a warning is written to the log. When defragmentation is completed, garbage collection waits `cfs_gc_delay` milliseconds and continues directory traversal. After the end of traversal, GC waits `cfs_gc_period` milliseconds and starts new GC iteration. If there are more than one GC workers, then they split work based on hash of file inode.

Several functions allow you to calculate the disk space used by different objects in CFS. For example:

- `pg_relation_size()` can compute the disk space used by the relation in CFS.
- `pg_total_relation_size()` computes the total disk space used by the specified table in CFS, including all indexes and TOAST data.
- `pg_indexes_size()` computes the total disk space used by indexes attached to the specified table in CFS.
- `pg_database_size()` computes the disk space used by the specified database in CFS.

See Section 9.27.7 for more details.

CFS provides several functions to manually control CFS garbage collection and get information on CFS state and activity. For the full list of functions, see Section 9.27.11.

To initiate garbage collection manually, use the `cfs_start_gc(n_workers)` function. This function returns number of workers which are actually started. Please notice that if `cfs_gc_workers` parameter is non zero, then GC is performed in background and `cfs_start_gc` function does nothing and returns 0.

Like the automatic garbage collection, the `cfs_start_gc(n_workers)` function only processes relations if the percent of garbage blocks in this relation exceeds the cfs_gc_threshold value. To defragment a relation with a smaller percent of garbage, you can temporarily set this parameter to a smaller value for your current session before calling this function.

It is possible to estimate effect of table compression using `cfs_estimate(relation)` function. This function takes first ten blocks of relation, tries to compress them, and returns average compress ratio. So if returned value is 7.8 then compressed table occupies about eight time less space than original table.

Function `cfs_compression_ratio(relation)` allows you to check how precise was the estimation of `cfs_estimate(relation)` function. It returns real compression ration for all segments of the compressed relation. Compression ration is total sum of virtual size of all relation segments (number of blocks multiplied by 8kb) divided by sum of physical size of the segment files.

As it was mentioned before, CFS always appends updated blocks to the end of the compressed file. So physical size of the file can be greater than used size in this file. I.e. CFS file is fragmented and defragmentation is periodically performed by CFS garbage collector. `cfs_fragmentation(relation)` functions returns average fragmentation of relation files. It is calculated as sum of physical sizes of the files minus sum of used size of the files divided by sum of physical sizes of the files.

To perform defragmentation for a particular compressed relation, use the `cfs_gc_relation(relation)` function. It returns the number of processed segments of the relation. Just like garbage collection performed in the background, this function only processes segments in which the percent of garbage blocks exceeds the cfs_gc_threshold value.

There are several functions allowing to monitors garbage collection activity: `cfs_gc_activity_scanned_files` returns number of files scanned by GC, `cfs_gc_activity_processed_files` returns number of file compacted by GC, `cfs_gc_activity_processed_pages` returns number of pages transferred by GC during files defragmentation, `cfs_gc_activity_processed_bytes` returns total size of transferred pages. All these functions calculate their values since system start.

Chapter 34. Built-In Connection Pooling

When establishing a connection, PostgreSQL spawns a separate backend process for each client. For a large number of clients, this model can cause high consumption of system resources and lead to significant performance degradation, especially on multicore systems. The reason is high contention for PostgreSQL resources between backends. Besides, the size of many PostgreSQL internal data structures is proportional to both the complexity of algorithms for these structures and the number of active backends.

Most production Postgres Pro installations reduce the number of spawned backends using external tools, such as J2EE, odyssey, or pgbouncer, one of the most popular connection poolers for Postgres Pro. However, external connection poolers require additional efforts for installation, configuration, and maintenance. If the pooler is single-threaded, like pgbouncer, you also have to launch multiple pooler instances as it can otherwise cause a bottleneck on high-load systems.

To address these challenges, Postgres Pro Enterprise provides a built-in connection pooler. Unlike external solutions, it does not require any additional maintenance and does not introduce any limitations for clients. With built-in connection pooling enabled, clients can continue using session configuration parameters, prepared statements, and temporary tables as if there is no proxy.

The chapters that follow describe built-in connection pooler architecture and provide configuration instructions.

34.1. Limitations

When using connection pooling, take the following limitations into account:

- SSL connections are currently not supported.
- Long-running transactions can suspend other sessions assigned to the same backend, as the backend cannot serve another session until the current transaction is complete. It is recommended to avoid such transactions in pooled sessions and set the idle_in_transaction_session_timeout or client_connection_check_interval configuration parameters, so that idle transactions can be terminated by timeout. For databases or users that are likely to run long transactions, you can also use dedicated backends.
- The level of the `FATAL: connection to client lost` error is lowered to `ERROR`. If such an error is trapped, Postgres Pro will fail to terminate hanging transactions by timeout.
- Using prepared transactions (2PC) in pooled sessions is only possible if you ensure that they are completed by the same session that has prepared them, and enable the hold_prepared_transactions configuration parameter to forbid rescheduling the backend to another session until all prepared transactions in the current session are committed or rolled back.
- Built-in connection pooler does not support advisory session-level locks (`pg_advisory_lock`) and returns an error if you try using them.
- Modules that maintain the session state internally, such as plantuner, are not guaranteed to work with connection pooling enabled.
- Connection pooling is incompatible with the following extensions:
  - multimaster
  - in_memory
  - online_analyze
  - pg_variables
- Changing configuration of other sessions as explained in Section 9.27.1 is not allowed if connection pooling is enabled.
- Asynchronous notifications are not supported, so you cannot use NOTIFY, LISTEN, and UNLISTEN SQL commands, or the `pg_notify` function.

- When the connection pooler is enabled and serves client sessions, “Smart” shutdown is performed as “Fast”.
- 1C solutions are not supported as they use their own built-in pooler.
- Windows systems are currently not supported.
- Closing connections due to idle_session_timeout is not supported when connection pooling is enabled.
- Login event triggers are not supported.

34.2. How It Works

When running in the regular mode, Postgres Pro spawns a separate backend for each connection request. With connection pooling enabled, the number of backends that can be used for each database is limited by the session_pool_size value. Once this limit is reached, `postmaster` stops spawning new backend processes for the corresponding sessions and redirects further connection requests to one of the backends that has already been started. Since each Postgres Pro backend can work with a single database only, built-in connection pooler has to maintain separate *connection pools* for each database. The number of pools is unlimited: each time a new database needs to be served, a new pool is added.

To assign sessions to an appropriate pool, `postmaster` needs to know the target database for the client connection, which requires receiving and parsing a startup packet from the client. To avoid a bottleneck at this stage, `postmaster` delegates the task of reading the startup packet to one of the *listener* processes. The listener fetches the startup packet and returns the result back to `postmaster`. Based on the received information, `postmaster` chooses the pool for this client and redirects the connection to this pool using the file descriptor transfer mechanism.

> **Note**
>
> You can disable connection pooling for some databases and users by specifying them in the dedicated_databases and dedicated_users parameters, respectively. Such databases and users can use an unlimited number of dedicated backends, thus getting priority access to available system resources.

To avoid substantial changes in Postgres Pro locking mechanism, only transaction-level pooling policy is supported. In this mode, the backend can be rescheduled to another session only after it has completed the current transaction. However, the built-in pooler provides session semantics for pooled connections, so that all changes in the session context made by a client application, such as session configuration parameters, preparing statements, or creating temporary tables, are saved/restored by Postgres Pro when the backend is rescheduled to another session. By contrast, pgbouncer can provide session semantics only in the session pooling mode, which does not limit the number of launched backends.

Pooled sessions are bound to backends and cannot be migrated between them. Migrating a session would also require serialization and transfer of the complete session context, which is a non-trivial task. By default, pooled backends continue running even if all sessions assigned to them have been already terminated. To change this behavior, you can set restart_pooler_on_reload or idle_pool_backend_timeout configuration parameters.

34.3. Configuring Built-in Connection Pooler

34.3.1. Enabling Connection Pooling

There are two main configuration parameters to manage connection pooling: session_pool_size and max_sessions. To enable connection pooling, set the `session_pool_size` parameter to a positive integer value. If set, Postgres Pro uses shared pools of backends for working with all databases, except for those that use dedicated backends.

The session_pool_size variable defines the maximal number of backends per connection pool, which is used for each specific database. Thus, the total number of backends running in the pooling mode is limited by session_pool_size * *N*, where *N* is the number of databases. The optimal session_pool_size value highly depends on your system resources. If the number of backends is too small, the server will not utilize all available resources, but a too large value can cause performance degradation because of large snapshots and lock contention.

The max_sessions parameter specifies the maximal number of sessions that can be handled by a single backend. Thus, the maximal number of connections for one database is limited by the session_pool_size * max_sessions value. The max_sessions setting affects only the potential size of the queue on each backend and does not cause any essential negative impact on resource consumption. The default value is 1000.

Additionally, you can configure the number of listeners that read the startup packets to determine the connection pool the client needs to connect to. By default, two workers are used. You can change this value using the connection_pool_workers configuration parameter.

If you are going to use prepared transactions (2PC) in pooled sessions, make sure to enable the hold_prepared_transactions configuration parameter, which forbids rescheduling the backend to another session until all prepared transactions in the current session are committed or rolled back. It prevents conflicts between prepared transactions of several sessions on the same backend, which can cause undetectable deadlocks. However, you must ensure that prepared transactions are completed by the same session that has prepared them; otherwise, using 2PC in pooled sessions is impossible.

34.3.2. Using Dedicated Backends

Postgres Pro enables you to override the pooling mode for some databases and users, so that a separate backend is spawned for each connection. Such databases and users do not use the shared pool of backends, but have their own *dedicated* backends that each serve a single connection. The number of dedicated backends is unlimited, so clients do not have to wait until one of the shared backends becomes available and can get connected to a database right away.

By default, dedicated backends are used for connections to postgres, template0, and template1 databases, as well as for all connections established on behalf of the postgres user. If you would like to use this behavior for other databases or users, modify dedicated_databases and dedicated_users configuration parameters, respectively, and call pg_reload_conf().

34.3.3. Choosing the Scheduling Policy

Since postmaster assigns client sessions to backends at connection time, workload imbalance can occur: while some backends are idle, other backends could be overloaded with work, so clients connected to these backends suffer from long latencies. To better distribute sessions between backends, set the session_schedule configuration parameter that defines the scheduling policy. You can choose between round-robin (default), random and load-balancing policies.

Both random and round-robin policies work well for uniform workloads. For unbalanced workloads, you can opt for the load-balancing policy. In this case, postmaster chooses the backend with the smallest *workload* when establishing a new connection. The workload is measured by the number of sessions waiting for transaction execution on this backend.

You can check the current workload of a backend by calling the pg_backend_load_average(*pid*) function, where *pid* is the process identifier of this backend (see Table 27.36). Unfortunately, even perfect scheduling at connection time does not guarantee that the workloads remain the same in the future: some sessions can get terminated, while idle sessions can become active any time.

34.3.4. Releasing Pooled Resources

Once started, pooled backends continue running even if all its clients get disconnected. While it allows to reuse the same backends for future connections, it may sometimes be required to shut down a backend

that is no longer in use. For example, you cannot drop a database or a user while at least one backend in the corresponding connection pool is still running.

To terminate backends that are no longer required without a server restart, do the following:

1. Set the `restart_pooler_on_reload` variable to `true`.
2. Call the `pg_reload_conf()` function to reload the server configuration.

Alternatively, you can set the idle_pool_backend_timeout configuration parameter to automatically terminate unused backends and release system resources after the specified timeout.

Chapter 35. Troubleshooting

Postgres Pro offers the ability to dump the state of a backend process, which can be useful for diagnostic and debugging purposes, by enabling the crash_info configuration parameter. Then the dump state file can be generated by sending the signal `40` (also known as the diagnostic dump signal):

```
kill -40 backend_pid
```

Here *`backend_pid`* is the process ID of the backend process to dump.

As a result, Postgres Pro will write the state dump to a file in the `$PGDATA/crash_info` directory by default or in the directory specified in the crash_info_location configuration parameter. The file will be named following this pattern: `crash_`*`file_id`*`_pid`*`pid`*`.state`. You can set the data sources to provide data for a crash dump in the crash_info_dump configuration parameter.

The below example shows how to generate and inspect the state dump file for the backend with PID `23111`:

```
-- Generate the state dump file
kill -40 23111

-- Inspect crash_info directory and its contents
SELECT pg_ls_dir('crash_info');

-- Read the contents of the state dump file
SELECT pg_read_file('crash_info/crash_1722943138419104_pid23111.state');
```

Part IV. Client Interfaces

This part describes the client programming interfaces distributed with Postgres Pro. Each of these chapters can be read independently. Note that there are many other programming interfaces for client programs that are distributed separately and contain their own documentation (Appendix J lists some of the more popular ones). Readers of this part should be familiar with using SQL commands to manipulate and query the database (see Part II) and of course with the programming language that the interface uses.

Chapter 36. libpq — C Library

libpq is the C application programmer's interface to Postgres Pro. libpq is a set of library functions that allow client programs to pass queries to the Postgres Pro backend server and to receive the results of these queries.

libpq is also the underlying engine for several other Postgres Pro application interfaces, including those written for C++, Perl, Python, Tcl and ECPG. So some aspects of libpq's behavior will be important to you if you use one of those packages. In particular, Section 36.15, Section 36.16 and Section 36.19 describe behavior that is visible to the user of any application that uses libpq.

Some short programs are included at the end of this chapter (Section 36.22) to show how to write programs that use libpq.

Client programs that use libpq must include the header file `libpq-fe.h`and must link with the libpq library.

36.1. Database Connection Control Functions

The following functions deal with making a connection to a Postgres Pro backend server. An application program can have several backend connections open at one time. (One reason to do that is to access more than one database.) Each connection is represented by a `PGconn`object, which is obtained from the function `PQconnectdb`, `PQconnectdbParams`, or `PQsetdbLogin`. Note that these functions will always return a non-null object pointer, unless perhaps there is too little memory even to allocate the `PGconn` object. The `PQstatus` function should be called to check the return value for a successful connection before queries are sent via the connection object.

> **Warning**
>
> If untrusted users have access to a database that has not adopted a secure schema usage pattern, begin each session by removing publicly-writable schemas from `search_path`. One can set parameter key word `options` to value `-csearch_path=`. Alternately, one can issue `PQexec(`*conn*`, "SELECT pg_catalog.set_config('search_path', '', false)")` after connecting. This consideration is not specific to libpq; it applies to every interface for executing arbitrary SQL commands.

> **Warning**
>
> On Unix, forking a process with open libpq connections can lead to unpredictable results because the parent and child processes share the same sockets and operating system resources. For this reason, such usage is not recommended, though doing an `exec` from the child process to load a new executable is safe.

`PQconnectdbParams`

Makes a new connection to the database server.

```
PGconn *PQconnectdbParams(const char * const *keywords,
                          const char * const *values,
                          int expand_dbname);
```

This function opens a new database connection using the parameters taken from two `NULL`-terminated arrays. The first, `keywords`, is defined as an array of strings, each one being a key word. The second, `values`, gives the value for each key word. Unlike `PQsetdbLogin` below, the parameter set can be extended without changing the function signature, so use of this function (or its nonblocking analogs `PQconnectStartParams` and `PQconnectPoll`) is preferred for new application programming.

The currently recognized parameter key words are listed in Section 36.1.2.

The passed arrays can be empty to use all default parameters, or can contain one or more parameter settings. They must be matched in length. Processing will stop at the first `NULL` entry in the `keywords` array. Also, if the `values` entry associated with a non-`NULL` `keywords` entry is `NULL` or an empty string, that entry is ignored and processing continues with the next pair of array entries.

When `expand_dbname` is non-zero, the value for the first *`dbname`* key word is checked to see if it is a *connection string*. If so, it is "expanded" into the individual connection parameters extracted from the string. The value is considered to be a connection string, rather than just a database name, if it contains an equal sign (`=`) or it begins with a URI scheme designator. (More details on connection string formats appear in Section 36.1.1.) Only the first occurrence of *`dbname`* is treated in this way; any subsequent *`dbname`* parameter is processed as a plain database name.

In general the parameter arrays are processed from start to end. If any key word is repeated, the last value (that is not `NULL` or empty) is used. This rule applies in particular when a key word found in a connection string conflicts with one appearing in the `keywords` array. Thus, the programmer may determine whether array entries can override or be overridden by values taken from a connection string. Array entries appearing before an expanded *`dbname`* entry can be overridden by fields of the connection string, and in turn those fields are overridden by array entries appearing after *`dbname`* (but, again, only if those entries supply non-empty values).

After processing all the array entries and any expanded connection string, any connection parameters that remain unset are filled with default values. If an unset parameter's corresponding environment variable (see Section 36.15) is set, its value is used. If the environment variable is not set either, then the parameter's built-in default value is used.

`PQconnectdb`

Makes a new connection to the database server.

```
PGconn *PQconnectdb(const char *conninfo);
```

This function opens a new database connection using the parameters taken from the string `conninfo`.

The passed string can be empty to use all default parameters, or it can contain one or more parameter settings separated by whitespace, or it can contain a URI. See Section 36.1.1 for details.

`PQsetdbLogin`

Makes a new connection to the database server.

```
PGconn *PQsetdbLogin(const char *pghost,
                     const char *pgport,
                     const char *pgoptions,
                     const char *pgtty,
                     const char *dbName,
                     const char *login,
                     const char *pwd);
```

This is the predecessor of `PQconnectdb` with a fixed set of parameters. It has the same functionality except that the missing parameters will always take on default values. Write `NULL` or an empty string for any one of the fixed parameters that is to be defaulted.

If the *`dbName`* contains an `=` sign or has a valid connection URI prefix, it is taken as a *`conninfo`* string in exactly the same way as if it had been passed to `PQconnectdb`, and the remaining parameters are then applied as specified for `PQconnectdbParams`.

`pgtty` is no longer used and any value passed will be ignored.

`PQsetdb`

Makes a new connection to the database server.

```
PGconn *PQsetdb(char *pghost,
```

```
                  char *pgport,
                  char *pgoptions,
                  char *pgtty,
                  char *dbName);
```

This is a macro that calls PQsetdbLogin with null pointers for the *login* and *pwd* parameters. It is provided for backward compatibility with very old programs.

PQconnectStartParams
PQconnectStart
PQconnectPoll

Make a connection to the database server in a nonblocking manner.

```
PGconn *PQconnectStartParams(const char * const *keywords,
                             const char * const *values,
                             int expand_dbname);

PGconn *PQconnectStart(const char *conninfo);

PostgresPollingStatusType PQconnectPoll(PGconn *conn);
```

These three functions are used to open a connection to a database server such that your application's thread of execution is not blocked on remote I/O whilst doing so. The point of this approach is that the waits for I/O to complete can occur in the application's main loop, rather than down inside PQconnectdbParams or PQconnectdb, and so the application can manage this operation in parallel with other activities.

With PQconnectStartParams, the database connection is made using the parameters taken from the keywords and values arrays, and controlled by expand_dbname, as described above for PQconnectdbParams.

With PQconnectStart, the database connection is made using the parameters taken from the string conninfo as described above for PQconnectdb.

Neither PQconnectStartParams nor PQconnectStart nor PQconnectPoll will block, so long as a number of restrictions are met:

- The hostaddr parameter must be used appropriately to prevent DNS queries from being made. See the documentation of this parameter in Section 36.1.2 for details.
- If you call PQtrace, ensure that the stream object into which you trace will not block.
- You must ensure that the socket is in the appropriate state before calling PQconnectPoll, as described below.

To begin a nonblocking connection request, call PQconnectStart or PQconnectStartParams. If the result is null, then libpq has been unable to allocate a new PGconn structure. Otherwise, a valid PGconn pointer is returned (though not yet representing a valid connection to the database). Next call PQstatus(conn). If the result is CONNECTION_BAD, the connection attempt has already failed, typically because of invalid connection parameters.

If PQconnectStart or PQconnectStartParams succeeds, the next stage is to poll libpq so that it can proceed with the connection sequence. Use PQsocket(conn) to obtain the descriptor of the socket underlying the database connection. (Caution: do not assume that the socket remains the same across PQconnectPoll calls.) Loop thus: If PQconnectPoll(conn) last returned PGRES_POLLING_READING, wait until the socket is ready to read (as indicated by select(), poll(), or similar system function). Then call PQconnectPoll(conn) again. Conversely, if PQconnectPoll(conn) last returned PGRES_POLLING_WRITING, wait until the socket is ready to write, then call PQconnectPoll(conn) again. On the first iteration, i.e., if you have yet to call PQconnectPoll, behave as if it last returned PGRES_POLLING_WRITING. Continue this loop until PQconnectPoll(conn) returns PGRES_POL-

LING_FAILED, indicating the connection procedure has failed, or PGRES_POLLING_OK, indicating the connection has been successfully made.

At any time during connection, the status of the connection can be checked by calling PQstatus. If this call returns CONNECTION_BAD, then the connection procedure has failed; if the call returns CONNECTION_OK, then the connection is ready. Both of these states are equally detectable from the return value of PQconnectPoll, described above. Other states might also occur during (and only during) an asynchronous connection procedure. These indicate the current stage of the connection procedure and might be useful to provide feedback to the user for example. These statuses are:

CONNECTION_STARTED

Waiting for connection to be made.

CONNECTION_MADE

Connection OK; waiting to send.

CONNECTION_AWAITING_RESPONSE

Waiting for a response from the server.

CONNECTION_AUTH_OK

Received authentication; waiting for backend start-up to finish.

CONNECTION_SSL_STARTUP

Negotiating SSL encryption.

CONNECTION_SETENV

Negotiating environment-driven parameter settings.

CONNECTION_CHECK_WRITABLE

Checking if connection is able to handle write transactions.

CONNECTION_CONSUME

Consuming any remaining response messages on connection.

Note that, although these constants will remain (in order to maintain compatibility), an application should never rely upon these occurring in a particular order, or at all, or on the status always being one of these documented values. An application might do something like this:

```
switch(PQstatus(conn))
{
        case CONNECTION_STARTED:
            feedback = "Connecting...";
            break;

        case CONNECTION_MADE:
            feedback = "Connected to server...";
            break;
.
.
.
        default:
            feedback = "Connecting...";
}
```

The connect_timeout connection parameter is ignored when using PQconnectPoll; it is the application's responsibility to decide whether an excessive amount of time has elapsed. Otherwise, PQconnectStart followed by a PQconnectPoll loop is equivalent to PQconnectdb.

Note that when PQconnectStart or PQconnectStartParams returns a non-null pointer, you must call PQfinish when you are finished with it, in order to dispose of the structure and any associated memory blocks. This must be done even if the connection attempt fails or is abandoned.

PQconndefaults

Returns the default connection options.

```
PQconninfoOption *PQconndefaults(void);

typedef struct
{
    char   *keyword;   /* The keyword of the option */
    char   *envvar;    /* Fallback environment variable name */
    char   *compiled;  /* Fallback compiled in default value */
    char   *val;       /* Option's current value, or NULL */
    char   *label;     /* Label for field in connect dialog */
    char   *dispchar;  /* Indicates how to display this field
                          in a connect dialog. Values are:
                          ""        Display entered value as is
                          "*"       Password field - hide value
                          "D"       Debug option - don't show by default */
    int     dispsize;  /* Field size in characters for dialog */
} PQconninfoOption;
```

Returns a connection options array. This can be used to determine all possible PQconnectdb options and their current default values. The return value points to an array of PQconninfoOption structures, which ends with an entry having a null keyword pointer. The null pointer is returned if memory could not be allocated. Note that the current default values (val fields) will depend on environment variables and other context. A missing or invalid service file will be silently ignored. Callers must treat the connection options data as read-only.

After processing the options array, free it by passing it to PQconninfoFree. If this is not done, a small amount of memory is leaked for each call to PQconndefaults.

PQconninfo

Returns the connection options used by a live connection.

```
PQconninfoOption *PQconninfo(PGconn *conn);
```

Returns a connection options array. This can be used to determine all possible PQconnectdb options and the values that were used to connect to the server. The return value points to an array of PQconninfoOption structures, which ends with an entry having a null keyword pointer. All notes above for PQconndefaults also apply to the result of PQconninfo.

PQconninfoParse

Returns parsed connection options from the provided connection string.

```
PQconninfoOption *PQconninfoParse(const char *conninfo, char **errmsg);
```

Parses a connection string and returns the resulting options as an array; or returns NULL if there is a problem with the connection string. This function can be used to extract the PQconnectdb options in the provided connection string. The return value points to an array of PQconninfoOption structures, which ends with an entry having a null keyword pointer.

All legal options will be present in the result array, but the PQconninfoOption for any option not present in the connection string will have val set to NULL; default values are not inserted.

If errmsg is not NULL, then *errmsg is set to NULL on success, else to a malloc'd error string explaining the problem. (It is also possible for *errmsg to be set to NULL and the function to return NULL; this indicates an out-of-memory condition.)

After processing the options array, free it by passing it to PQconninfoFree. If this is not done, some memory is leaked for each call to PQconninfoParse. Conversely, if an error occurs and errmsg is not NULL, be sure to free the error string using PQfreemem.

PQfinish

Closes the connection to the server. Also frees memory used by the PGconn object.

```
void PQfinish(PGconn *conn);
```

Note that even if the server connection attempt fails (as indicated by PQstatus), the application should call PQfinish to free the memory used by the PGconn object. The PGconn pointer must not be used again after PQfinish has been called.

PQreset

Resets the communication channel to the server.

```
void PQreset(PGconn *conn);
```

This function will close the connection to the server and attempt to establish a new connection, using all the same parameters previously used. This might be useful for error recovery if a working connection is lost.

PQresetStart
PQresetPoll

Reset the communication channel to the server, in a nonblocking manner.

```
int PQresetStart(PGconn *conn);

PostgresPollingStatusType PQresetPoll(PGconn *conn);
```

These functions will close the connection to the server and attempt to establish a new connection, using all the same parameters previously used. This can be useful for error recovery if a working connection is lost. They differ from PQreset (above) in that they act in a nonblocking manner. These functions suffer from the same restrictions as PQconnectStartParams, PQconnectStart and PQconnectPoll.

To initiate a connection reset, call PQresetStart. If it returns 0, the reset has failed. If it returns 1, poll the reset using PQresetPoll in exactly the same way as you would create the connection using PQconnectPoll.

PQpingParams

PQpingParams reports the status of the server. It accepts connection parameters identical to those of PQconnectdbParams, described above. It is not necessary to supply correct user name, password, or database name values to obtain the server status; however, if incorrect values are provided, the server will log a failed connection attempt.

```
PGPing PQpingParams(const char * const *keywords,
                    const char * const *values,
                    int expand_dbname);
```

The function returns one of the following values:

PQPING_OK

The server is running and appears to be accepting connections.

PQPING_REJECT

The server is running but is in a state that disallows connections (startup, shutdown, or crash recovery).

`PQPING_NO_RESPONSE`

The server could not be contacted. This might indicate that the server is not running, or that there is something wrong with the given connection parameters (for example, wrong port number), or that there is a network connectivity problem (for example, a firewall blocking the connection request).

`PQPING_NO_ATTEMPT`

No attempt was made to contact the server, because the supplied parameters were obviously incorrect or there was some client-side problem (for example, out of memory).

`PQping`

`PQping` reports the status of the server. It accepts connection parameters identical to those of `PQconnectdb`, described above. It is not necessary to supply correct user name, password, or database name values to obtain the server status; however, if incorrect values are provided, the server will log a failed connection attempt.

```
PGPing PQping(const char *conninfo);
```

The return values are the same as for `PQpingParams`.

`PQsetSSLKeyPassHook_OpenSSL`

`PQsetSSLKeyPassHook_OpenSSL` lets an application override libpq's default handling of encrypted client certificate key files using sslpassword or interactive prompting.

```
void PQsetSSLKeyPassHook_OpenSSL(PQsslKeyPassHook_OpenSSL_type hook);
```

The application passes a pointer to a callback function with signature:

```
int callback_fn(char *buf, int size, PGconn *conn);
```

which libpq will then call *instead of* its default `PQdefaultSSLKeyPassHook_OpenSSL` handler. The callback should determine the password for the key and copy it to result-buffer *`buf`* of size *`size`*. The string in *`buf`* must be null-terminated. The callback must return the length of the password stored in *`buf`* excluding the null terminator. On failure, the callback should set `buf[0] = '\0'` and return 0.

If the user specified an explicit key location, its path will be in `conn->sslkey` when the callback is invoked. This will be empty if the default key path is being used. For keys that are engine specifiers, it is up to engine implementations whether they use the OpenSSL password callback or define their own handling.

The app callback may choose to delegate unhandled cases to `PQdefaultSSLKeyPassHook_OpenSSL`, or call it first and try something else if it returns 0, or completely override it.

The callback *must not* escape normal flow control with exceptions, `longjmp(...)`, etc. It must return normally.

`PQgetSSLKeyPassHook_OpenSSL`

`PQgetSSLKeyPassHook_OpenSSL` returns the current client certificate key password hook, or `NULL` if none has been set.

```
PQsslKeyPassHook_OpenSSL_type PQgetSSLKeyPassHook_OpenSSL(void);
```

36.1.1. Connection Strings

Several libpq functions parse a user-specified string to obtain connection parameters. There are two accepted formats for these strings: plain keyword/value strings and URIs. URIs generally follow *RFC 3986*, except that multi-host connection strings are allowed as further described below.

36.1.1.1. Keyword/Value Connection Strings

In the keyword/value format, each parameter setting is in the form *`keyword = value`*, with space(s) between settings. Spaces around a setting's equal sign are optional. To write an empty value, or a value

containing spaces, surround it with single quotes, for example `keyword = 'a value'`. Single quotes and backslashes within a value must be escaped with a backslash, i.e., `\'` and `\\`.

Example:

```
host=localhost port=5432 dbname=mydb connect_timeout=10
```

The recognized parameter key words are listed in Section 36.1.2.

36.1.1.2. Connection URIs

The general form for a connection URI is:

```
postgresql://[userspec@][hostspec][/dbname][?paramspec]

where userspec is:

user[:password]

and hostspec is:

[host][:port][,...]

and paramspec is:

name=value[&...]
```

The URI scheme designator can be either `postgresql://` or `postgres://`. Each of the remaining URI parts is optional. The following examples illustrate valid URI syntax:

```
postgresql://
postgresql://localhost
postgresql://localhost:5433
postgresql://localhost/mydb
postgresql://user@localhost
postgresql://user:secret@localhost
postgresql://other@localhost/otherdb?connect_timeout=10&application_name=myapp
postgresql://host1:123,host2:456/somedb?
hostorder=random&target_session_attrs=any&application_name=myapp
```

Values that would normally appear in the hierarchical part of the URI can alternatively be given as named parameters. For example:

```
postgresql:///mydb?host=localhost&port=5433
```

All named parameters must match key words listed in Section 36.1.2, except that for compatibility with JDBC connection URIs, instances of `ssl=true` are translated into `sslmode=require`.

The connection URI needs to be encoded with *percent-encoding* if it includes symbols with special meaning in any of its parts. Here is an example where the equal sign (`=`) is replaced with `%3D` and the space character with `%20`:

```
postgresql://user@localhost:5433/mydb?options=-c%20synchronous_commit%3Doff
```

The host part may be either a host name or an IP address. To specify an IPv6 address, enclose it in square brackets:

```
postgresql://[2001:db8::1234]/database
```

The host part is interpreted as described for the parameter host. In particular, a Unix-domain socket connection is chosen if the host part is either empty or looks like an absolute path name, otherwise a TCP/IP connection is initiated. Note, however, that the slash is a reserved character in the hierarchical part of the URI. So, to specify a non-standard Unix-domain socket directory, either omit the host part of the URI and specify the host as a named parameter, or percent-encode the path in the host part of the URI:

```
postgresql:///dbname?host=/var/lib/postgresql
postgresql://%2Fvar%2Flib%2Fpostgresql/dbname
```

It is possible to specify multiple host components, each with an optional port component, in a single URI. A URI of the form `postgresql://host1:port1,host2:port2,host3:port3/` is equivalent to a connection string of the form `host=host1,host2,host3 port=port1,port2,port3`. Each host will be tried in the order defined by the hostorder parameter until a connection is successfully established, all hosts have been tried, or failover_timeout is reached. For details, see Section 36.1.1.3.

36.1.1.3. Specifying Multiple Hosts

It is possible to specify multiple hosts to connect to. In the Keyword/Value format, the `host`, `hostaddr`, and `port` options accept a comma-separated list of values. The same number of elements must be given in each option that is specified, such that e.g. the first `hostaddr` corresponds to the first host name, the second `hostaddr` corresponds to the second host name, and so forth. As an exception, if only one `port` is specified, it applies to all the hosts.

In the connection URI format, you can list multiple `host:port` pairs separated by commas in the `host` component of the URI.

In either format, a single host name can translate to multiple network addresses. A common example of this is a host that has both an IPv4 and an IPv6 address.

When multiple hosts are specified, or when a single host name is translated to multiple addresses, all the hosts and addresses will be tried in the order defined by the hostorder parameter until one succeeds. By default, each host is tried only once. You can allow multiple connection attempts to each host using the failover_timeout parameter, which specifies the maximum time for making a connection. If none of the hosts can be reached, the connection fails. If a connection is established successfully, but authentication fails, the remaining hosts in the list are not tried.

If a password file is used, you can have different passwords for different hosts. All the other connection options are the same for every host in the list; it is not possible to e.g., specify different usernames for different hosts.

36.1.2. Parameter Key Words

The currently recognized parameter key words are:

`host`

Name of host to connect to. If a host name looks like an absolute path name, it specifies Unix-domain communication rather than TCP/IP communication; the value is the name of the directory in which the socket file is stored. (On Unix, an absolute path name begins with a slash. On Windows, paths starting with drive letters are also recognized.) If the host name starts with `@`, it is taken as a Unix-domain socket in the abstract namespace (currently supported on Linux and Windows). The default behavior when `host` is not specified, or is empty, is to connect to a Unix-domain socket in `/tmp` (or whatever socket directory was specified when Postgres Pro was built). On Windows and on machines without Unix-domain sockets, the default is to connect to `localhost`.

A comma-separated list of host names is also accepted, in which case each host name in the list is tried in the order defined by the hostorder parameter; an empty item in the list selects the default behavior as explained above. See Section 36.1.1.3 for details.

`hostaddr`

Numeric IP address of host to connect to. This should be in the standard IPv4 address format, e.g., `172.28.40.9`. If your machine supports IPv6, you can also use those addresses. TCP/IP communication is always used when a nonempty string is specified for this parameter. If this parameter is not specified, the value of `host` will be looked up to find the corresponding IP address — or, if `host` specifies an IP address, that value will be used directly.

Using `hostaddr` allows the application to avoid a host name look-up, which might be important in applications with time constraints. However, a host name is required for GSSAPI or SSPI authentication methods, as well as for `verify-full` SSL certificate verification. The following rules are used:

- If `host` is specified without `hostaddr`, a host name lookup occurs. (When using `PQconnectPoll`, the lookup occurs when `PQconnectPoll` first considers this host name, and it may cause `PQconnectPoll` to block for a significant amount of time.)
- If `hostaddr` is specified without `host`, the value for `hostaddr` gives the server network address. The connection attempt will fail if the authentication method requires a host name.
- If both `host` and `hostaddr` are specified, the value for `hostaddr` gives the server network address. The value for `host` is ignored unless the authentication method requires it, in which case it will be used as the host name.

Note that authentication is likely to fail if `host` is not the name of the server at network address `hostaddr`. Also, when both `host` and `hostaddr` are specified, `host` is used to identify the connection in a password file (see Section 36.16).

A comma-separated list of `hostaddr` values is also accepted, in which case each host in the list is tried in the order defined by the hostorder parameter. An empty item in the list causes the corresponding host name to be used, or the default host name if that is empty as well. See Section 36.1.1.3 for details.

Without either a host name or host address, libpq will connect using a local Unix-domain socket; or on Windows and on machines without Unix-domain sockets, it will attempt to connect to `localhost`.

`hostorder`

Defines the order of connecting to the hosts specified by the host or hostaddr parameter.

If the value of this parameter is `sequential` (the default), connections to the hosts are attempted in the order in which the hosts are listed.

If the value is `random`, the host to connect to is randomly picked from the list. This setting can help you balance the load between several cluster nodes instead of always connecting to the first available host in the list. You can also use the target_session_attrs parameter to forbid read-only connections.

`port`

Port number to connect to at the server host, or socket file name extension for Unix-domain connections. If multiple hosts were given in the `host` or `hostaddr` parameters, this parameter may specify a comma-separated list of ports of the same length as the host list, or it may specify a single port number to be used for all hosts. An empty string, or an empty item in a comma-separated list, specifies the default port number established when Postgres Pro was built.

`dbname`

The database name. Defaults to be the same as the user name. In certain contexts, the value is checked for extended formats; see Section 36.1.1 for more details on those.

`user`

Postgres Pro user name to connect as. Defaults to be the same as the operating system name of the user running the application.

`password`

Password to be used if the server demands password authentication.

`passfile`

Specifies the name of the file used to store passwords (see Section 36.16). Defaults to `~/.pgpass`, or `%APPDATA%\postgresql\pgpass.conf` on Microsoft Windows. (No error is reported if this file does not exist.)

`channel_binding`

This option controls the client's use of channel binding. A setting of `require` means that the connection must employ channel binding, `prefer` means that the client will choose channel binding if available, and `disable` prevents the use of channel binding. The default is `prefer` if Postgres Pro is compiled with SSL support; otherwise the default is `disable`.

Channel binding is a method for the server to authenticate itself to the client. It is only supported over SSL connections with Postgres Pro 11 or later servers using the `SCRAM` authentication method.

`reusepass`

Specifies whether reusing the prompted password is allowed when reestablishing connections. To forbid password reuse, set `reusepass` to `0`. You can use this option together with idle_session_timeout to define the reconnection behavior for sessions terminated by timeout.

Default: `1`

`connect_timeout`

Maximum time to wait while connecting, in seconds (write as a decimal integer, e.g., `10`). Zero, negative, or not specified means wait indefinitely. The minimum allowed timeout is 2 seconds, therefore a value of `1` is interpreted as `2`. This timeout applies separately to each host name or IP address. For example, if you specify two hosts and `connect_timeout` is 5, each host will time out if no connection is made within 5 seconds, so the total time spent waiting for a connection might be up to 10 seconds.

`failover_timeout`

Maximum time, in seconds, to cyclically retry to connect to the hosts specified in the connection string. If this parameter is not set (the default), connection to each host is tried only once. The specified value must be a decimal integer number.

When using this parameter in clusters with primary-standby replication, make sure that its value provides enough time for a standby node to become the new primary if the current primary node fails. In this case, clients will be able to reconnect to the new primary once failover is complete.

`client_encoding`

This sets the `client_encoding` configuration parameter for this connection. In addition to the values accepted by the corresponding server option, you can use `auto` to determine the right encoding from the current locale in the client (`LC_CTYPE` environment variable on Unix systems).

`options`

Specifies command-line options to send to the server at connection start. For example, setting this to `-c geqo=off` sets the session's value of the `geqo` parameter to `off`. Spaces within this string are considered to separate command-line arguments, unless escaped with a backslash (`\`); write `\\` to represent a literal backslash. For a detailed discussion of the available options, consult Chapter 19.

`application_name`

Specifies a value for the application_name configuration parameter.

`fallback_application_name`

Specifies a fallback value for the application_name configuration parameter. This value will be used if no value has been given for `application_name` via a connection parameter or the `PGAPPNAME` environment variable. Specifying a fallback name is useful in generic utility programs that wish to set a default application name but allow it to be overridden by the user.

`keepalives`

Controls whether client-side TCP keepalives are used. The default value is 1, meaning on, but you can change this to 0, meaning off, if keepalives are not wanted. This parameter is ignored for connections made via a Unix-domain socket.

`keepalives_idle`

Controls the number of seconds of inactivity after which TCP should send a keepalive message to the server. A value of zero uses the system default. This parameter is ignored for connections made via a Unix-domain socket, or if keepalives are disabled. It is only supported on systems where `TCP_KEEPIDLE` or an equivalent socket option is available, and on Windows; on other systems, it has no effect.

`keepalives_interval`

Controls the number of seconds after which a TCP keepalive message that is not acknowledged by the server should be retransmitted. A value of zero uses the system default. This parameter is ignored for connections made via a Unix-domain socket, or if keepalives are disabled. It is only supported on systems where `TCP_KEEPINTVL` or an equivalent socket option is available, and on Windows; on other systems, it has no effect.

`keepalives_count`

Controls the number of TCP keepalives that can be lost before the client's connection to the server is considered dead. A value of zero uses the system default. This parameter is ignored for connections made via a Unix-domain socket, or if keepalives are disabled. It is only supported on systems where `TCP_KEEPCNT` or an equivalent socket option is available; on other systems, it has no effect.

`tcp_user_timeout`

Controls the number of milliseconds that transmitted data may remain unacknowledged before a connection is forcibly closed. A value of zero uses the system default. This parameter is ignored for connections made via a Unix-domain socket. It is only supported on systems where `TCP_USER_TIMEOUT` is available; on other systems, it has no effect.

`replication`

This option determines whether the connection should use the replication protocol instead of the normal protocol. This is what Postgres Pro replication connections as well as tools such as pg_basebackup use internally, but it can also be used by third-party applications. For a description of the replication protocol, consult Section 55.4.

The following values, which are case-insensitive, are supported:

`true`, `on`, `yes`, `1`

The connection goes into physical replication mode.

`database`

The connection goes into logical replication mode, connecting to the database specified in the `dbname` parameter.

`false`, `off`, `no`, `0`

The connection is a regular one, which is the default behavior.

In physical or logical replication mode, only the simple query protocol can be used.

`gssencmode`

This option determines whether or with what priority a secure GSS TCP/IP connection will be negotiated with the server. There are three modes:

`disable`

only try a non-GSSAPI-encrypted connection

`prefer` (default)

if there are GSSAPI credentials present (i.e., in a credentials cache), first try a GSSAPI-encrypted connection; if that fails or there are no credentials, try a non-GSSAPI-encrypted connection. This is the default when Postgres Pro has been compiled with GSSAPI support.

`require`

only try a GSSAPI-encrypted connection

`gssencmode` is ignored for Unix domain socket communication. If Postgres Pro is compiled without GSSAPI support, using the `require` option will cause an error, while `prefer` will be accepted but libpq will not actually attempt a GSSAPI-encrypted connection.

`sslmode`

This option determines whether or with what priority a secure SSL TCP/IP connection will be negotiated with the server. There are six modes:

`disable`

only try a non-SSL connection

`allow`

first try a non-SSL connection; if that fails, try an SSL connection

`prefer` (default)

first try an SSL connection; if that fails, try a non-SSL connection

`require`

only try an SSL connection. If a root CA file is present, verify the certificate in the same way as if `verify-ca` was specified

`verify-ca`

only try an SSL connection, and verify that the server certificate is issued by a trusted certificate authority (CA)

`verify-full`

only try an SSL connection, verify that the server certificate is issued by a trusted CA and that the requested server host name matches that in the certificate

See Section 36.19 for a detailed description of how these options work.

`sslmode` is ignored for Unix domain socket communication. If Postgres Pro is compiled without SSL support, using options `require`, `verify-ca`, or `verify-full` will cause an error, while options `allow` and `prefer` will be accepted but libpq will not actually attempt an SSL connection.

Note that if GSSAPI encryption is possible, that will be used in preference to SSL encryption, regardless of the value of `sslmode`. To force use of SSL encryption in an environment that has working GSSAPI infrastructure (such as a Kerberos server), also set `gssencmode` to `disable`.

`requiressl`

This option is deprecated in favor of the `sslmode` setting.

If set to 1, an SSL connection to the server is required (this is equivalent to `sslmode require`). libpq will then refuse to connect if the server does not accept an SSL connection. If set to 0 (default), libpq will negotiate the connection type with the server (equivalent to `sslmode prefer`). This option is only available if Postgres Pro is compiled with SSL support.

`sslcompression`

If set to 1, data sent over SSL connections will be compressed. If set to 0, compression will be disabled. The default is 0. This parameter is ignored if a connection without SSL is made.

SSL compression is nowadays considered insecure and its use is no longer recommended. OpenSSL 1.1.0 disables compression by default, and many operating system distributions disable it in prior

versions as well, so setting this parameter to on will not have any effect if the server does not accept compression. Postgres Pro 14 disables compression completely in the backend.

If security is not a primary concern, compression can improve throughput if the network is the bottleneck. Disabling compression can improve response time and throughput if CPU performance is the limiting factor.

`sslcert`

This parameter specifies the file name of the client SSL certificate, replacing the default `~/.postgresql/postgresql.crt`. This parameter is ignored if an SSL connection is not made.

`sslkey`

This parameter specifies the location for the secret key used for the client certificate. It can either specify a file name that will be used instead of the default `~/.postgresql/postgresql.key`, or it can specify a key obtained from an external "engine" (engines are OpenSSL loadable modules). An external engine specification should consist of a colon-separated engine name and an engine-specific key identifier. This parameter is ignored if an SSL connection is not made.

`sslpassword`

This parameter specifies the password for the secret key specified in `sslkey`, allowing client certificate private keys to be stored in encrypted form on disk even when interactive passphrase input is not practical.

Specifying this parameter with any non-empty value suppresses the `Enter PEM pass phrase:` prompt that OpenSSL will emit by default when an encrypted client certificate key is provided to `libpq`.

If the key is not encrypted this parameter is ignored. The parameter has no effect on keys specified by OpenSSL engines unless the engine uses the OpenSSL password callback mechanism for prompts.

There is no environment variable equivalent to this option, and no facility for looking it up in `.pgpass`. It can be used in a service file connection definition. Users with more sophisticated uses should consider using OpenSSL engines and tools like PKCS#11 or USB crypto offload devices.

`sslrootcert`

This parameter specifies the name of a file containing SSL certificate authority (CA) certificate(s). If the file exists, the server's certificate will be verified to be signed by one of these authorities. The default is `~/.postgresql/root.crt`.

`sslcrl`

This parameter specifies the file name of the SSL server certificate revocation list (CRL). Certificates listed in this file, if it exists, will be rejected while attempting to authenticate the server's certificate. If neither sslcrl nor sslcrldir is set, this setting is taken as `~/.postgresql/root.crl`.

`sslcrldir`

This parameter specifies the directory name of the SSL server certificate revocation list (CRL). Certificates listed in the files in this directory, if it exists, will be rejected while attempting to authenticate the server's certificate.

The directory needs to be prepared with the OpenSSL command `openssl rehash` or `c_rehash`. See its documentation for details.

Both `sslcrl` and `sslcrldir` can be specified together.

`sslsni`

If set to 1 (default), libpq sets the TLS extension "Server Name Indication" (SNI) on SSL-enabled connections. By setting this parameter to 0, this is turned off.

The Server Name Indication can be used by SSL-aware proxies to route connections without having to decrypt the SSL stream. (Note that this requires a proxy that is aware of the PostgreSQL protocol handshake, not just any SSL proxy.) However, SNI makes the destination host name appear in cleartext in the network traffic, so it might be undesirable in some cases.

`requirepeer`

This parameter specifies the operating-system user name of the server, for example `requirepeer=postgres`. When making a Unix-domain socket connection, if this parameter is set, the client checks at the beginning of the connection that the server process is running under the specified user name; if it is not, the connection is aborted with an error. This parameter can be used to provide server authentication similar to that available with SSL certificates on TCP/IP connections. (Note that if the Unix-domain socket is in `/tmp` or another publicly writable location, any user could start a server listening there. Use this parameter to ensure that you are connected to a server run by a trusted user.) This option is only supported on platforms for which the `peer` authentication method is implemented; see Section 20.9.

`ssl_min_protocol_version`

This parameter specifies the minimum SSL/TLS protocol version to allow for the connection. Valid values are `TLSv1`, `TLSv1.1`, `TLSv1.2` and `TLSv1.3`. The supported protocols depend on the version of OpenSSL used, older versions not supporting the most modern protocol versions. If not specified, the default is `TLSv1.2`, which satisfies industry best practices as of this writing.

`ssl_max_protocol_version`

This parameter specifies the maximum SSL/TLS protocol version to allow for the connection. Valid values are `TLSv1`, `TLSv1.1`, `TLSv1.2` and `TLSv1.3`. The supported protocols depend on the version of OpenSSL used, older versions not supporting the most modern protocol versions. If not set, this parameter is ignored and the connection will use the maximum bound defined by the backend, if set. Setting the maximum protocol version is mainly useful for testing or if some component has issues working with a newer protocol.

`krbsrvname`

Kerberos service name to use when authenticating with GSSAPI. This must match the service name specified in the server configuration for Kerberos authentication to succeed. (See also Section 20.6.) The default value is normally `postgres`, but that can be changed when building Postgres Pro via the `--with-krb-srvnam` option of configure. In most environments, this parameter never needs to be changed. Some Kerberos implementations might require a different service name, such as Microsoft Active Directory which requires the service name to be in upper case (`POSTGRES`).

`gsslib`

GSS library to use for GSSAPI authentication. Currently this is disregarded except on Windows builds that include both GSSAPI and SSPI support. In that case, set this to `gssapi` to cause libpq to use the GSSAPI library for authentication instead of the default SSPI.

`service`

Service name to use for additional parameters. It specifies a service name in `pg_service.conf` that holds additional connection parameters. This allows applications to specify only a service name so connection parameters can be centrally maintained. See Section 36.17.

`target_session_attrs`

This option determines whether the session must have certain properties to be acceptable. It's typically used in combination with multiple host names to select the first acceptable alternative among several hosts. There are six modes:

`any` (default)

any successful connection is acceptable

`read-write`

session must accept read-write transactions by default (that is, the server must not be in hot standby mode and the `default_transaction_read_only` parameter must be `off`)

`read-only`

session must not accept read-write transactions by default (the converse)

`primary`

server must not be in hot standby mode

`standby`

server must be in hot standby mode

`prefer-standby`

first try to find a standby server, but if none of the listed hosts is a standby server, try again in `any` mode

`target_server_type`

Same as target_session_attrs. This parameter is provided for backward compatibility with Postgres Pro Enterprise 9.6.

36.2. Connection Status Functions

These functions can be used to interrogate the status of an existing database connection object.

> **Tip**
>
> libpq application programmers should be careful to maintain the `PGconn` abstraction. Use the accessor functions described below to get at the contents of `PGconn`. Reference to internal `PGconn` fields using `libpq-int.h` is not recommended because they are subject to change in the future.

The following functions return parameter values established at connection. These values are fixed for the life of the connection. If a multi-host connection string is used, the values of `PQhost`, `PQport`, and `PQpass` can change if a new connection is established using the same `PGconn` object. Other values are fixed for the lifetime of the `PGconn` object.

`PQdb`

Returns the database name of the connection.

```
char *PQdb(const PGconn *conn);
```

`PQuser`

Returns the user name of the connection.

```
char *PQuser(const PGconn *conn);
```

`PQpass`

Returns the password of the connection.

```
char *PQpass(const PGconn *conn);
```

`PQpass` will return either the password specified in the connection parameters, or if there was none and the password was obtained from the password file, it will return that. In the latter case, if multiple hosts were specified in the connection parameters, it is not possible to rely on the result of `PQpass` until the connection is established. The status of the connection can be checked using the function `PQstatus`.

`PQhost`

Returns the server host name of the active connection. This can be a host name, an IP address, or a directory path if the connection is via Unix socket. (The path case can be distinguished because it will always be an absolute path, beginning with `/`.)

```
char *PQhost(const PGconn *conn);
```

If the connection parameters specified both `host` and `hostaddr`, then `PQhost` will return the `host` information. If only `hostaddr` was specified, then that is returned. If multiple hosts were specified in the connection parameters, `PQhost` returns the host actually connected to.

`PQhost` returns `NULL` if the *conn* argument is `NULL`. Otherwise, if there is an error producing the host information (perhaps if the connection has not been fully established or there was an error), it returns an empty string.

If multiple hosts were specified in the connection parameters, it is not possible to rely on the result of `PQhost` until the connection is established. The status of the connection can be checked using the function `PQstatus`.

`PQhostaddr`

Returns the server IP address of the active connection. This can be the address that a host name resolved to, or an IP address provided through the `hostaddr` parameter.

```
char *PQhostaddr(const PGconn *conn);
```

`PQhostaddr` returns `NULL` if the *conn* argument is `NULL`. Otherwise, if there is an error producing the host information (perhaps if the connection has not been fully established or there was an error), it returns an empty string.

`PQport`

Returns the port of the active connection.

```
char *PQport(const PGconn *conn);
```

If multiple ports were specified in the connection parameters, `PQport` returns the port actually connected to.

`PQport` returns `NULL` if the *conn* argument is `NULL`. Otherwise, if there is an error producing the port information (perhaps if the connection has not been fully established or there was an error), it returns an empty string.

If multiple ports were specified in the connection parameters, it is not possible to rely on the result of `PQport` until the connection is established. The status of the connection can be checked using the function `PQstatus`.

`PQtty`

This function no longer does anything, but it remains for backwards compatibility. The function always return an empty string, or `NULL` if the *conn* argument is `NULL`.

```
char *PQtty(const PGconn *conn);
```

`PQoptions`

Returns the command-line options passed in the connection request.

```
char *PQoptions(const PGconn *conn);
```

The following functions return status data that can change as operations are executed on the `PGconn` object.

`PQstatus`

Returns the status of the connection.

```
ConnStatusType PQstatus(const PGconn *conn);
```

The status can be one of a number of values. However, only two of these are seen outside of an asynchronous connection procedure: `CONNECTION_OK` and `CONNECTION_BAD`. A good connection to the database has the status `CONNECTION_OK`. A failed connection attempt is signaled by status `CONNECTION_BAD`. Ordinarily, an OK status will remain so until `PQfinish`, but a communications failure might result in the status changing to `CONNECTION_BAD` prematurely. In that case the application could try to recover by calling `PQreset`.

See the entry for `PQconnectStartParams`, `PQconnectStart` and `PQconnectPoll` with regards to other status codes that might be returned.

`PQtransactionStatus`

Returns the current in-transaction status of the server.

```
PGTransactionStatusType PQtransactionStatus(const PGconn *conn);
```

The status can be `PQTRANS_IDLE` (currently idle), `PQTRANS_ACTIVE` (a command is in progress), `PQTRANS_INTRANS` (idle, in a valid transaction block), or `PQTRANS_INERROR` (idle, in a failed transaction block). `PQTRANS_UNKNOWN` is reported if the connection is bad. `PQTRANS_ACTIVE` is reported only when a query has been sent to the server and not yet completed.

`PQparameterStatus`

Looks up a current parameter setting of the server.

```
const char *PQparameterStatus(const PGconn *conn, const char *paramName);
```

Certain parameter values are reported by the server automatically at connection startup or whenever their values change. `PQparameterStatus` can be used to interrogate these settings. It returns the current value of a parameter if known, or `NULL` if the parameter is not known.

Parameters reported as of the current release include `server_version`, `server_encoding`, `client_encoding`, `application_name`, `default_transaction_read_only`, `in_hot_standby`, `is_superuser`, `session_authorization`, `DateStyle`, `IntervalStyle`, `TimeZone`, `integer_datetimes`, and `standard_conforming_strings`. (`server_encoding`, `TimeZone`, and `integer_datetimes` were not reported by releases before 8.0; `standard_conforming_strings` was not reported by releases before 8.1; `IntervalStyle` was not reported by releases before 8.4; `application_name` was not reported by releases before 9.0; `default_transaction_read_only` and `in_hot_standby` were not reported by releases before 14.) Note that `server_version`, `server_encoding` and `integer_datetimes` cannot change after startup.

If no value for `standard_conforming_strings` is reported, applications can assume it is `off`, that is, backslashes are treated as escapes in string literals. Also, the presence of this parameter can be taken as an indication that the escape string syntax (`E'...'`) is accepted.

Although the returned pointer is declared `const`, it in fact points to mutable storage associated with the `PGconn` structure. It is unwise to assume the pointer will remain valid across queries.

`PQprotocolVersion`

Interrogates the frontend/backend protocol being used.

```
int PQprotocolVersion(const PGconn *conn);
```

Applications might wish to use this function to determine whether certain features are supported. Currently, the possible values are 3 (3.0 protocol), or zero (connection bad). The protocol version will not change after connection startup is complete, but it could theoretically change during a connection reset. The 3.0 protocol is supported by PostgreSQL server versions 7.4 and above.

`PQserverVersion`

Returns an integer representing the server version.

```
int PQserverVersion(const PGconn *conn);
```

Applications might use this function to determine the version of the database server they are connected to. The result is formed by multiplying the server's major version number by 10000 and adding the minor version number. For example, version 10.1 will be returned as 100001, and version 11.0 will be returned as 110000. Zero is returned if the connection is bad.

Prior to major version 10, Postgres Pro used three-part version numbers in which the first two parts together represented the major version. For those versions, `PQserverVersion` uses two digits for each part; for example version 9.1.5 will be returned as 90105, and version 9.2.0 will be returned as 90200.

Therefore, for purposes of determining feature compatibility, applications should divide the result of `PQserverVersion` by 100 not 10000 to determine a logical major version number. In all release series, only the last two digits differ between minor releases (bug-fix releases).

`PQerrorMessage`

Returns the error message most recently generated by an operation on the connection.

```
char *PQerrorMessage(const PGconn *conn);
```

Nearly all libpq functions will set a message for `PQerrorMessage` if they fail. Note that by libpq convention, a nonempty `PQerrorMessage` result can consist of multiple lines, and will include a trailing newline. The caller should not free the result directly. It will be freed when the associated `PGconn` handle is passed to `PQfinish`. The result string should not be expected to remain the same across operations on the `PGconn` structure.

`PQsocket`

Obtains the file descriptor number of the connection socket to the server. A valid descriptor will be greater than or equal to 0; a result of -1 indicates that no server connection is currently open. (This will not change during normal operation, but could change during connection setup or reset.)

```
int PQsocket(const PGconn *conn);
```

`PQbackendPID`

Returns the process ID (PID) of the backend process handling this connection.

```
int PQbackendPID(const PGconn *conn);
```

The backend PID is useful for debugging purposes and for comparison to `NOTIFY` messages (which include the PID of the notifying backend process). Note that the PID belongs to a process executing on the database server host, not the local host!

`PQconnectionNeedsPassword`

Returns true (1) if the connection authentication method required a password, but none was available. Returns false (0) if not.

```
int PQconnectionNeedsPassword(const PGconn *conn);
```

This function can be applied after a failed connection attempt to decide whether to prompt the user for a password.

`PQconnectionUsedPassword`

Returns true (1) if the connection authentication method used a password. Returns false (0) if not.

```
int PQconnectionUsedPassword(const PGconn *conn);
```

This function can be applied after either a failed or successful connection attempt to detect whether the server demanded a password.

The following functions return information related to SSL. This information usually doesn't change after a connection is established.

`PQsslInUse`

Returns true (1) if the connection uses SSL, false (0) if not.

```
int PQsslInUse(const PGconn *conn);
```

`PQsslAttribute`

Returns SSL-related information about the connection.

```
const char *PQsslAttribute(const PGconn *conn, const char *attribute_name);
```

The list of available attributes varies depending on the SSL library being used, and the type of connection. If an attribute is not available, returns NULL.

The following attributes are commonly available:

`library`

Name of the SSL implementation in use. (Currently, only `"OpenSSL"` is implemented)

`protocol`

SSL/TLS version in use. Common values are `"TLSv1"`, `"TLSv1.1"` and `"TLSv1.2"`, but an implementation may return other strings if some other protocol is used.

`key_bits`

Number of key bits used by the encryption algorithm.

`cipher`

A short name of the ciphersuite used, e.g., `"DHE-RSA-DES-CBC3-SHA"`. The names are specific to each SSL implementation.

`compression`

Returns "on" if SSL compression is in use, else it returns "off".

`PQsslAttributeNames`

Return an array of SSL attribute names available. The array is terminated by a NULL pointer.

```
const char * const * PQsslAttributeNames(const PGconn *conn);
```

`PQsslStruct`

Return a pointer to an SSL-implementation-specific object describing the connection.

```
void *PQsslStruct(const PGconn *conn, const char *struct_name);
```

The struct(s) available depend on the SSL implementation in use. For OpenSSL, there is one struct, available under the name "OpenSSL", and it returns a pointer to the OpenSSL `SSL` struct. To use this function, code along the following lines could be used:

```
#include <libpq-fe.h>
#include <openssl/ssl.h>

...

    SSL *ssl;

    dbconn = PQconnectdb(...);
    ...

    ssl = PQsslStruct(dbconn, "OpenSSL");
```

```
if (ssl)
{
    /* use OpenSSL functions to access ssl */
}
```

This structure can be used to verify encryption levels, check server certificates, and more. Refer to the OpenSSL documentation for information about this structure.

`PQgetssl`

Returns the SSL structure used in the connection, or null if SSL is not in use.

```
void *PQgetssl(const PGconn *conn);
```

This function is equivalent to `PQsslStruct(conn, "OpenSSL")`. It should not be used in new applications, because the returned struct is specific to OpenSSL and will not be available if another SSL implementation is used. To check if a connection uses SSL, call `PQsslInUse` instead, and for more details about the connection, use `PQsslAttribute`.

36.3. Command Execution Functions

Once a connection to a database server has been successfully established, the functions described here are used to perform SQL queries and commands.

36.3.1. Main Functions

`PQexec`

Submits a command to the server and waits for the result.

```
PGresult *PQexec(PGconn *conn, const char *command);
```

Returns a `PGresult` pointer or possibly a null pointer. A non-null pointer will generally be returned except in out-of-memory conditions or serious errors such as inability to send the command to the server. The `PQresultStatus` function should be called to check the return value for any errors (including the value of a null pointer, in which case it will return `PGRES_FATAL_ERROR`). Use `PQerrorMessage` to get more information about such errors.

The command string can include multiple SQL commands (separated by semicolons). Multiple queries sent in a single `PQexec` call are processed in a single transaction, unless there are explicit `BEGIN`/`COMMIT` commands included in the query string to divide it into multiple transactions. (See Section 55.2.2.1 for more details about how the server handles multi-query strings.) Note however that the returned `PGresult` structure describes only the result of the last command executed from the string. Should one of the commands fail, processing of the string stops with it and the returned `PGresult` describes the error condition.

`PQexecParams`

Submits a command to the server and waits for the result, with the ability to pass parameters separately from the SQL command text.

```
PGresult *PQexecParams(PGconn *conn,
                       const char *command,
                       int nParams,
                       const Oid *paramTypes,
                       const char * const *paramValues,
                       const int *paramLengths,
                       const int *paramFormats,
                       int resultFormat);
```

`PQexecParams` is like `PQexec`, but offers additional functionality: parameter values can be specified separately from the command string proper, and query results can be requested in either text or binary format.

The function arguments are:

conn

The connection object to send the command through.

command

The SQL command string to be executed. If parameters are used, they are referred to in the command string as `$1`, `$2`, etc.

nParams

The number of parameters supplied; it is the length of the arrays *paramTypes[]*, *paramValues[]*, *paramLengths[]*, and *paramFormats[]*. (The array pointers can be `NULL` when *nParams* is zero.)

paramTypes[]

Specifies, by OID, the data types to be assigned to the parameter symbols. If *paramTypes* is `NULL`, or any particular element in the array is zero, the server infers a data type for the parameter symbol in the same way it would do for an untyped literal string.

paramValues[]

Specifies the actual values of the parameters. A null pointer in this array means the corresponding parameter is null; otherwise the pointer points to a zero-terminated text string (for text format) or binary data in the format expected by the server (for binary format).

paramLengths[]

Specifies the actual data lengths of binary-format parameters. It is ignored for null parameters and text-format parameters. The array pointer can be null when there are no binary parameters.

paramFormats[]

Specifies whether parameters are text (put a zero in the array entry for the corresponding parameter) or binary (put a one in the array entry for the corresponding parameter). If the array pointer is null then all parameters are presumed to be text strings.

Values passed in binary format require knowledge of the internal representation expected by the backend. For example, integers must be passed in network byte order. Passing `numeric` values requires knowledge of the server storage format.

resultFormat

Specify zero to obtain results in text format, or one to obtain results in binary format. (There is not currently a provision to obtain different result columns in different formats, although that is possible in the underlying protocol.)

The primary advantage of `PQexecParams` over `PQexec` is that parameter values can be separated from the command string, thus avoiding the need for tedious and error-prone quoting and escaping.

Unlike `PQexec`, `PQexecParams` allows at most one SQL command in the given string. (There can be semicolons in it, but not more than one nonempty command.) This is a limitation of the underlying protocol, but has some usefulness as an extra defense against SQL-injection attacks.

> **Tip**
>
> Specifying parameter types via OIDs is tedious, particularly if you prefer not to hard-wire particular OID values into your program. However, you can avoid doing so even in cases where the server by itself cannot determine the type of the parameter, or chooses a different type than you want. In the SQL command text, attach an explicit cast to the parameter symbol to show what data type you will send. For example:
>
> ```
> SELECT * FROM mytable WHERE x = $1::bigint;
> ```

This forces parameter `$1` to be treated as `bigint`, whereas by default it would be assigned the same type as `x`. Forcing the parameter type decision, either this way or by specifying a numeric type OID, is strongly recommended when sending parameter values in binary format, because binary format has less redundancy than text format and so there is less chance that the server will detect a type mismatch mistake for you.

`PQprepare`

Submits a request to create a prepared statement with the given parameters, and waits for completion.

```
PGresult *PQprepare(PGconn *conn,
                    const char *stmtName,
                    const char *query,
                    int nParams,
                    const Oid *paramTypes);
```

`PQprepare` creates a prepared statement for later execution with `PQexecPrepared`. This feature allows commands to be executed repeatedly without being parsed and planned each time; see PREPARE for details.

The function creates a prepared statement named *`stmtName`* from the *`query`* string, which must contain a single SQL command. *`stmtName`* can be `""` to create an unnamed statement, in which case any pre-existing unnamed statement is automatically replaced; otherwise it is an error if the statement name is already defined in the current session. If any parameters are used, they are referred to in the query as `$1`, `$2`, etc. *`nParams`* is the number of parameters for which types are pre-specified in the array *`paramTypes[]`*. (The array pointer can be `NULL` when *`nParams`* is zero.) *`paramTypes[]`* specifies, by OID, the data types to be assigned to the parameter symbols. If *`paramTypes`* is `NULL`, or any particular element in the array is zero, the server assigns a data type to the parameter symbol in the same way it would do for an untyped literal string. Also, the query can use parameter symbols with numbers higher than *`nParams`*; data types will be inferred for these symbols as well. (See `PQdescribePrepared` for a means to find out what data types were inferred.)

As with `PQexec`, the result is normally a `PGresult` object whose contents indicate server-side success or failure. A null result indicates out-of-memory or inability to send the command at all. Use `PQerrorMessage` to get more information about such errors.

Prepared statements for use with `PQexecPrepared` can also be created by executing SQL PREPARE statements. Also, although there is no libpq function for deleting a prepared statement, the SQL DEALLOCATE statement can be used for that purpose.

`PQexecPrepared`

Sends a request to execute a prepared statement with given parameters, and waits for the result.

```
PGresult *PQexecPrepared(PGconn *conn,
                         const char *stmtName,
                         int nParams,
                         const char * const *paramValues,
                         const int *paramLengths,
                         const int *paramFormats,
                         int resultFormat);
```

`PQexecPrepared` is like `PQexecParams`, but the command to be executed is specified by naming a previously-prepared statement, instead of giving a query string. This feature allows commands that will be used repeatedly to be parsed and planned just once, rather than each time they are executed. The statement must have been prepared previously in the current session.

The parameters are identical to `PQexecParams`, except that the name of a prepared statement is given instead of a query string, and the *`paramTypes[]`* parameter is not present (it is not needed since the prepared statement's parameter types were determined when it was created).

PQdescribePrepared

Submits a request to obtain information about the specified prepared statement, and waits for completion.

```
PGresult *PQdescribePrepared(PGconn *conn, const char *stmtName);
```

PQdescribePrepared allows an application to obtain information about a previously prepared statement.

stmtName can be "" or NULL to reference the unnamed statement, otherwise it must be the name of an existing prepared statement. On success, a PGresult with status PGRES_COMMAND_OK is returned. The functions PQnparams and PQparamtype can be applied to this PGresult to obtain information about the parameters of the prepared statement, and the functions PQnfields, PQfname, PQftype, etc provide information about the result columns (if any) of the statement.

PQdescribePortal

Submits a request to obtain information about the specified portal, and waits for completion.

```
PGresult *PQdescribePortal(PGconn *conn, const char *portalName);
```

PQdescribePortal allows an application to obtain information about a previously created portal. (libpq does not provide any direct access to portals, but you can use this function to inspect the properties of a cursor created with a DECLARE CURSOR SQL command.)

portalName can be "" or NULL to reference the unnamed portal, otherwise it must be the name of an existing portal. On success, a PGresult with status PGRES_COMMAND_OK is returned. The functions PQnfields, PQfname, PQftype, etc can be applied to the PGresult to obtain information about the result columns (if any) of the portal.

The PGresultstructure encapsulates the result returned by the server. libpq application programmers should be careful to maintain the PGresult abstraction. Use the accessor functions below to get at the contents of PGresult. Avoid directly referencing the fields of the PGresult structure because they are subject to change in the future.

PQresultStatus

Returns the result status of the command.

```
ExecStatusType PQresultStatus(const PGresult *res);
```

PQresultStatus can return one of the following values:

PGRES_EMPTY_QUERY

The string sent to the server was empty.

PGRES_COMMAND_OK

Successful completion of a command returning no data.

PGRES_TUPLES_OK

Successful completion of a command returning data (such as a SELECT or SHOW).

PGRES_COPY_OUT

Copy Out (from server) data transfer started.

PGRES_COPY_IN

Copy In (to server) data transfer started.

PGRES_BAD_RESPONSE

The server's response was not understood.

PGRES_NONFATAL_ERROR

A nonfatal error (a notice or warning) occurred.

PGRES_FATAL_ERROR

A fatal error occurred.

PGRES_COPY_BOTH

Copy In/Out (to and from server) data transfer started. This feature is currently used only for streaming replication, so this status should not occur in ordinary applications.

PGRES_SINGLE_TUPLE

The PGresult contains a single result tuple from the current command. This status occurs only when single-row mode has been selected for the query (see Section 36.6).

PGRES_PIPELINE_SYNC

The PGresult represents a synchronization point in pipeline mode, requested by PQpipelineSync. This status occurs only when pipeline mode has been selected.

PGRES_PIPELINE_ABORTED

The PGresult represents a pipeline that has received an error from the server. PQgetResult must be called repeatedly, and each time it will return this status code until the end of the current pipeline, at which point it will return PGRES_PIPELINE_SYNC and normal processing can resume.

If the result status is PGRES_TUPLES_OK or PGRES_SINGLE_TUPLE, then the functions described below can be used to retrieve the rows returned by the query. Note that a SELECT command that happens to retrieve zero rows still shows PGRES_TUPLES_OK. PGRES_COMMAND_OK is for commands that can never return rows (INSERT or UPDATE without a RETURNING clause, etc.). A response of PGRES_EMPTY_QUERY might indicate a bug in the client software.

A result of status PGRES_NONFATAL_ERROR will never be returned directly by PQexec or other query execution functions; results of this kind are instead passed to the notice processor (see Section 36.13).

PQresStatus

Converts the enumerated type returned by PQresultStatus into a string constant describing the status code. The caller should not free the result.

```
char *PQresStatus(ExecStatusType status);
```

PQresultErrorMessage

Returns the error message associated with the command, or an empty string if there was no error.

```
char *PQresultErrorMessage(const PGresult *res);
```

If there was an error, the returned string will include a trailing newline. The caller should not free the result directly. It will be freed when the associated PGresult handle is passed to PQclear.

Immediately following a PQexec or PQgetResult call, PQerrorMessage (on the connection) will return the same string as PQresultErrorMessage (on the result). However, a PGresult will retain its error message until destroyed, whereas the connection's error message will change when subsequent operations are done. Use PQresultErrorMessage when you want to know the status associated with a particular PGresult; use PQerrorMessage when you want to know the status from the latest operation on the connection.

PQresultVerboseErrorMessage

Returns a reformatted version of the error message associated with a PGresult object.

```
char *PQresultVerboseErrorMessage(const PGresult *res,
```

```
                                    PGVerbosity verbosity,
                                    PGContextVisibility show_context);
```

In some situations a client might wish to obtain a more detailed version of a previously-reported error. PQresultVerboseErrorMessage addresses this need by computing the message that would have been produced by PQresultErrorMessage if the specified verbosity settings had been in effect for the connection when the given PGresult was generated. If the PGresult is not an error result, "PGresult is not an error result" is reported instead. The returned string includes a trailing newline.

Unlike most other functions for extracting data from a PGresult, the result of this function is a freshly allocated string. The caller must free it using PQfreemem() when the string is no longer needed.

A NULL return is possible if there is insufficient memory.

PQresultErrorField

Returns an individual field of an error report.

```
char *PQresultErrorField(const PGresult *res, int fieldcode);
```

fieldcode is an error field identifier; see the symbols listed below. NULL is returned if the PGresult is not an error or warning result, or does not include the specified field. Field values will normally not include a trailing newline. The caller should not free the result directly. It will be freed when the associated PGresult handle is passed to PQclear.

The following field codes are available:

PG_DIAG_SEVERITY

The severity; the field contents are ERROR, FATAL, or PANIC (in an error message), or WARNING, NOTICE, DEBUG, INFO, or LOG (in a notice message), or a localized translation of one of these. Always present.

PG_DIAG_SEVERITY_NONLOCALIZED

The severity; the field contents are ERROR, FATAL, or PANIC (in an error message), or WARNING, NOTICE, DEBUG, INFO, or LOG (in a notice message). This is identical to the PG_DIAG_SEVERITY field except that the contents are never localized. This is present only in reports generated by Postgres Pro versions 9.6 and later.

PG_DIAG_SQLSTATE

The SQLSTATE code for the error. The SQLSTATE code identifies the type of error that has occurred; it can be used by front-end applications to perform specific operations (such as error handling) in response to a particular database error. For a list of the possible SQLSTATE codes, see Appendix A. This field is not localizable, and is always present.

PG_DIAG_MESSAGE_PRIMARY

The primary human-readable error message (typically one line). Always present.

PG_DIAG_MESSAGE_DETAIL

Detail: an optional secondary error message carrying more detail about the problem. Might run to multiple lines.

PG_DIAG_MESSAGE_HINT

Hint: an optional suggestion what to do about the problem. This is intended to differ from detail in that it offers advice (potentially inappropriate) rather than hard facts. Might run to multiple lines.

PG_DIAG_STATEMENT_POSITION

A string containing a decimal integer indicating an error cursor position as an index into the original statement string. The first character has index 1, and positions are measured in characters not bytes.

`PG_DIAG_INTERNAL_POSITION`

This is defined the same as the `PG_DIAG_STATEMENT_POSITION` field, but it is used when the cursor position refers to an internally generated command rather than the one submitted by the client. The `PG_DIAG_INTERNAL_QUERY` field will always appear when this field appears.

`PG_DIAG_INTERNAL_QUERY`

The text of a failed internally-generated command. This could be, for example, an SQL query issued by a PL/pgSQL function.

`PG_DIAG_CONTEXT`

An indication of the context in which the error occurred. Presently this includes a call stack traceback of active procedural language functions and internally-generated queries. The trace is one entry per line, most recent first.

`PG_DIAG_SCHEMA_NAME`

If the error was associated with a specific database object, the name of the schema containing that object, if any.

`PG_DIAG_TABLE_NAME`

If the error was associated with a specific table, the name of the table. (Refer to the schema name field for the name of the table's schema.)

`PG_DIAG_COLUMN_NAME`

If the error was associated with a specific table column, the name of the column. (Refer to the schema and table name fields to identify the table.)

`PG_DIAG_DATATYPE_NAME`

If the error was associated with a specific data type, the name of the data type. (Refer to the schema name field for the name of the data type's schema.)

`PG_DIAG_CONSTRAINT_NAME`

If the error was associated with a specific constraint, the name of the constraint. Refer to fields listed above for the associated table or domain. (For this purpose, indexes are treated as constraints, even if they weren't created with constraint syntax.)

`PG_DIAG_SOURCE_FILE`

The file name of the source-code location where the error was reported.

`PG_DIAG_SOURCE_LINE`

The line number of the source-code location where the error was reported.

`PG_DIAG_SOURCE_FUNCTION`

The name of the source-code function reporting the error.

> **Note**
>
> The fields for schema name, table name, column name, data type name, and constraint name are supplied only for a limited number of error types; see Appendix A. Do not assume that the presence of any of these fields guarantees the presence of another field. Core error sources observe the interrelationships noted above, but user-defined functions may use these fields in other ways. In the same vein, do not assume that these fields denote contemporary objects in the current database.

The client is responsible for formatting displayed information to meet its needs; in particular it should break long lines as needed. Newline characters appearing in the error message fields should be treated as paragraph breaks, not line breaks.

Errors generated internally by libpq will have severity and primary message, but typically no other fields.

Note that error fields are only available from `PGresult` objects, not `PGconn` objects; there is no `PQerrorField` function.

`PQclear`

Frees the storage associated with a `PGresult`. Every command result should be freed via `PQclear` when it is no longer needed.

```
void PQclear(PGresult *res);
```

You can keep a `PGresult` object around for as long as you need it; it does not go away when you issue a new command, nor even if you close the connection. To get rid of it, you must call `PQclear`. Failure to do this will result in memory leaks in your application.

36.3.2. Retrieving Query Result Information

These functions are used to extract information from a `PGresult` object that represents a successful query result (that is, one that has status `PGRES_TUPLES_OK` or `PGRES_SINGLE_TUPLE`). They can also be used to extract information from a successful Describe operation: a Describe's result has all the same column information that actual execution of the query would provide, but it has zero rows. For objects with other status values, these functions will act as though the result has zero rows and zero columns.

`PQntuples`

Returns the number of rows (tuples) in the query result. (Note that `PGresult` objects are limited to no more than `INT_MAX` rows, so an `int` result is sufficient.)

```
int PQntuples(const PGresult *res);
```

`PQnfields`

Returns the number of columns (fields) in each row of the query result.

```
int PQnfields(const PGresult *res);
```

`PQfname`

Returns the column name associated with the given column number. Column numbers start at 0. The caller should not free the result directly. It will be freed when the associated `PGresult` handle is passed to `PQclear`.

```
char *PQfname(const PGresult *res,
              int column_number);
```

`NULL` is returned if the column number is out of range.

`PQfnumber`

Returns the column number associated with the given column name.

```
int PQfnumber(const PGresult *res,
              const char *column_name);
```

-1 is returned if the given name does not match any column.

The given name is treated like an identifier in an SQL command, that is, it is downcased unless double-quoted. For example, given a query result generated from the SQL command:

```
SELECT 1 AS FOO, 2 AS "BAR";
```

we would have the results:

```
PQfname(res, 0)              foo
PQfname(res, 1)              BAR
PQfnumber(res, "FOO")        0
PQfnumber(res, "foo")        0
PQfnumber(res, "BAR")        -1
PQfnumber(res, "\"BAR\"")    1
```

`PQftable`

Returns the OID of the table from which the given column was fetched. Column numbers start at 0.

```
Oid PQftable(const PGresult *res,
             int column_number);
```

`InvalidOid` is returned if the column number is out of range, or if the specified column is not a simple reference to a table column. You can query the system table `pg_class` to determine exactly which table is referenced.

The type `Oid` and the constant `InvalidOid` will be defined when you include the libpq header file. They will both be some integer type.

`PQftablecol`

Returns the column number (within its table) of the column making up the specified query result column. Query-result column numbers start at 0, but table columns have nonzero numbers.

```
int PQftablecol(const PGresult *res,
                int column_number);
```

Zero is returned if the column number is out of range, or if the specified column is not a simple reference to a table column.

`PQfformat`

Returns the format code indicating the format of the given column. Column numbers start at 0.

```
int PQfformat(const PGresult *res,
              int column_number);
```

Format code zero indicates textual data representation, while format code one indicates binary representation. (Other codes are reserved for future definition.)

`PQftype`

Returns the data type associated with the given column number. The integer returned is the internal OID number of the type. Column numbers start at 0.

```
Oid PQftype(const PGresult *res,
            int column_number);
```

You can query the system table `pg_type` to obtain the names and properties of the various data types.

`PQfmod`

Returns the type modifier of the column associated with the given column number. Column numbers start at 0.

```
int PQfmod(const PGresult *res,
           int column_number);
```

The interpretation of modifier values is type-specific; they typically indicate precision or size limits. The value -1 is used to indicate “no information available”. Most data types do not use modifiers, in which case the value is always -1.

`PQfsize`

Returns the size in bytes of the column associated with the given column number. Column numbers start at 0.

```
int PQfsize(const PGresult *res,
            int column_number);
```

PQfsize returns the space allocated for this column in a database row, in other words the size of the server's internal representation of the data type. (Accordingly, it is not really very useful to clients.) A negative value indicates the data type is variable-length.

PQbinaryTuples

Returns 1 if the PGresult contains binary data and 0 if it contains text data.

```
int PQbinaryTuples(const PGresult *res);
```

This function is deprecated (except for its use in connection with COPY), because it is possible for a single PGresult to contain text data in some columns and binary data in others. PQfformat is preferred. PQbinaryTuples returns 1 only if all columns of the result are binary (format 1).

PQgetvalue

Returns a single field value of one row of a PGresult. Row and column numbers start at 0. The caller should not free the result directly. It will be freed when the associated PGresult handle is passed to PQclear.

```
char *PQgetvalue(const PGresult *res,
                 int row_number,
                 int column_number);
```

For data in text format, the value returned by PQgetvalue is a null-terminated character string representation of the field value. For data in binary format, the value is in the binary representation determined by the data type's typsend and typreceive functions. (The value is actually followed by a zero byte in this case too, but that is not ordinarily useful, since the value is likely to contain embedded nulls.)

An empty string is returned if the field value is null. See PQgetisnull to distinguish null values from empty-string values.

The pointer returned by PQgetvalue points to storage that is part of the PGresult structure. One should not modify the data it points to, and one must explicitly copy the data into other storage if it is to be used past the lifetime of the PGresult structure itself.

PQgetisnull

Tests a field for a null value. Row and column numbers start at 0.

```
int PQgetisnull(const PGresult *res,
                int row_number,
                int column_number);
```

This function returns 1 if the field is null and 0 if it contains a non-null value. (Note that PQgetvalue will return an empty string, not a null pointer, for a null field.)

PQgetlength

Returns the actual length of a field value in bytes. Row and column numbers start at 0.

```
int PQgetlength(const PGresult *res,
                int row_number,
                int column_number);
```

This is the actual data length for the particular data value, that is, the size of the object pointed to by PQgetvalue. For text data format this is the same as strlen(). For binary format this is essential information. Note that one should *not* rely on PQfsize to obtain the actual data length.

PQnparams

Returns the number of parameters of a prepared statement.

```
int PQnparams(const PGresult *res);
```

This function is only useful when inspecting the result of PQdescribePrepared. For other types of queries it will return zero.

PQparamtype

Returns the data type of the indicated statement parameter. Parameter numbers start at 0.

```
Oid PQparamtype(const PGresult *res, int param_number);
```

This function is only useful when inspecting the result of PQdescribePrepared. For other types of queries it will return zero.

PQprint

Prints out all the rows and, optionally, the column names to the specified output stream.

```
void PQprint(FILE *fout,      /* output stream */
             const PGresult *res,
             const PQprintOpt *po);
typedef struct
{
    pqbool  header;      /* print output field headings and row count */
    pqbool  align;       /* fill align the fields */
    pqbool  standard;    /* old brain dead format */
    pqbool  html3;       /* output HTML tables */
    pqbool  expanded;    /* expand tables */
    pqbool  pager;       /* use pager for output if needed */
    char    *fieldSep;   /* field separator */
    char    *tableOpt;   /* attributes for HTML table element */
    char    *caption;    /* HTML table caption */
    char    **fieldName; /* null-terminated array of replacement field names */
} PQprintOpt;
```

This function was formerly used by psql to print query results, but this is no longer the case. Note that it assumes all the data is in text format.

36.3.3. Retrieving Other Result Information

These functions are used to extract other information from PGresult objects.

PQcmdStatus

Returns the command status tag from the SQL command that generated the PGresult.

```
char *PQcmdStatus(PGresult *res);
```

Commonly this is just the name of the command, but it might include additional data such as the number of rows processed. The caller should not free the result directly. It will be freed when the associated PGresult handle is passed to PQclear.

PQcmdTuples

Returns the number of rows affected by the SQL command.

```
char *PQcmdTuples(PGresult *res);
```

This function returns a string containing the number of rows affected by the SQL statement that generated the PGresult. This function can only be used following the execution of a SELECT, CREATE TABLE AS, INSERT, UPDATE, DELETE, MOVE, FETCH, or COPY statement, or an EXECUTE of a prepared query that contains an INSERT, UPDATE, or DELETE statement. If the command that generated the PGresult was anything else, PQcmdTuples returns an empty string. The caller should not free the return value directly. It will be freed when the associated PGresult handle is passed to PQclear.

PQoidValue

Returns the OID of the inserted row, if the SQL command was an INSERT that inserted exactly one row into a table that has OIDs, or a EXECUTE of a prepared query containing a suitable INSERT statement. Otherwise, this function returns InvalidOid. This function will also return InvalidOid if the table affected by the INSERT statement does not contain OIDs.

```
Oid PQoidValue(const PGresult *res);
```

PQoidStatus

This function is deprecated in favor of PQoidValue and is not thread-safe. It returns a string with the OID of the inserted row, while PQoidValue returns the OID value.

```
char *PQoidStatus(const PGresult *res);
```

36.3.4. Escaping Strings for Inclusion in SQL Commands

PQescapeLiteral

```
char *PQescapeLiteral(PGconn *conn, const char *str, size_t length);
```

PQescapeLiteral escapes a string for use within an SQL command. This is useful when inserting data values as literal constants in SQL commands. Certain characters (such as quotes and backslashes) must be escaped to prevent them from being interpreted specially by the SQL parser. PQescapeLiteral performs this operation.

PQescapeLiteral returns an escaped version of the *str* parameter in memory allocated with malloc(). This memory should be freed using PQfreemem() when the result is no longer needed. A terminating zero byte is not required, and should not be counted in *length*. (If a terminating zero byte is found before *length* bytes are processed, PQescapeLiteral stops at the zero; the behavior is thus rather like strncpy.) The return string has all special characters replaced so that they can be properly processed by the Postgres Pro string literal parser. A terminating zero byte is also added. The single quotes that must surround Postgres Pro string literals are included in the result string.

On error, PQescapeLiteral returns NULL and a suitable message is stored in the *conn* object.

> **Tip**
>
> It is especially important to do proper escaping when handling strings that were received from an untrustworthy source. Otherwise there is a security risk: you are vulnerable to “SQL injection” attacks wherein unwanted SQL commands are fed to your database.

Note that it is neither necessary nor correct to do escaping when a data value is passed as a separate parameter in PQexecParams or its sibling routines.

PQescapeIdentifier

```
char *PQescapeIdentifier(PGconn *conn, const char *str, size_t length);
```

PQescapeIdentifier escapes a string for use as an SQL identifier, such as a table, column, or function name. This is useful when a user-supplied identifier might contain special characters that would otherwise not be interpreted as part of the identifier by the SQL parser, or when the identifier might contain upper case characters whose case should be preserved.

PQescapeIdentifier returns a version of the *str* parameter escaped as an SQL identifier in memory allocated with malloc(). This memory must be freed using PQfreemem() when the result is no longer needed. A terminating zero byte is not required, and should not be counted in *length*. (If a terminating zero byte is found before *length* bytes are processed, PQescapeIdentifier stops at the zero; the behavior is thus rather like strncpy.) The return string has all special characters replaced so that it will be properly processed as an SQL identifier. A terminating zero byte is also added. The return string will also be surrounded by double quotes.

On error, PQescapeIdentifier returns NULL and a suitable message is stored in the *conn* object.

> **Tip**
>
> As with string literals, to prevent SQL injection attacks, SQL identifiers must be escaped when they are received from an untrustworthy source.

PQescapeStringConn

```
size_t PQescapeStringConn(PGconn *conn,
                          char *to, const char *from, size_t length,
                          int *error);
```

PQescapeStringConn escapes string literals, much like PQescapeLiteral. Unlike PQescapeLiteral, the caller is responsible for providing an appropriately sized buffer. Furthermore, PQescapeStringConn does not generate the single quotes that must surround Postgres Pro string literals; they should be provided in the SQL command that the result is inserted into. The parameter *from* points to the first character of the string that is to be escaped, and the *length* parameter gives the number of bytes in this string. A terminating zero byte is not required, and should not be counted in *length*. (If a terminating zero byte is found before *length* bytes are processed, PQescapeStringConn stops at the zero; the behavior is thus rather like strncpy.) *to* shall point to a buffer that is able to hold at least one more byte than twice the value of *length*, otherwise the behavior is undefined. Behavior is likewise undefined if the *to* and *from* strings overlap.

If the *error* parameter is not NULL, then *error is set to zero on success, nonzero on error. Presently the only possible error conditions involve invalid multibyte encoding in the source string. The output string is still generated on error, but it can be expected that the server will reject it as malformed. On error, a suitable message is stored in the *conn* object, whether or not *error* is NULL.

PQescapeStringConn returns the number of bytes written to *to*, not including the terminating zero byte.

PQescapeString

PQescapeString is an older, deprecated version of PQescapeStringConn.

```
size_t PQescapeString (char *to, const char *from, size_t length);
```

The only difference from PQescapeStringConn is that PQescapeString does not take PGconn or *error* parameters. Because of this, it cannot adjust its behavior depending on the connection properties (such as character encoding) and therefore *it might give the wrong results*. Also, it has no way to report error conditions.

PQescapeString can be used safely in client programs that work with only one Postgres Pro connection at a time (in this case it can find out what it needs to know “behind the scenes”). In other contexts it is a security hazard and should be avoided in favor of PQescapeStringConn.

PQescapeByteaConn

Escapes binary data for use within an SQL command with the type bytea. As with PQescapeStringConn, this is only used when inserting data directly into an SQL command string.

```
unsigned char *PQescapeByteaConn(PGconn *conn,
                                 const unsigned char *from,
                                 size_t from_length,
                                 size_t *to_length);
```

Certain byte values must be escaped when used as part of a bytea literal in an SQL statement. PQescapeByteaConn escapes bytes using either hex encoding or backslash escaping. See Section 8.4 for more information.

The *from* parameter points to the first byte of the string that is to be escaped, and the *from_length* parameter gives the number of bytes in this binary string. (A terminating zero byte is neither necessary nor counted.) The *to_length* parameter points to a variable that will hold the resultant escaped string length. This result string length includes the terminating zero byte of the result.

PQescapeByteaConn returns an escaped version of the *from* parameter binary string in memory allocated with malloc(). This memory should be freed using PQfreemem() when the result is no longer needed. The return string has all special characters replaced so that they can be properly processed by the Postgres Pro string literal parser, and the bytea input function. A terminating zero byte is also added. The single quotes that must surround Postgres Pro string literals are not part of the result string.

On error, a null pointer is returned, and a suitable error message is stored in the *conn* object. Currently, the only possible error is insufficient memory for the result string.

PQescapeBytea

PQescapeBytea is an older, deprecated version of PQescapeByteaConn.

```
unsigned char *PQescapeBytea(const unsigned char *from,
                             size_t from_length,
                             size_t *to_length);
```

The only difference from PQescapeByteaConn is that PQescapeBytea does not take a PGconn parameter. Because of this, PQescapeBytea can only be used safely in client programs that use a single Postgres Pro connection at a time (in this case it can find out what it needs to know “behind the scenes”). It *might give the wrong results* if used in programs that use multiple database connections (use PQescapeByteaConn in such cases).

PQunescapeBytea

Converts a string representation of binary data into binary data — the reverse of PQescapeBytea. This is needed when retrieving bytea data in text format, but not when retrieving it in binary format.

```
unsigned char *PQunescapeBytea(const unsigned char *from, size_t *to_length);
```

The *from* parameter points to a string such as might be returned by PQgetvalue when applied to a bytea column. PQunescapeBytea converts this string representation into its binary representation. It returns a pointer to a buffer allocated with malloc(), or NULL on error, and puts the size of the buffer in *to_length*. The result must be freed using PQfreemem when it is no longer needed.

This conversion is not exactly the inverse of PQescapeBytea, because the string is not expected to be “escaped” when received from PQgetvalue. In particular this means there is no need for string quoting considerations, and so no need for a PGconn parameter.

36.4. Asynchronous Command Processing

The PQexec function is adequate for submitting commands in normal, synchronous applications. It has a few deficiencies, however, that can be of importance to some users:

- PQexec waits for the command to be completed. The application might have other work to do (such as maintaining a user interface), in which case it won't want to block waiting for the response.
- Since the execution of the client application is suspended while it waits for the result, it is hard for the application to decide that it would like to try to cancel the ongoing command. (It can be done from a signal handler, but not otherwise.)
- PQexec can return only one PGresult structure. If the submitted command string contains multiple SQL commands, all but the last PGresult are discarded by PQexec.
- PQexec always collects the command's entire result, buffering it in a single PGresult. While this simplifies error-handling logic for the application, it can be impractical for results containing many rows.

Applications that do not like these limitations can instead use the underlying functions that PQexec is built from: PQsendQuery and PQgetResult. There are also PQsendQueryParams, PQsendPrepare, PQsendQueryPrepared, PQsendDescribePrepared, and PQsendDescribePortal, which can be used with PQgetResult to duplicate the functionality of PQexecParams, PQprepare, PQexecPrepared, PQdescribePrepared, and PQdescribePortal respectively.

PQsendQuery

Submits a command to the server without waiting for the result(s). 1 is returned if the command was successfully dispatched and 0 if not (in which case, use PQerrorMessage to get more information about the failure).

```
int PQsendQuery(PGconn *conn, const char *command);
```

After successfully calling PQsendQuery, call PQgetResult one or more times to obtain the results. PQsendQuery cannot be called again (on the same connection) until PQgetResult has returned a null pointer, indicating that the command is done.

In pipeline mode, command strings containing more than one SQL command are disallowed.

PQsendQueryParams

Submits a command and separate parameters to the server without waiting for the result(s).

```
int PQsendQueryParams(PGconn *conn,
                      const char *command,
                      int nParams,
                      const Oid *paramTypes,
                      const char * const *paramValues,
                      const int *paramLengths,
                      const int *paramFormats,
                      int resultFormat);
```

This is equivalent to PQsendQuery except that query parameters can be specified separately from the query string. The function's parameters are handled identically to PQexecParams. Like PQexecParams, it allows only one command in the query string.

PQsendPrepare

Sends a request to create a prepared statement with the given parameters, without waiting for completion.

```
int PQsendPrepare(PGconn *conn,
                  const char *stmtName,
                  const char *query,
                  int nParams,
                  const Oid *paramTypes);
```

This is an asynchronous version of PQprepare: it returns 1 if it was able to dispatch the request, and 0 if not. After a successful call, call PQgetResult to determine whether the server successfully created the prepared statement. The function's parameters are handled identically to PQprepare.

PQsendQueryPrepared

Sends a request to execute a prepared statement with given parameters, without waiting for the result(s).

```
int PQsendQueryPrepared(PGconn *conn,
                        const char *stmtName,
                        int nParams,
                        const char * const *paramValues,
                        const int *paramLengths,
                        const int *paramFormats,
                        int resultFormat);
```

This is similar to PQsendQueryParams, but the command to be executed is specified by naming a previously-prepared statement, instead of giving a query string. The function's parameters are handled identically to PQexecPrepared.

PQsendDescribePrepared

Submits a request to obtain information about the specified prepared statement, without waiting for completion.

```
int PQsendDescribePrepared(PGconn *conn, const char *stmtName);
```

This is an asynchronous version of PQdescribePrepared: it returns 1 if it was able to dispatch the request, and 0 if not. After a successful call, call PQgetResult to obtain the results. The function's parameters are handled identically to PQdescribePrepared.

PQsendDescribePortal

Submits a request to obtain information about the specified portal, without waiting for completion.

```
int PQsendDescribePortal(PGconn *conn, const char *portalName);
```

This is an asynchronous version of PQdescribePortal: it returns 1 if it was able to dispatch the request, and 0 if not. After a successful call, call PQgetResult to obtain the results. The function's parameters are handled identically to PQdescribePortal.

PQgetResult

Waits for the next result from a prior PQsendQuery, PQsendQueryParams, PQsendPrepare, PQsendQueryPrepared, PQsendDescribePrepared, PQsendDescribePortal, or PQpipelineSync call, and returns it. A null pointer is returned when the command is complete and there will be no more results.

```
PGresult *PQgetResult(PGconn *conn);
```

PQgetResult must be called repeatedly until it returns a null pointer, indicating that the command is done. (If called when no command is active, PQgetResult will just return a null pointer at once.) Each non-null result from PQgetResult should be processed using the same PGresult accessor functions previously described. Don't forget to free each result object with PQclear when done with it. Note that PQgetResult will block only if a command is active and the necessary response data has not yet been read by PQconsumeInput .

In pipeline mode, PQgetResult will return normally unless an error occurs; for any subsequent query sent after the one that caused the error until (and excluding) the next synchronization point, a special result of type PGRES_PIPELINE_ABORTED will be returned, and a null pointer will be returned after it. When the pipeline synchronization point is reached, a result of type PGRES_PIPELINE_SYNC will be returned. The result of the next query after the synchronization point follows immediately (that is, no null pointer is returned after the synchronization point).

> **Note**
>
> Even when PQresultStatus indicates a fatal error, PQgetResult should be called until it returns a null pointer, to allow libpq to process the error information completely.

Using PQsendQuery and PQgetResult solves one of PQexec's problems: If a command string contains multiple SQL commands, the results of those commands can be obtained individually. (This allows a simple form of overlapped processing, by the way: the client can be handling the results of one command while the server is still working on later queries in the same command string.)

Another frequently-desired feature that can be obtained with PQsendQuery and PQgetResult is retrieving large query results a row at a time. This is discussed in Section 36.6.

By itself, calling PQgetResult will still cause the client to block until the server completes the next SQL command. This can be avoided by proper use of two more functions:

`PQconsumeInput`

If input is available from the server, consume it.

```
int PQconsumeInput(PGconn *conn);
```

`PQconsumeInput` normally returns 1 indicating "no error", but returns 0 if there was some kind of trouble (in which case `PQerrorMessage` can be consulted). Note that the result does not say whether any input data was actually collected. After calling `PQconsumeInput`, the application can check `PQisBusy` and/or `PQnotifies` to see if their state has changed.

`PQconsumeInput` can be called even if the application is not prepared to deal with a result or notification just yet. The function will read available data and save it in a buffer, thereby causing a `select()` read-ready indication to go away. The application can thus use `PQconsumeInput` to clear the `select()` condition immediately, and then examine the results at leisure.

`PQisBusy`

Returns 1 if a command is busy, that is, `PQgetResult` would block waiting for input. A 0 return indicates that `PQgetResult` can be called with assurance of not blocking.

```
int PQisBusy(PGconn *conn);
```

`PQisBusy` will not itself attempt to read data from the server; therefore `PQconsumeInput` must be invoked first, or the busy state will never end.

A typical application using these functions will have a main loop that uses `select()` or `poll()` to wait for all the conditions that it must respond to. One of the conditions will be input available from the server, which in terms of `select()` means readable data on the file descriptor identified by `PQsocket`. When the main loop detects input ready, it should call `PQconsumeInput` to read the input. It can then call `PQisBusy`, followed by `PQgetResult` if `PQisBusy` returns false (0). It can also call `PQnotifies` to detect `NOTIFY` messages (see Section 36.9).

A client that uses `PQsendQuery`/`PQgetResult` can also attempt to cancel a command that is still being processed by the server; see Section 36.7. But regardless of the return value of `PQcancel`, the application must continue with the normal result-reading sequence using `PQgetResult`. A successful cancellation will simply cause the command to terminate sooner than it would have otherwise.

By using the functions described above, it is possible to avoid blocking while waiting for input from the database server. However, it is still possible that the application will block waiting to send output to the server. This is relatively uncommon but can happen if very long SQL commands or data values are sent. (It is much more probable if the application sends data via `COPY IN`, however.) To prevent this possibility and achieve completely nonblocking database operation, the following additional functions can be used.

`PQsetnonblocking`

Sets the nonblocking status of the connection.

```
int PQsetnonblocking(PGconn *conn, int arg);
```

Sets the state of the connection to nonblocking if *`arg`* is 1, or blocking if *`arg`* is 0. Returns 0 if OK, -1 if error.

In the nonblocking state, successful calls to `PQsendQuery`, `PQputline`, `PQputnbytes`, `PQputCopyData`, and `PQendcopy` will not block; their changes are stored in the local output buffer until they are flushed. Unsuccessful calls will return an error and must be retried.

Note that `PQexec` does not honor nonblocking mode; if it is called, it will act in blocking fashion anyway.

`PQisnonblocking`

Returns the blocking status of the database connection.

```
int PQisnonblocking(const PGconn *conn);
```

Returns 1 if the connection is set to nonblocking mode and 0 if blocking.

`PQflush`

Attempts to flush any queued output data to the server. Returns 0 if successful (or if the send queue is empty), -1 if it failed for some reason, or 1 if it was unable to send all the data in the send queue yet (this case can only occur if the connection is nonblocking).

```
int PQflush(PGconn *conn);
```

After sending any command or data on a nonblocking connection, call `PQflush`. If it returns 1, wait for the socket to become read- or write-ready. If it becomes write-ready, call `PQflush` again. If it becomes read-ready, call `PQconsumeInput` , then call `PQflush` again. Repeat until `PQflush` returns 0. (It is necessary to check for read-ready and drain the input with `PQconsumeInput` , because the server can block trying to send us data, e.g., NOTICE messages, and won't read our data until we read its.) Once `PQflush` returns 0, wait for the socket to be read-ready and then read the response as described above.

36.5. Pipeline Mode

libpq pipeline mode allows applications to send a query without having to read the result of the previously sent query. Taking advantage of the pipeline mode, a client will wait less for the server, since multiple queries/results can be sent/received in a single network transaction.

While pipeline mode provides a significant performance boost, writing clients using the pipeline mode is more complex because it involves managing a queue of pending queries and finding which result corresponds to which query in the queue.

Pipeline mode also generally consumes more memory on both the client and server, though careful and aggressive management of the send/receive queue can mitigate this. This applies whether or not the connection is in blocking or non-blocking mode.

While libpq's pipeline API was introduced in PostgreSQL 14, it is a client-side feature which doesn't require special server support and works on any server that supports the v3 extended query protocol. For more information see Section 55.2.4.

36.5.1. Using Pipeline Mode

To issue pipelines, the application must switch the connection into pipeline mode, which is done with `PQenterPipelineMode`. `PQpipelineStatus` can be used to test whether pipeline mode is active. In pipeline mode, only asynchronous operations are permitted, command strings containing multiple SQL commands are disallowed, and so is `COPY`. Using synchronous command execution functions such as `PQfn`, `PQexec`, `PQexecParams`, `PQprepare`, `PQexecPrepared`, `PQdescribePrepared`, `PQdescribePortal`, is an error condition. Once all dispatched commands have had their results processed, and the end pipeline result has been consumed, the application may return to non-pipelined mode with `PQexitPipelineMode`.

> **Note**
>
> It is best to use pipeline mode with libpq in non-blocking mode. If used in blocking mode it is possible for a client/server deadlock to occur. [1]

36.5.1.1. Issuing Queries

After entering pipeline mode, the application dispatches requests using `PQsendQuery`, `PQsendQueryParams`, or its prepared-query sibling `PQsendQueryPrepared`. These requests are queued on the client-

[1] The client will block trying to send queries to the server, but the server will block trying to send results to the client from queries it has already processed. This only occurs when the client sends enough queries to fill both its output buffer and the server's receive buffer before it switches to processing input from the server, but it's hard to predict exactly when that will happen.

side until flushed to the server; this occurs when PQpipelineSync is used to establish a synchronization point in the pipeline, or when PQflush is called. The functions PQsendPrepare, PQsendDescribePrepared, and PQsendDescribePortal also work in pipeline mode. Result processing is described below.

The server executes statements, and returns results, in the order the client sends them. The server will begin executing the commands in the pipeline immediately, not waiting for the end of the pipeline. Note that results are buffered on the server side; the server flushes that buffer when a synchronization point is established with PQpipelineSync, or when PQsendFlushRequest is called. If any statement encounters an error, the server aborts the current transaction and does not execute any subsequent command in the queue until the next synchronization point; a PGRES_PIPELINE_ABORTED result is produced for each such command. (This remains true even if the commands in the pipeline would rollback the transaction.) Query processing resumes after the synchronization point.

It's fine for one operation to depend on the results of a prior one; for example, one query may define a table that the next query in the same pipeline uses. Similarly, an application may create a named prepared statement and execute it with later statements in the same pipeline.

36.5.1.2. Processing Results

To process the result of one query in a pipeline, the application calls PQgetResult repeatedly and handles each result until PQgetResult returns null. The result from the next query in the pipeline may then be retrieved using PQgetResult again and the cycle repeated. The application handles individual statement results as normal. When the results of all the queries in the pipeline have been returned, PQgetResult returns a result containing the status value PGRES_PIPELINE_SYNC

The client may choose to defer result processing until the complete pipeline has been sent, or interleave that with sending further queries in the pipeline; see Section 36.5.1.4.

To enter single-row mode, call PQsetSingleRowMode before retrieving results with PQgetResult. This mode selection is effective only for the query currently being processed. For more information on the use of PQsetSingleRowMode, refer to Section 36.6.

PQgetResult behaves the same as for normal asynchronous processing except that it may contain the new PGresult types PGRES_PIPELINE_SYNC and PGRES_PIPELINE_ABORTED. PGRES_PIPELINE_SYNC is reported exactly once for each PQpipelineSync at the corresponding point in the pipeline. PGRES_PIPELINE_ABORTED is emitted in place of a normal query result for the first error and all subsequent results until the next PGRES_PIPELINE_SYNC; see Section 36.5.1.3.

PQisBusy, PQconsumeInput, etc operate as normal when processing pipeline results. In particular, a call to PQisBusy in the middle of a pipeline returns 0 if the results for all the queries issued so far have been consumed.

libpq does not provide any information to the application about the query currently being processed (except that PQgetResult returns null to indicate that we start returning the results of next query). The application must keep track of the order in which it sent queries, to associate them with their corresponding results. Applications will typically use a state machine or a FIFO queue for this.

36.5.1.3. Error Handling

From the client's perspective, after PQresultStatus returns PGRES_FATAL_ERROR, the pipeline is flagged as aborted. PQresultStatus will report a PGRES_PIPELINE_ABORTED result for each remaining queued operation in an aborted pipeline. The result for PQpipelineSync is reported as PGRES_PIPELINE_SYNC to signal the end of the aborted pipeline and resumption of normal result processing.

The client *must* process results with PQgetResult during error recovery.

If the pipeline used an implicit transaction, then operations that have already executed are rolled back and operations that were queued to follow the failed operation are skipped entirely. The same behavior holds if the pipeline starts and commits a single explicit transaction (i.e. the first statement is BEGIN

and the last is COMMIT) except that the session remains in an aborted transaction state at the end of the pipeline. If a pipeline contains *multiple explicit transactions*, all transactions that committed prior to the error remain committed, the currently in-progress transaction is aborted, and all subsequent operations are skipped completely, including subsequent transactions. If a pipeline synchronization point occurs with an explicit transaction block in aborted state, the next pipeline will become aborted immediately unless the next command puts the transaction in normal mode with ROLLBACK.

> **Note**
>
> The client must not assume that work is committed when it *sends* a COMMIT — only when the corresponding result is received to confirm the commit is complete. Because errors arrive asynchronously, the application needs to be able to restart from the last *received* committed change and resend work done after that point if something goes wrong.

36.5.1.4. Interleaving Result Processing and Query Dispatch

To avoid deadlocks on large pipelines the client should be structured around a non-blocking event loop using operating system facilities such as select, poll, WaitForMultipleObjectEx, etc.

The client application should generally maintain a queue of work remaining to be dispatched and a queue of work that has been dispatched but not yet had its results processed. When the socket is writable it should dispatch more work. When the socket is readable it should read results and process them, matching them up to the next entry in its corresponding results queue. Based on available memory, results from the socket should be read frequently: there's no need to wait until the pipeline end to read the results. Pipelines should be scoped to logical units of work, usually (but not necessarily) one transaction per pipeline. There's no need to exit pipeline mode and re-enter it between pipelines, or to wait for one pipeline to finish before sending the next.

36.5.2. Functions Associated with Pipeline Mode

`PQpipelineStatus`

Returns the current pipeline mode status of the libpq connection.

```
PGpipelineStatus PQpipelineStatus(const PGconn *conn);
```

`PQpipelineStatus` can return one of the following values:

`PQ_PIPELINE_ON`

The libpq connection is in pipeline mode.

`PQ_PIPELINE_OFF`

The libpq connection is *not* in pipeline mode.

`PQ_PIPELINE_ABORTED`

The libpq connection is in pipeline mode and an error occurred while processing the current pipeline. The aborted flag is cleared when `PQgetResult` returns a result of type `PGRES_PIPELINE_SYNC`.

`PQenterPipelineMode`

Causes a connection to enter pipeline mode if it is currently idle or already in pipeline mode.

```
int PQenterPipelineMode(PGconn *conn);
```

Returns 1 for success. Returns 0 and has no effect if the connection is not currently idle, i.e., it has a result ready, or it is waiting for more input from the server, etc. This function does not actually send anything to the server, it just changes the libpq connection state.

`PQexitPipelineMode`

Causes a connection to exit pipeline mode if it is currently in pipeline mode with an empty queue and no pending results.

```
int PQexitPipelineMode(PGconn *conn);
```

Returns 1 for success. Returns 1 and takes no action if not in pipeline mode. If the current statement isn't finished processing, or `PQgetResult` has not been called to collect results from all previously sent query, returns 0 (in which case, use `PQerrorMessage` to get more information about the failure).

`PQpipelineSync`

Marks a synchronization point in a pipeline by sending a sync message and flushing the send buffer. This serves as the delimiter of an implicit transaction and an error recovery point; see Section 36.5.1.3.

```
int PQpipelineSync(PGconn *conn);
```

Returns 1 for success. Returns 0 if the connection is not in pipeline mode or sending a sync message failed.

`PQsendFlushRequest`

Sends a request for the server to flush its output buffer.

```
int PQsendFlushRequest(PGconn *conn);
```

Returns 1 for success. Returns 0 on any failure.

The server flushes its output buffer automatically as a result of `PQpipelineSync` being called, or on any request when not in pipeline mode; this function is useful to cause the server to flush its output buffer in pipeline mode without establishing a synchronization point. Note that the request is not itself flushed to the server automatically; use `PQflush` if necessary.

36.5.3. When to Use Pipeline Mode

Much like asynchronous query mode, there is no meaningful performance overhead when using pipeline mode. It increases client application complexity, and extra caution is required to prevent client/server deadlocks, but pipeline mode can offer considerable performance improvements, in exchange for increased memory usage from leaving state around longer.

Pipeline mode is most useful when the server is distant, i.e., network latency (“ping time”) is high, and also when many small operations are being performed in rapid succession. There is usually less benefit in using pipelined commands when each query takes many multiples of the client/server round-trip time to execute. A 100-statement operation run on a server 300 ms round-trip-time away would take 30 seconds in network latency alone without pipelining; with pipelining it may spend as little as 0.3 s waiting for results from the server.

Use pipelined commands when your application does lots of small `INSERT`, `UPDATE` and `DELETE` operations that can't easily be transformed into operations on sets, or into a `COPY` operation.

Pipeline mode is not useful when information from one operation is required by the client to produce the next operation. In such cases, the client would have to introduce a synchronization point and wait for a full client/server round-trip to get the results it needs. However, it's often possible to adjust the client design to exchange the required information server-side. Read-modify-write cycles are especially good candidates; for example:

```
BEGIN;
SELECT x FROM mytable WHERE id = 42 FOR UPDATE;
-- result: x=2
-- client adds 1 to x:
UPDATE mytable SET x = 3 WHERE id = 42;
```

```
COMMIT;
```

could be much more efficiently done with:

```
UPDATE mytable SET x = x + 1 WHERE id = 42;
```

Pipelining is less useful, and more complex, when a single pipeline contains multiple transactions (see Section 36.5.1.3).

36.6. Retrieving Query Results Row-by-Row

Ordinarily, libpq collects an SQL command's entire result and returns it to the application as a single `PGresult`. This can be unworkable for commands that return a large number of rows. For such cases, applications can use `PQsendQuery` and `PQgetResult` in *single-row mode*. In this mode, the result row(s) are returned to the application one at a time, as they are received from the server.

To enter single-row mode, call `PQsetSingleRowMode` immediately after a successful call of `PQsendQuery` (or a sibling function). This mode selection is effective only for the currently executing query. Then call `PQgetResult` repeatedly, until it returns null, as documented in Section 36.4. If the query returns any rows, they are returned as individual `PGresult` objects, which look like normal query results except for having status code `PGRES_SINGLE_TUPLE` instead of `PGRES_TUPLES_OK`. After the last row, or immediately if the query returns zero rows, a zero-row object with status `PGRES_TUPLES_OK` is returned; this is the signal that no more rows will arrive. (But note that it is still necessary to continue calling `PQgetResult` until it returns null.) All of these `PGresult` objects will contain the same row description data (column names, types, etc) that an ordinary `PGresult` object for the query would have. Each object should be freed with `PQclear` as usual.

When using pipeline mode, single-row mode needs to be activated for each query in the pipeline before retrieving results for that query with `PQgetResult`. See Section 36.5 for more information.

`PQsetSingleRowMode`

Select single-row mode for the currently-executing query.

```
int PQsetSingleRowMode(PGconn *conn);
```

This function can only be called immediately after `PQsendQuery` or one of its sibling functions, before any other operation on the connection such as `PQconsumeInput` or `PQgetResult`. If called at the correct time, the function activates single-row mode for the current query and returns 1. Otherwise the mode stays unchanged and the function returns 0. In any case, the mode reverts to normal after completion of the current query.

Caution

While processing a query, the server may return some rows and then encounter an error, causing the query to be aborted. Ordinarily, libpq discards any such rows and reports only the error. But in single-row mode, those rows will have already been returned to the application. Hence, the application will see some `PGRES_SINGLE_TUPLE` `PGresult` objects followed by a `PGRES_FATAL_ERROR` object. For proper transactional behavior, the application must be designed to discard or undo whatever has been done with the previously-processed rows, if the query ultimately fails.

36.7. Canceling Queries in Progress

A client application can request cancellation of a command that is still being processed by the server, using the functions described in this section.

`PQgetCancel`

Creates a data structure containing the information needed to cancel a command issued through a particular database connection.

```
PGcancel *PQgetCancel(PGconn *conn);
```

PQgetCancel creates a PGcancelobject given a PGconn connection object. It will return NULL if the given *conn* is NULL or an invalid connection. The PGcancel object is an opaque structure that is not meant to be accessed directly by the application; it can only be passed to PQcancel or PQfreeCancel.

PQfreeCancel

Frees a data structure created by PQgetCancel.

```
void PQfreeCancel(PGcancel *cancel);
```

PQfreeCancel frees a data object previously created by PQgetCancel.

PQcancel

Requests that the server abandon processing of the current command.

```
int PQcancel(PGcancel *cancel, char *errbuf, int errbufsize);
```

The return value is 1 if the cancel request was successfully dispatched and 0 if not. If not, *errbuf* is filled with an explanatory error message. *errbuf* must be a char array of size *errbufsize* (the recommended size is 256 bytes).

Successful dispatch is no guarantee that the request will have any effect, however. If the cancellation is effective, the current command will terminate early and return an error result. If the cancellation fails (say, because the server was already done processing the command), then there will be no visible result at all.

PQcancel can safely be invoked from a signal handler, if the *errbuf* is a local variable in the signal handler. The PGcancel object is read-only as far as PQcancel is concerned, so it can also be invoked from a thread that is separate from the one manipulating the PGconn object.

PQrequestCancel

PQrequestCancel is a deprecated variant of PQcancel.

```
int PQrequestCancel(PGconn *conn);
```

Requests that the server abandon processing of the current command. It operates directly on the PGconn object, and in case of failure stores the error message in the PGconn object (whence it can be retrieved by PQerrorMessage). Although the functionality is the same, this approach creates hazards for multiple-thread programs and signal handlers, since it is possible that overwriting the PGconn's error message will mess up the operation currently in progress on the connection.

36.8. The Fast-Path Interface

Postgres Pro provides a fast-path interface to send simple function calls to the server.

> **Tip**
>
> This interface is somewhat obsolete, as one can achieve similar performance and greater functionality by setting up a prepared statement to define the function call. Then, executing the statement with binary transmission of parameters and results substitutes for a fast-path function call.

The function PQfnrequests execution of a server function via the fast-path interface:

```
PGresult *PQfn(PGconn *conn,
               int fnid,
               int *result_buf,
               int *result_len,
```

```
                int result_is_int,
                const PQArgBlock *args,
                int nargs);

typedef struct
{
    int len;
    int isint;
    union
    {
        int *ptr;
        int integer;
    } u;
} PQArgBlock;
```

The *fnid* argument is the OID of the function to be executed. *args* and *nargs* define the parameters to be passed to the function; they must match the declared function argument list. When the *isint* field of a parameter structure is true, the *u.integer* value is sent to the server as an integer of the indicated length (this must be 2 or 4 bytes); proper byte-swapping occurs. When *isint* is false, the indicated number of bytes at **u.ptr* are sent with no processing; the data must be in the format expected by the server for binary transmission of the function's argument data type. (The declaration of *u.ptr* as being of type `int *` is historical; it would be better to consider it `void *`.) *result_buf* points to the buffer in which to place the function's return value. The caller must have allocated sufficient space to store the return value. (There is no check!) The actual result length in bytes will be returned in the integer pointed to by *result_len*. If a 2- or 4-byte integer result is expected, set *result_is_int* to 1, otherwise set it to 0. Setting *result_is_int* to 1 causes libpq to byte-swap the value if necessary, so that it is delivered as a proper `int` value for the client machine; note that a 4-byte integer is delivered into **result_buf* for either allowed result size. When *result_is_int* is 0, the binary-format byte string sent by the server is returned unmodified. (In this case it's better to consider *result_buf* as being of type `void *`.)

`PQfn` always returns a valid `PGresult` pointer, with status `PGRES_COMMAND_OK` for success or `PGRES_FATAL_ERROR` if some problem was encountered. The result status should be checked before the result is used. The caller is responsible for freeing the `PGresult` with `PQclear` when it is no longer needed.

To pass a NULL argument to the function, set the *len* field of that parameter structure to `-1`; the *isint* and *u* fields are then irrelevant.

If the function returns NULL, **result_len* is set to `-1`, and **result_buf* is not modified.

Note that it is not possible to handle set-valued results when using this interface. Also, the function must be a plain function, not an aggregate, window function, or procedure.

36.9. Asynchronous Notification

Postgres Pro offers asynchronous notification via the `LISTEN` and `NOTIFY` commands. A client session registers its interest in a particular notification channel with the `LISTEN` command (and can stop listening with the `UNLISTEN` command). All sessions listening on a particular channel will be notified asynchronously when a `NOTIFY` command with that channel name is executed by any session. A “payload” string can be passed to communicate additional data to the listeners.

libpq applications submit `LISTEN`, `UNLISTEN`, and `NOTIFY` commands as ordinary SQL commands. The arrival of `NOTIFY` messages can subsequently be detected by calling `PQnotifies`.

The function `PQnotifies` returns the next notification from a list of unhandled notification messages received from the server. It returns a null pointer if there are no pending notifications. Once a notification is returned from `PQnotifies`, it is considered handled and will be removed from the list of notifications.

```
PGnotify *PQnotifies(PGconn *conn);
```

```
typedef struct pgNotify
{
    char *relname;              /* notification channel name */
    int  be_pid;                /* process ID of notifying server process */
    char *extra;                /* notification payload string */
} PGnotify;
```

After processing a PGnotify object returned by PQnotifies, be sure to free it with PQfreemem. It is sufficient to free the PGnotify pointer; the relname and extra fields do not represent separate allocations. (The names of these fields are historical; in particular, channel names need not have anything to do with relation names.)

Example 36.2 gives a sample program that illustrates the use of asynchronous notification.

PQnotifies does not actually read data from the server; it just returns messages previously absorbed by another libpq function. In ancient releases of libpq, the only way to ensure timely receipt of NOTIFY messages was to constantly submit commands, even empty ones, and then check PQnotifies after each PQexec. While this still works, it is deprecated as a waste of processing power.

A better way to check for NOTIFY messages when you have no useful commands to execute is to call PQconsumeInput , then check PQnotifies. You can use select() to wait for data to arrive from the server, thereby using no CPU power unless there is something to do. (See PQsocket to obtain the file descriptor number to use with select().) Note that this will work OK whether you submit commands with PQsendQuery/PQgetResult or simply use PQexec. You should, however, remember to check PQnotifies after each PQgetResult or PQexec, to see if any notifications came in during the processing of the command.

36.10. Functions Associated with the COPY Command

The COPY command in Postgres Pro has options to read from or write to the network connection used by libpq. The functions described in this section allow applications to take advantage of this capability by supplying or consuming copied data.

The overall process is that the application first issues the SQL COPY command via PQexec or one of the equivalent functions. The response to this (if there is no error in the command) will be a PGresult object bearing a status code of PGRES_COPY_OUT or PGRES_COPY_IN (depending on the specified copy direction). The application should then use the functions of this section to receive or transmit data rows. When the data transfer is complete, another PGresult object is returned to indicate success or failure of the transfer. Its status will be PGRES_COMMAND_OK for success or PGRES_FATAL_ERROR if some problem was encountered. At this point further SQL commands can be issued via PQexec. (It is not possible to execute other SQL commands using the same connection while the COPY operation is in progress.)

If a COPY command is issued via PQexec in a string that could contain additional commands, the application must continue fetching results via PQgetResult after completing the COPY sequence. Only when PQgetResult returns NULL is it certain that the PQexec command string is done and it is safe to issue more commands.

The functions of this section should be executed only after obtaining a result status of PGRES_COPY_OUT or PGRES_COPY_IN from PQexec or PQgetResult.

A PGresult object bearing one of these status values carries some additional data about the COPY operation that is starting. This additional data is available using functions that are also used in connection with query results:

PQnfields

Returns the number of columns (fields) to be copied.

PQbinaryTuples

0 indicates the overall copy format is textual (rows separated by newlines, columns separated by separator characters, etc). 1 indicates the overall copy format is binary. See COPY for more information.

`PQfformat`

Returns the format code (0 for text, 1 for binary) associated with each column of the copy operation. The per-column format codes will always be zero when the overall copy format is textual, but the binary format can support both text and binary columns. (However, as of the current implementation of `COPY`, only binary columns appear in a binary copy; so the per-column formats always match the overall format at present.)

36.10.1. Functions for Sending `COPY` Data

These functions are used to send data during `COPY FROM STDIN`. They will fail if called when the connection is not in `COPY_IN` state.

`PQputCopyData`

Sends data to the server during `COPY_IN` state.

```
int PQputCopyData(PGconn *conn,
                  const char *buffer,
                  int nbytes);
```

Transmits the `COPY` data in the specified *`buffer`*, of length *`nbytes`*, to the server. The result is 1 if the data was queued, zero if it was not queued because of full buffers (this will only happen in nonblocking mode), or -1 if an error occurred. (Use `PQerrorMessage` to retrieve details if the return value is -1. If the value is zero, wait for write-ready and try again.)

The application can divide the `COPY` data stream into buffer loads of any convenient size. Buffer-load boundaries have no semantic significance when sending. The contents of the data stream must match the data format expected by the `COPY` command; see COPY for details.

`PQputCopyEnd`

Sends end-of-data indication to the server during `COPY_IN` state.

```
int PQputCopyEnd(PGconn *conn,
                 const char *errormsg);
```

Ends the `COPY_IN` operation successfully if *`errormsg`* is `NULL`. If *`errormsg`* is not `NULL` then the `COPY` is forced to fail, with the string pointed to by *`errormsg`* used as the error message. (One should not assume that this exact error message will come back from the server, however, as the server might have already failed the `COPY` for its own reasons.)

The result is 1 if the termination message was sent; or in nonblocking mode, this may only indicate that the termination message was successfully queued. (In nonblocking mode, to be certain that the data has been sent, you should next wait for write-ready and call `PQflush`, repeating until it returns zero.) Zero indicates that the function could not queue the termination message because of full buffers; this will only happen in nonblocking mode. (In this case, wait for write-ready and try the `PQputCopyEnd` call again.) If a hard error occurs, -1 is returned; you can use `PQerrorMessage` to retrieve details.

After successfully calling `PQputCopyEnd`, call `PQgetResult` to obtain the final result status of the `COPY` command. One can wait for this result to be available in the usual way. Then return to normal operation.

36.10.2. Functions for Receiving `COPY` Data

These functions are used to receive data during `COPY TO STDOUT`. They will fail if called when the connection is not in `COPY_OUT` state.

`PQgetCopyData`

Receives data from the server during `COPY_OUT` state.

```
int PQgetCopyData(PGconn *conn,
                  char **buffer,
                  int async);
```

Attempts to obtain another row of data from the server during a COPY. Data is always returned one data row at a time; if only a partial row is available, it is not returned. Successful return of a data row involves allocating a chunk of memory to hold the data. The *buffer* parameter must be non-NULL. **buffer* is set to point to the allocated memory, or to NULL in cases where no buffer is returned. A non-NULL result buffer should be freed using PQfreemem when no longer needed.

When a row is successfully returned, the return value is the number of data bytes in the row (this will always be greater than zero). The returned string is always null-terminated, though this is probably only useful for textual COPY. A result of zero indicates that the COPY is still in progress, but no row is yet available (this is only possible when *async* is true). A result of -1 indicates that the COPY is done. A result of -2 indicates that an error occurred (consult PQerrorMessage for the reason).

When *async* is true (not zero), PQgetCopyData will not block waiting for input; it will return zero if the COPY is still in progress but no complete row is available. (In this case wait for read-ready and then call PQconsumeInput before calling PQgetCopyData again.) When *async* is false (zero), PQgetCopyData will block until data is available or the operation completes.

After PQgetCopyData returns -1, call PQgetResult to obtain the final result status of the COPY command. One can wait for this result to be available in the usual way. Then return to normal operation.

36.10.3. Obsolete Functions for COPY

These functions represent older methods of handling COPY. Although they still work, they are deprecated due to poor error handling, inconvenient methods of detecting end-of-data, and lack of support for binary or nonblocking transfers.

PQgetline

Reads a newline-terminated line of characters (transmitted by the server) into a buffer string of size *length*.

```
int PQgetline(PGconn *conn,
              char *buffer,
              int length);
```

This function copies up to *length*-1 characters into the buffer and converts the terminating newline into a zero byte. PQgetline returns EOF at the end of input, 0 if the entire line has been read, and 1 if the buffer is full but the terminating newline has not yet been read.

Note that the application must check to see if a new line consists of the two characters \., which indicates that the server has finished sending the results of the COPY command. If the application might receive lines that are more than *length*-1 characters long, care is needed to be sure it recognizes the \. line correctly (and does not, for example, mistake the end of a long data line for a terminator line).

PQgetlineAsync

Reads a row of COPY data (transmitted by the server) into a buffer without blocking.

```
int PQgetlineAsync(PGconn *conn,
                   char *buffer,
                   int bufsize);
```

This function is similar to PQgetline, but it can be used by applications that must read COPY data asynchronously, that is, without blocking. Having issued the COPY command and gotten a PGRES_COPY_OUT response, the application should call PQconsumeInput and PQgetlineAsync until the end-of-data signal is detected.

Unlike PQgetline, this function takes responsibility for detecting end-of-data.

On each call, PQgetlineAsync will return data if a complete data row is available in libpq's input buffer. Otherwise, no data is returned until the rest of the row arrives. The function returns -1 if the end-of-copy-data marker has been recognized, or 0 if no data is available, or a positive number giving the number of bytes of data returned. If -1 is returned, the caller must next call PQendcopy, and then return to normal processing.

The data returned will not extend beyond a data-row boundary. If possible a whole row will be returned at one time. But if the buffer offered by the caller is too small to hold a row sent by the server, then a partial data row will be returned. With textual data this can be detected by testing whether the last returned byte is \n or not. (In a binary COPY, actual parsing of the COPY data format will be needed to make the equivalent determination.) The returned string is not null-terminated. (If you want to add a terminating null, be sure to pass a *bufsize* one smaller than the room actually available.)

PQputline

Sends a null-terminated string to the server. Returns 0 if OK and EOF if unable to send the string.

```
int PQputline(PGconn *conn,
              const char *string);
```

The COPY data stream sent by a series of calls to PQputline has the same format as that returned by PQgetlineAsync, except that applications are not obliged to send exactly one data row per PQputline call; it is okay to send a partial line or multiple lines per call.

> **Note**
>
> Before Postgres Pro protocol 3.0, it was necessary for the application to explicitly send the two characters \. as a final line to indicate to the server that it had finished sending COPY data. While this still works, it is deprecated and the special meaning of \. can be expected to be removed in a future release. It is sufficient to call PQendcopy after having sent the actual data.

PQputnbytes

Sends a non-null-terminated string to the server. Returns 0 if OK and EOF if unable to send the string.

```
int PQputnbytes(PGconn *conn,
                const char *buffer,
                int nbytes);
```

This is exactly like PQputline, except that the data buffer need not be null-terminated since the number of bytes to send is specified directly. Use this procedure when sending binary data.

PQendcopy

Synchronizes with the server.

```
int PQendcopy(PGconn *conn);
```

This function waits until the server has finished the copying. It should either be issued when the last string has been sent to the server using PQputline or when the last string has been received from the server using PQgetline. It must be issued or the server will get “out of sync” with the client. Upon return from this function, the server is ready to receive the next SQL command. The return value is 0 on successful completion, nonzero otherwise. (Use PQerrorMessage to retrieve details if the return value is nonzero.)

When using PQgetResult, the application should respond to a PGRES_COPY_OUT result by executing PQgetline repeatedly, followed by PQendcopy after the terminator line is seen. It should then return to the PQgetResult loop until PQgetResult returns a null pointer. Similarly a PGRES_COPY_IN result

is processed by a series of PQputline calls followed by PQendcopy, then return to the PQgetResult loop. This arrangement will ensure that a COPY command embedded in a series of SQL commands will be executed correctly.

Older applications are likely to submit a COPY via PQexec and assume that the transaction is done after PQendcopy. This will work correctly only if the COPY is the only SQL command in the command string.

36.11. Control Functions

These functions control miscellaneous details of libpq's behavior.

PQclientEncoding

Returns the client encoding.

```
int PQclientEncoding(const PGconn *conn);
```

Note that it returns the encoding ID, not a symbolic string such as EUC_JP. If unsuccessful, it returns -1. To convert an encoding ID to an encoding name, you can use:

```
char *pg_encoding_to_char(int encoding_id);
```

PQsetClientEncoding

Sets the client encoding.

```
int PQsetClientEncoding(PGconn *conn, const char *encoding);
```

conn is a connection to the server, and *encoding* is the encoding you want to use. If the function successfully sets the encoding, it returns 0, otherwise -1. The current encoding for this connection can be determined by using PQclientEncoding.

PQsetErrorVerbosity

Determines the verbosity of messages returned by PQerrorMessage and PQresultErrorMessage.

```
typedef enum
{
    PQERRORS_TERSE,
    PQERRORS_DEFAULT,
    PQERRORS_VERBOSE,
    PQERRORS_SQLSTATE
} PGVerbosity;

PGVerbosity PQsetErrorVerbosity(PGconn *conn, PGVerbosity verbosity);
```

PQsetErrorVerbosity sets the verbosity mode, returning the connection's previous setting. In *TERSE* mode, returned messages include severity, primary text, and position only; this will normally fit on a single line. The *DEFAULT* mode produces messages that include the above plus any detail, hint, or context fields (these might span multiple lines). The *VERBOSE* mode includes all available fields. The *SQLSTATE* mode includes only the error severity and the SQLSTATE error code, if one is available (if not, the output is like *TERSE* mode).

Changing the verbosity setting does not affect the messages available from already-existing PGresult objects, only subsequently-created ones. (But see PQresultVerboseErrorMessage if you want to print a previous error with a different verbosity.)

PQsetErrorContextVisibility

Determines the handling of CONTEXT fields in messages returned by PQerrorMessage and PQresultErrorMessage.

```
typedef enum
{
```

```
    PQSHOW_CONTEXT_NEVER,
    PQSHOW_CONTEXT_ERRORS,
    PQSHOW_CONTEXT_ALWAYS
} PGContextVisibility;

PGContextVisibility PQsetErrorContextVisibility(PGconn *conn, PGContextVisibility
 show_context);
```

`PQsetErrorContextVisibility` sets the context display mode, returning the connection's previous setting. This mode controls whether the `CONTEXT` field is included in messages. The *NEVER* mode never includes `CONTEXT`, while *ALWAYS* always includes it if available. In *ERRORS* mode (the default), `CONTEXT` fields are included only in error messages, not in notices and warnings. (However, if the verbosity setting is *TERSE* or *SQLSTATE*, `CONTEXT` fields are omitted regardless of the context display mode.)

Changing this mode does not affect the messages available from already-existing `PGresult` objects, only subsequently-created ones. (But see `PQresultVerboseErrorMessage` if you want to print a previous error with a different display mode.)

`PQtrace`

Enables tracing of the client/server communication to a debugging file stream.

```
void PQtrace(PGconn *conn, FILE *stream);
```

Each line consists of: an optional timestamp, a direction indicator (`F` for messages from client to server or `B` for messages from server to client), message length, message type, and message contents. Non-message contents fields (timestamp, direction, length and message type) are separated by a tab. Message contents are separated by a space. Protocol strings are enclosed in double quotes, while strings used as data values are enclosed in single quotes. Non-printable chars are printed as hexadecimal escapes. Further message-type-specific detail can be found in Section 55.7.

> **Note**
>
> On Windows, if the libpq library and an application are compiled with different flags, this function call will crash the application because the internal representation of the `FILE` pointers differ. Specifically, multithreaded/single-threaded, release/debug, and static/dynamic flags should be the same for the library and all applications using that library.

`PQsetTraceFlags`

Controls the tracing behavior of client/server communication.

```
void PQsetTraceFlags(PGconn *conn, int flags);
```

`flags` contains flag bits describing the operating mode of tracing. If `flags` contains `PQTRACE_SUPPRESS_TIMESTAMPS`, then the timestamp is not included when printing each message. If `flags` contains `PQTRACE_REGRESS_MODE`, then some fields are redacted when printing each message, such as object OIDs, to make the output more convenient to use in testing frameworks. This function must be called after calling `PQtrace`.

`PQuntrace`

Disables tracing started by `PQtrace`.

```
void PQuntrace(PGconn *conn);
```

36.12. Miscellaneous Functions

As always, there are some functions that just don't fit anywhere.

PQfreemem

Frees memory allocated by libpq.

```
void PQfreemem(void *ptr);
```

Frees memory allocated by libpq, particularly PQescapeByteaConn, PQescapeBytea, PQunescapeBytea, and PQnotifies. It is particularly important that this function, rather than free(), be used on Microsoft Windows. This is because allocating memory in a DLL and releasing it in the application works only if multithreaded/single-threaded, release/debug, and static/dynamic flags are the same for the DLL and the application. On non-Microsoft Windows platforms, this function is the same as the standard library function free().

PQconninfoFree

Frees the data structures allocated by PQconndefaults or PQconninfoParse.

```
void PQconninfoFree(PQconninfoOption *connOptions);
```

A simple PQfreemem will not do for this, since the array contains references to subsidiary strings.

PQencryptPasswordConn

Prepares the encrypted form of a Postgres Pro password.

```
char *PQencryptPasswordConn(PGconn *conn, const char *passwd, const char *user,
 const char *algorithm);
```

This function is intended to be used by client applications that wish to send commands like ALTER USER joe PASSWORD 'pwd'. It is good practice not to send the original cleartext password in such a command, because it might be exposed in command logs, activity displays, and so on. Instead, use this function to convert the password to encrypted form before it is sent.

The *passwd* and *user* arguments are the cleartext password, and the SQL name of the user it is for. *algorithm* specifies the encryption algorithm to use to encrypt the password. Currently supported algorithms are md5 and scram-sha-256 (on and off are also accepted as aliases for md5, for compatibility with older server versions). Note that support for scram-sha-256 was introduced in Postgres Pro version 10, and will not work correctly with older server versions. If *algorithm* is NULL, this function will query the server for the current value of the password_encryption setting. That can block, and will fail if the current transaction is aborted, or if the connection is busy executing another query. If you wish to use the default algorithm for the server but want to avoid blocking, query password_encryption yourself before calling PQencryptPasswordConn, and pass that value as the *algorithm*.

The return value is a string allocated by malloc. The caller can assume the string doesn't contain any special characters that would require escaping. Use PQfreemem to free the result when done with it. On error, returns NULL, and a suitable message is stored in the connection object.

PQencryptPassword

Prepares the md5-encrypted form of a Postgres Pro password.

```
char *PQencryptPassword(const char *passwd, const char *user);
```

PQencryptPassword is an older, deprecated version of PQencryptPasswordConn. The difference is that PQencryptPassword does not require a connection object, and md5 is always used as the encryption algorithm.

PQmakeEmptyPGresult

Constructs an empty PGresult object with the given status.

```
PGresult *PQmakeEmptyPGresult(PGconn *conn, ExecStatusType status);
```

This is libpq's internal function to allocate and initialize an empty PGresult object. This function returns NULL if memory could not be allocated. It is exported because some applications find it useful to generate result objects (particularly objects with error status) themselves. If *conn* is not null and *status* indicates an error, the current error message of the specified connection is copied into the PGresult. Also, if *conn* is not null, any event procedures registered in the connection are copied into the PGresult. (They do not get PGEVT_RESULTCREATE calls, but see PQfireResultCreateEvents.) Note that PQclear should eventually be called on the object, just as with a PGresult returned by libpq itself.

PQfireResultCreateEvents

Fires a PGEVT_RESULTCREATE event (see Section 36.14) for each event procedure registered in the PGresult object. Returns non-zero for success, zero if any event procedure fails.

```
int PQfireResultCreateEvents(PGconn *conn, PGresult *res);
```

The conn argument is passed through to event procedures but not used directly. It can be NULL if the event procedures won't use it.

Event procedures that have already received a PGEVT_RESULTCREATE or PGEVT_RESULTCOPY event for this object are not fired again.

The main reason that this function is separate from PQmakeEmptyPGresult is that it is often appropriate to create a PGresult and fill it with data before invoking the event procedures.

PQcopyResult

Makes a copy of a PGresult object. The copy is not linked to the source result in any way and PQclear must be called when the copy is no longer needed. If the function fails, NULL is returned.

```
PGresult *PQcopyResult(const PGresult *src, int flags);
```

This is not intended to make an exact copy. The returned result is always put into PGRES_TUPLES_OK status, and does not copy any error message in the source. (It does copy the command status string, however.) The *flags* argument determines what else is copied. It is a bitwise OR of several flags. PG_COPYRES_ATTRS specifies copying the source result's attributes (column definitions). PG_COPYRES_TUPLES specifies copying the source result's tuples. (This implies copying the attributes, too.) PG_COPYRES_NOTICEHOOKS specifies copying the source result's notify hooks. PG_COPYRES_EVENTS specifies copying the source result's events. (But any instance data associated with the source is not copied.)

PQsetResultAttrs

Sets the attributes of a PGresult object.

```
int PQsetResultAttrs(PGresult *res, int numAttributes, PGresAttDesc *attDescs);
```

The provided *attDescs* are copied into the result. If the *attDescs* pointer is NULL or *numAttributes* is less than one, the request is ignored and the function succeeds. If *res* already contains attributes, the function will fail. If the function fails, the return value is zero. If the function succeeds, the return value is non-zero.

PQsetvalue

Sets a tuple field value of a PGresult object.

```
int PQsetvalue(PGresult *res, int tup_num, int field_num, char *value, int len);
```

The function will automatically grow the result's internal tuples array as needed. However, the *tup_num* argument must be less than or equal to PQntuples, meaning this function can only grow the tuples array one tuple at a time. But any field of any existing tuple can be modified in any order. If a value at *field_num* already exists, it will be overwritten. If *len* is -1 or *value* is NULL, the field value will be set to an SQL null value. The *value* is copied into the result's private storage, thus is no

longer needed after the function returns. If the function fails, the return value is zero. If the function succeeds, the return value is non-zero.

`PQresultAlloc`

Allocate subsidiary storage for a `PGresult` object.

```
void *PQresultAlloc(PGresult *res, size_t nBytes);
```

Any memory allocated with this function will be freed when *`res`* is cleared. If the function fails, the return value is `NULL`. The result is guaranteed to be adequately aligned for any type of data, just as for `malloc`.

`PQresultMemorySize`

Retrieves the number of bytes allocated for a `PGresult` object.

```
size_t PQresultMemorySize(const PGresult *res);
```

This value is the sum of all `malloc` requests associated with the `PGresult` object, that is, all the space that will be freed by `PQclear`. This information can be useful for managing memory consumption.

`PQlibVersion`

Return the version of libpq that is being used.

```
int PQlibVersion(void);
```

The result of this function can be used to determine, at run time, whether specific functionality is available in the currently loaded version of libpq. The function can be used, for example, to determine which connection options are available in `PQconnectdb`.

The result is formed by multiplying the library's major version number by 10000 and adding the minor version number. For example, version 10.1 will be returned as 100001, and version 11.0 will be returned as 110000.

Prior to major version 10, Postgres Pro used three-part version numbers in which the first two parts together represented the major version. For those versions, `PQlibVersion` uses two digits for each part; for example version 9.1.5 will be returned as 90105, and version 9.2.0 will be returned as 90200.

Therefore, for purposes of determining feature compatibility, applications should divide the result of `PQlibVersion` by 100 not 10000 to determine a logical major version number. In all release series, only the last two digits differ between minor releases (bug-fix releases).

> **Note**
>
> This function appeared in PostgreSQL version 9.1, so it cannot be used to detect required functionality in earlier versions, since calling it will create a link dependency on version 9.1 or later.

36.13. Notice Processing

Notice and warning messages generated by the server are not returned by the query execution functions, since they do not imply failure of the query. Instead they are passed to a notice handling function, and execution continues normally after the handler returns. The default notice handling function prints the message on `stderr`, but the application can override this behavior by supplying its own handling function.

For historical reasons, there are two levels of notice handling, called the notice receiver and notice processor. The default behavior is for the notice receiver to format the notice and pass a string to the

notice processor for printing. However, an application that chooses to provide its own notice receiver will typically ignore the notice processor layer and just do all the work in the notice receiver.

The function PQsetNoticeReceiver sets or examines the current notice receiver for a connection object. Similarly, PQsetNoticeProcessor sets or examines the current notice processor.

```
typedef void (*PQnoticeReceiver) (void *arg, const PGresult *res);

PQnoticeReceiver
PQsetNoticeReceiver(PGconn *conn,
                    PQnoticeReceiver proc,
                    void *arg);

typedef void (*PQnoticeProcessor) (void *arg, const char *message);

PQnoticeProcessor
PQsetNoticeProcessor(PGconn *conn,
                     PQnoticeProcessor proc,
                     void *arg);
```

Each of these functions returns the previous notice receiver or processor function pointer, and sets the new value. If you supply a null function pointer, no action is taken, but the current pointer is returned.

When a notice or warning message is received from the server, or generated internally by libpq, the notice receiver function is called. It is passed the message in the form of a PGRES_NONFATAL_ERROR PGresult. (This allows the receiver to extract individual fields using PQresultErrorField, or obtain a complete preformatted message using PQresultErrorMessage or PQresultVerboseErrorMessage.) The same void pointer passed to PQsetNoticeReceiver is also passed. (This pointer can be used to access application-specific state if needed.)

The default notice receiver simply extracts the message (using PQresultErrorMessage) and passes it to the notice processor.

The notice processor is responsible for handling a notice or warning message given in text form. It is passed the string text of the message (including a trailing newline), plus a void pointer that is the same one passed to PQsetNoticeProcessor. (This pointer can be used to access application-specific state if needed.)

The default notice processor is simply:

```
static void
defaultNoticeProcessor(void *arg, const char *message)
{
    fprintf(stderr, "%s", message);
}
```

Once you have set a notice receiver or processor, you should expect that that function could be called as long as either the PGconn object or PGresult objects made from it exist. At creation of a PGresult, the PGconn's current notice handling pointers are copied into the PGresult for possible use by functions like PQgetvalue.

36.14. Event System

libpq's event system is designed to notify registered event handlers about interesting libpq events, such as the creation or destruction of PGconn and PGresult objects. A principal use case is that this allows applications to associate their own data with a PGconn or PGresult and ensure that that data is freed at an appropriate time.

Each registered event handler is associated with two pieces of data, known to libpq only as opaque void * pointers. There is a *pass-through* pointer that is provided by the application when the event handler

is registered with a PGconn. The pass-through pointer never changes for the life of the PGconn and all PGresults generated from it; so if used, it must point to long-lived data. In addition there is an *instance data* pointer, which starts out NULL in every PGconn and PGresult. This pointer can be manipulated using the PQinstanceData, PQsetInstanceData, PQresultInstanceData and PQsetResultInstanceData functions. Note that unlike the pass-through pointer, instance data of a PGconn is not automatically inherited by PGresults created from it. libpq does not know what pass-through and instance data pointers point to (if anything) and will never attempt to free them — that is the responsibility of the event handler.

36.14.1. Event Types

The enum PGEventId names the types of events handled by the event system. All its values have names beginning with PGEVT. For each event type, there is a corresponding event info structure that carries the parameters passed to the event handlers. The event types are:

PGEVT_REGISTER

The register event occurs when PQregisterEventProc is called. It is the ideal time to initialize any instanceData an event procedure may need. Only one register event will be fired per event handler per connection. If the event procedure fails, the registration is aborted.

```
typedef struct
{
    PGconn *conn;
} PGEventRegister;
```

When a PGEVT_REGISTER event is received, the *evtInfo* pointer should be cast to a PGEventRegister *. This structure contains a PGconn that should be in the CONNECTION_OK status; guaranteed if one calls PQregisterEventProc right after obtaining a good PGconn. When returning a failure code, all cleanup must be performed as no PGEVT_CONNDESTROY event will be sent.

PGEVT_CONNRESET

The connection reset event is fired on completion of PQreset or PQresetPoll. In both cases, the event is only fired if the reset was successful. If the event procedure fails, the entire connection reset will fail; the PGconn is put into CONNECTION_BAD status and PQresetPoll will return PGRES_POLLING_FAILED.

```
typedef struct
{
    PGconn *conn;
} PGEventConnReset;
```

When a PGEVT_CONNRESET event is received, the *evtInfo* pointer should be cast to a PGEventConnReset *. Although the contained PGconn was just reset, all event data remains unchanged. This event should be used to reset/reload/requery any associated instanceData. Note that even if the event procedure fails to process PGEVT_CONNRESET, it will still receive a PGEVT_CONNDESTROY event when the connection is closed.

PGEVT_CONNDESTROY

The connection destroy event is fired in response to PQfinish. It is the event procedure's responsibility to properly clean up its event data as libpq has no ability to manage this memory. Failure to clean up will lead to memory leaks.

```
typedef struct
{
    PGconn *conn;
} PGEventConnDestroy;
```

When a PGEVT_CONNDESTROY event is received, the *evtInfo* pointer should be cast to a PGEventConnDestroy *. This event is fired prior to PQfinish performing any other cleanup. The return value of the event procedure is ignored since there is no way of indicating a failure from PQfinish. Also, an event procedure failure should not abort the process of cleaning up unwanted memory.

PGEVT_RESULTCREATE

The result creation event is fired in response to any query execution function that generates a result, including PQgetResult. This event will only be fired after the result has been created successfully.

```
typedef struct
{
    PGconn *conn;
    PGresult *result;
} PGEventResultCreate;
```

When a PGEVT_RESULTCREATE event is received, the *evtInfo* pointer should be cast to a PGEventResultCreate *. The *conn* is the connection used to generate the result. This is the ideal place to initialize any instanceData that needs to be associated with the result. If the event procedure fails, the result will be cleared and the failure will be propagated. The event procedure must not try to PQclear the result object for itself. When returning a failure code, all cleanup must be performed as no PGEVT_RESULTDESTROY event will be sent.

PGEVT_RESULTCOPY

The result copy event is fired in response to PQcopyResult. This event will only be fired after the copy is complete. Only event procedures that have successfully handled the PGEVT_RESULTCREATE or PGEVT_RESULTCOPY event for the source result will receive PGEVT_RESULTCOPY events.

```
typedef struct
{
    const PGresult *src;
    PGresult *dest;
} PGEventResultCopy;
```

When a PGEVT_RESULTCOPY event is received, the *evtInfo* pointer should be cast to a PGEventResultCopy *. The *src* result is what was copied while the *dest* result is the copy destination. This event can be used to provide a deep copy of instanceData, since PQcopyResult cannot do that. If the event procedure fails, the entire copy operation will fail and the *dest* result will be cleared. When returning a failure code, all cleanup must be performed as no PGEVT_RESULTDESTROY event will be sent for the destination result.

PGEVT_RESULTDESTROY

The result destroy event is fired in response to a PQclear. It is the event procedure's responsibility to properly clean up its event data as libpq has no ability to manage this memory. Failure to clean up will lead to memory leaks.

```
typedef struct
{
    PGresult *result;
} PGEventResultDestroy;
```

When a PGEVT_RESULTDESTROY event is received, the *evtInfo* pointer should be cast to a PGEventResultDestroy *. This event is fired prior to PQclear performing any other cleanup. The return value of the event procedure is ignored since there is no way of indicating a failure from PQclear. Also, an event procedure failure should not abort the process of cleaning up unwanted memory.

36.14.2. Event Callback Procedure

PGEventProc

PGEventProc is a typedef for a pointer to an event procedure, that is, the user callback function that receives events from libpq. The signature of an event procedure must be

```
int eventproc(PGEventId evtId, void *evtInfo, void *passThrough)
```

The *evtId* parameter indicates which PGEVT event occurred. The *evtInfo* pointer must be cast to the appropriate structure type to obtain further information about the event. The *passThrough* pa-

rameter is the pointer provided to PQregisterEventProc when the event procedure was registered. The function should return a non-zero value if it succeeds and zero if it fails.

A particular event procedure can be registered only once in any PGconn. This is because the address of the procedure is used as a lookup key to identify the associated instance data.

> **Caution**
>
> On Windows, functions can have two different addresses: one visible from outside a DLL and another visible from inside the DLL. One should be careful that only one of these addresses is used with libpq's event-procedure functions, else confusion will result. The simplest rule for writing code that will work is to ensure that event procedures are declared static. If the procedure's address must be available outside its own source file, expose a separate function to return the address.

36.14.3. Event Support Functions

PQregisterEventProc

Registers an event callback procedure with libpq.

```
int PQregisterEventProc(PGconn *conn, PGEventProc proc,
                        const char *name, void *passThrough);
```

An event procedure must be registered once on each PGconn you want to receive events about. There is no limit, other than memory, on the number of event procedures that can be registered with a connection. The function returns a non-zero value if it succeeds and zero if it fails.

The *proc* argument will be called when a libpq event is fired. Its memory address is also used to lookup instanceData. The *name* argument is used to refer to the event procedure in error messages. This value cannot be NULL or a zero-length string. The name string is copied into the PGconn, so what is passed need not be long-lived. The *passThrough* pointer is passed to the *proc* whenever an event occurs. This argument can be NULL.

PQsetInstanceData

Sets the connection *conn*'s instanceData for procedure *proc* to *data*. This returns non-zero for success and zero for failure. (Failure is only possible if *proc* has not been properly registered in *conn*.)

```
int PQsetInstanceData(PGconn *conn, PGEventProc proc, void *data);
```

PQinstanceData

Returns the connection *conn*'s instanceData associated with procedure *proc*, or NULL if there is none.

```
void *PQinstanceData(const PGconn *conn, PGEventProc proc);
```

PQresultSetInstanceData

Sets the result's instanceData for *proc* to *data*. This returns non-zero for success and zero for failure. (Failure is only possible if *proc* has not been properly registered in the result.)

```
int PQresultSetInstanceData(PGresult *res, PGEventProc proc, void *data);
```

Beware that any storage represented by *data* will not be accounted for by PQresultMemorySize, unless it is allocated using PQresultAlloc. (Doing so is recommendable because it eliminates the need to free such storage explicitly when the result is destroyed.)

PQresultInstanceData

Returns the result's instanceData associated with *proc*, or NULL if there is none.

```
void *PQresultInstanceData(const PGresult *res, PGEventProc proc);
```

36.14.4. Event Example

Here is a skeleton example of managing private data associated with libpq connections and results.

```
/* required header for libpq events (note: includes libpq-fe.h) */
#include <libpq-events.h>

/* The instanceData */
typedef struct
{
    int n;
    char *str;
} mydata;

/* PGEventProc */
static int myEventProc(PGEventId evtId, void *evtInfo, void *passThrough);

int
main(void)
{
    mydata *data;
    PGresult *res;
    PGconn *conn =
        PQconnectdb("dbname=postgres options=-csearch_path=");

    if (PQstatus(conn) != CONNECTION_OK)
    {
        /* PQerrorMessage's result includes a trailing newline */
        fprintf(stderr, "%s", PQerrorMessage(conn));
        PQfinish(conn);
        return 1;
    }

    /* called once on any connection that should receive events.
     * Sends a PGEVT_REGISTER to myEventProc.
     */
    if (!PQregisterEventProc(conn, myEventProc, "mydata_proc", NULL))
    {
        fprintf(stderr, "Cannot register PGEventProc\n");
        PQfinish(conn);
        return 1;
    }

    /* conn instanceData is available */
    data = PQinstanceData(conn, myEventProc);

    /* Sends a PGEVT_RESULTCREATE to myEventProc */
    res = PQexec(conn, "SELECT 1 + 1");

    /* result instanceData is available */
    data = PQresultInstanceData(res, myEventProc);

    /* If PG_COPYRES_EVENTS is used, sends a PGEVT_RESULTCOPY to myEventProc */
    res_copy = PQcopyResult(res, PG_COPYRES_TUPLES | PG_COPYRES_EVENTS);

    /* result instanceData is available if PG_COPYRES_EVENTS was
     * used during the PQcopyResult call.
```

```
     */
    data = PQresultInstanceData(res_copy, myEventProc);

    /* Both clears send a PGEVT_RESULTDESTROY to myEventProc */
    PQclear(res);
    PQclear(res_copy);

    /* Sends a PGEVT_CONNDESTROY to myEventProc */
    PQfinish(conn);

    return 0;
}

static int
myEventProc(PGEventId evtId, void *evtInfo, void *passThrough)
{
    switch (evtId)
    {
        case PGEVT_REGISTER:
        {
            PGEventRegister *e = (PGEventRegister *)evtInfo;
            mydata *data = get_mydata(e->conn);

            /* associate app specific data with connection */
            PQsetInstanceData(e->conn, myEventProc, data);
            break;
        }

        case PGEVT_CONNRESET:
        {
            PGEventConnReset *e = (PGEventConnReset *)evtInfo;
            mydata *data = PQinstanceData(e->conn, myEventProc);

            if (data)
              memset(data, 0, sizeof(mydata));
            break;
        }

        case PGEVT_CONNDESTROY:
        {
            PGEventConnDestroy *e = (PGEventConnDestroy *)evtInfo;
            mydata *data = PQinstanceData(e->conn, myEventProc);

            /* free instance data because the conn is being destroyed */
            if (data)
              free_mydata(data);
            break;
        }

        case PGEVT_RESULTCREATE:
        {
            PGEventResultCreate *e = (PGEventResultCreate *)evtInfo;
            mydata *conn_data = PQinstanceData(e->conn, myEventProc);
            mydata *res_data = dup_mydata(conn_data);

            /* associate app specific data with result (copy it from conn) */
            PQsetResultInstanceData(e->result, myEventProc, res_data);
            break;
```

```
        }

        case PGEVT_RESULTCOPY:
        {
            PGEventResultCopy *e = (PGEventResultCopy *)evtInfo;
            mydata *src_data = PQresultInstanceData(e->src, myEventProc);
            mydata *dest_data = dup_mydata(src_data);

            /* associate app specific data with result (copy it from a result) */
            PQsetResultInstanceData(e->dest, myEventProc, dest_data);
            break;
        }

        case PGEVT_RESULTDESTROY:
        {
            PGEventResultDestroy *e = (PGEventResultDestroy *)evtInfo;
            mydata *data = PQresultInstanceData(e->result, myEventProc);

            /* free instance data because the result is being destroyed */
            if (data)
              free_mydata(data);
            break;
        }

        /* unknown event ID, just return true. */
        default:
            break;
    }

    return true; /* event processing succeeded */
}
```

36.15. Environment Variables

The following environment variables can be used to select default connection parameter values, which will be used by PQconnectdb, PQsetdbLogin and PQsetdb if no value is directly specified by the calling code. These are useful to avoid hard-coding database connection information into simple client applications, for example.

- PGHOST behaves the same as the host connection parameter.
- PGHOSTADDR behaves the same as the hostaddr connection parameter. This can be set instead of or in addition to PGHOST to avoid DNS lookup overhead.
- PGPORT behaves the same as the port connection parameter.
- PGDATABASE behaves the same as the dbname connection parameter.
- PGUSER behaves the same as the user connection parameter.
- PGPASSWORD behaves the same as the password connection parameter. Use of this environment variable is not recommended for security reasons, as some operating systems allow non-root users to see process environment variables via ps; instead consider using a password file (see Section 36.16).
- PGPASSFILE behaves the same as the passfile connection parameter.
- PGCHANNELBINDING behaves the same as the channel_binding connection parameter.
- PGSERVICE behaves the same as the service connection parameter.

- PGSERVICEFILE specifies the name of the per-user connection service file (see Section 36.17). Defaults to ~/.pg_service.conf, or %APPDATA%\postgresql\.pg_service.conf on Microsoft Windows.
- PGOPTIONS behaves the same as the options connection parameter.
- PGAPPNAME behaves the same as the application_name connection parameter.
- PGSSLMODE behaves the same as the sslmode connection parameter.
- PGREQUIRESSL behaves the same as the requiressl connection parameter. This environment variable is deprecated in favor of the PGSSLMODE variable; setting both variables suppresses the effect of this one.
- PGSSLCOMPRESSION behaves the same as the sslcompression connection parameter.
- PGSSLCERT behaves the same as the sslcert connection parameter.
- PGSSLKEY behaves the same as the sslkey connection parameter.
- PGSSLROOTCERT behaves the same as the sslrootcert connection parameter.
- PGSSLCRL behaves the same as the sslcrl connection parameter.
- PGSSLCRLDIR behaves the same as the sslcrldir connection parameter.
- PGSSLSNI behaves the same as the sslsni connection parameter.
- PGREQUIREPEER behaves the same as the requirepeer connection parameter.
- PGSSLMINPROTOCOLVERSION behaves the same as the ssl_min_protocol_version connection parameter.
- PGSSLMAXPROTOCOLVERSION behaves the same as the ssl_max_protocol_version connection parameter.
- PGGSSENCMODE behaves the same as the gssencmode connection parameter.
- PGKRBSRVNAME behaves the same as the krbsrvname connection parameter.
- PGGSSLIB behaves the same as the gsslib connection parameter.
- PGCONNECT_TIMEOUT behaves the same as the connect_timeout connection parameter.
- PGCLIENTENCODING behaves the same as the client_encoding connection parameter.
- PGTARGETSESSIONATTRS behaves the same as the target_session_attrs connection parameter.

The following environment variables can be used to specify default behavior for each Postgres Pro session. (See also the ALTER ROLE and ALTER DATABASE commands for ways to set default behavior on a per-user or per-database basis.)

- PGDATESTYLE sets the default style of date/time representation. (Equivalent to SET datestyle TO ....)
- PGTZ sets the default time zone. (Equivalent to SET timezone TO ....)
- PGGEQO sets the default mode for the genetic query optimizer. (Equivalent to SET geqo TO ....)

Refer to the SQL command SET for information on correct values for these environment variables.

The following environment variables determine internal behavior of libpq; they override compiled-in defaults.

- PGSYSCONFDIR sets the directory containing the pg_service.conf file and in a future version possibly other system-wide configuration files.
- PGREUSEPASS behaves the same as the reusepass connection parameter. Use of this environment variable can disable automatic reconnection.
- PGLOCALEDIR sets the directory containing the locale files for message localization.

36.16. The Password File

The file `.pgpass` in a user's home directory can contain passwords to be used if the connection requires a password (and no password has been specified otherwise). On Microsoft Windows the file is named `%APPDATA%\postgresql\pgpass.conf` (where `%APPDATA%` refers to the Application Data subdirectory in the user's profile). Alternatively, the password file to use can be specified using the connection parameter passfile or the environment variable `PGPASSFILE`.

This file should contain lines of the following format:

hostname:*port*:*database*:*username*:*password*

(You can add a reminder comment to the file by copying the line above and preceding it with `#`.) Each of the first four fields can be a literal value, or `*`, which matches anything. The password field from the first line that matches the current connection parameters will be used. (Therefore, put more-specific entries first when you are using wildcards.) If an entry needs to contain `:` or `\`, escape this character with `\`. The host name field is matched to the `host` connection parameter if that is specified, otherwise to the `hostaddr` parameter if that is specified; if neither are given then the host name `localhost` is searched for. The host name `localhost` is also searched for when the connection is a Unix-domain socket connection and the `host` parameter matches libpq's default socket directory path. In a standby server, a database field of `replication` matches streaming replication connections made to the primary server. The database field is of limited usefulness otherwise, because users have the same password for all databases in the same cluster.

On Unix systems, the permissions on a password file must disallow any access to world or group; achieve this by a command such as `chmod 0600 ~/.pgpass`. If the permissions are less strict than this, the file will be ignored. On Microsoft Windows, it is assumed that the file is stored in a directory that is secure, so no special permissions check is made.

36.17. The Connection Service File

The connection service file allows libpq connection parameters to be associated with a single service name. That service name can then be specified in a libpq connection string, and the associated settings will be used. This allows connection parameters to be modified without requiring a recompile of the libpq-using application. The service name can also be specified using the `PGSERVICE` environment variable.

Service names can be defined in either a per-user service file or a system-wide file. If the same service name exists in both the user and the system file, the user file takes precedence. By default, the per-user service file is named `~/.pg_service.conf`. On Microsoft Windows, it is named `%APPDATA%\postgresql\.pg_service.conf` (where `%APPDATA%` refers to the Application Data subdirectory in the user's profile). A different file name can be specified by setting the environment variable `PGSERVICEFILE`. The system-wide file is named `pg_service.conf`. By default it is sought in the `etc` directory of the Postgres Pro installation (use `pg_config --sysconfdir` to identify this directory precisely). Another directory, but not a different file name, can be specified by setting the environment variable `PGSYSCONFDIR`.

Either service file uses an “INI file” format where the section name is the service name and the parameters are connection parameters; see Section 36.1.2 for a list. For example:

```
# comment
[mydb]
host=somehost
port=5433
user=admin
```

An example file is provided in the Postgres Pro installation at `share/pg_service.conf.sample`.

Connection parameters obtained from a service file are combined with parameters obtained from other sources. A service file setting overrides the corresponding environment variable, and in turn can be overridden by a value given directly in the connection string. For example, using the above service file, a connection string `service=mydb port=5434` will use host `somehost`, port `5434`, user `admin`, and other parameters as set by environment variables or built-in defaults.

36.18. LDAP Lookup of Connection Parameters

If libpq has been compiled with LDAP support (option `--with-ldap` for `configure`) it is possible to retrieve connection options like `host` or `dbname` via LDAP from a central server. The advantage is that if the connection parameters for a database change, the connection information doesn't have to be updated on all client machines.

LDAP connection parameter lookup uses the connection service file `pg_service.conf` (see Section 36.17). A line in a `pg_service.conf` stanza that starts with `ldap://` will be recognized as an LDAP URL and an LDAP query will be performed. The result must be a list of `keyword = value` pairs which will be used to set connection options. The URL must conform to *RFC 1959* and be of the form

`ldap://[`*`hostname`*`[:`*`port`*`]]/`*`search_base`*`?`*`attribute`*`?`*`search_scope`*`?`*`filter`*

where *`hostname`* defaults to `localhost` and *`port`* defaults to 389.

Processing of `pg_service.conf` is terminated after a successful LDAP lookup, but is continued if the LDAP server cannot be contacted. This is to provide a fallback with further LDAP URL lines that point to different LDAP servers, classical `keyword = value` pairs, or default connection options. If you would rather get an error message in this case, add a syntactically incorrect line after the LDAP URL.

A sample LDAP entry that has been created with the LDIF file

```
version:1
dn:cn=mydatabase,dc=mycompany,dc=com
changetype:add
objectclass:top
objectclass:device
cn:mydatabase
description:host=dbserver.mycompany.com
description:port=5439
description:dbname=mydb
description:user=mydb_user
description:sslmode=require
```

might be queried with the following LDAP URL:

```
ldap://ldap.mycompany.com/dc=mycompany,dc=com?description?one?(cn=mydatabase)
```

You can also mix regular service file entries with LDAP lookups. A complete example for a stanza in `pg_service.conf` would be:

```
# only host and port are stored in LDAP, specify dbname and user explicitly
[customerdb]
dbname=customer
user=appuser
ldap://ldap.acme.com/cn=dbserver,cn=hosts?pgconnectinfo?base?(objectclass=*)
```

36.19. SSL Support

Postgres Pro has native support for using SSL connections to encrypt client/server communications for increased security. See Section 18.9 for details about the server-side SSL functionality.

libpq reads the system-wide OpenSSL configuration file. By default, this file is named `openssl.cnf` and is located in the directory reported by `openssl version -d`. This default can be overridden by setting environment variable `OPENSSL_CONF` to the name of the desired configuration file.

36.19.1. Client Verification of Server Certificates

By default, Postgres Pro will not perform any verification of the server certificate. This means that it is possible to spoof the server identity (for example by modifying a DNS record or by taking over the server IP address) without the client knowing. In order to prevent spoofing, the client must be able to verify the server's identity via a chain of trust. A chain of trust is established by placing a root (self-signed) certificate authority (CA) certificate on one computer and a leaf certificate *signed* by the root certificate on another computer. It is also possible to use an “intermediate” certificate which is signed by the root certificate and signs leaf certificates.

To allow the client to verify the identity of the server, place a root certificate on the client and a leaf certificate signed by the root certificate on the server. To allow the server to verify the identity of the client, place a root certificate on the server and a leaf certificate signed by the root certificate on the client. One or more intermediate certificates (usually stored with the leaf certificate) can also be used to link the leaf certificate to the root certificate.

Once a chain of trust has been established, there are two ways for the client to validate the leaf certificate sent by the server. If the parameter `sslmode` is set to `verify-ca`, libpq will verify that the server is trustworthy by checking the certificate chain up to the root certificate stored on the client. If `sslmode` is set to `verify-full`, libpq will *also* verify that the server host name matches the name stored in the server certificate. The SSL connection will fail if the server certificate cannot be verified. `verify-full` is recommended in most security-sensitive environments.

In `verify-full` mode, the host name is matched against the certificate's Subject Alternative Name attribute(s), or against the Common Name attribute if no Subject Alternative Name of type `dNSName` is present. If the certificate's name attribute starts with an asterisk (`*`), the asterisk will be treated as a wildcard, which will match all characters *except* a dot (`.`). This means the certificate will not match subdomains. If the connection is made using an IP address instead of a host name, the IP address will be matched (without doing any DNS lookups).

To allow server certificate verification, one or more root certificates must be placed in the file `~/.postgresql/root.crt` in the user's home directory. (On Microsoft Windows the file is named `%APPDATA%\postgresql\root.crt`.) Intermediate certificates should also be added to the file if they are needed to link the certificate chain sent by the server to the root certificates stored on the client.

Certificate Revocation List (CRL) entries are also checked if the file `~/.postgresql/root.crl` exists (`%APPDATA%\postgresql\root.crl` on Microsoft Windows).

The location of the root certificate file and the CRL can be changed by setting the connection parameters `sslrootcert` and `sslcrl` or the environment variables `PGSSLROOTCERT` and `PGSSLCRL`. `sslcrldir` or the environment variable `PGSSLCRLDIR` can also be used to specify a directory containing CRL files.

> **Note**
>
> For backwards compatibility with earlier versions of Postgres Pro, if a root CA file exists, the behavior of `sslmode=require` will be the same as that of `verify-ca`, meaning the server certificate is validated against the CA. Relying on this behavior is discouraged, and applications that need certificate validation should always use `verify-ca` or `verify-full`.

36.19.2. Client Certificates

If the server attempts to verify the identity of the client by requesting the client's leaf certificate, libpq will send the certificate(s) stored in file `~/.postgresql/postgresql.crt` in the user's home directory. The certificates must chain to the root certificate trusted by the server. A matching private key file `~/.postgresql/postgresql.key` must also be present. On Microsoft Windows these files are named `%APPDATA%\postgresql\postgresql.crt` and `%APPDATA%\postgresql\postgresql.key`. The location of the certificate and key files can be overridden by the connection parameters `sslcert` and `sslkey`, or by the environment variables `PGSSLCERT` and `PGSSLKEY`.

On Unix systems, the permissions on the private key file must disallow any access to world or group; achieve this by a command such as `chmod 0600 ~/.postgresql/postgresql.key`. Alternatively, the file can be owned by root and have group read access (that is, `0640` permissions). That setup is intended for installations where certificate and key files are managed by the operating system. The user of libpq should then be made a member of the group that has access to those certificate and key files. (On Microsoft Windows, there is no file permissions check, since the `%APPDATA%\postgresql` directory is presumed secure.)

The first certificate in `postgresql.crt` must be the client's certificate because it must match the client's private key. “Intermediate” certificates can be optionally appended to the file — doing so avoids requiring storage of intermediate certificates on the server (ssl_ca_file).

The certificate and key may be in PEM or ASN.1 DER format.

The key may be stored in cleartext or encrypted with a passphrase using any algorithm supported by OpenSSL, like AES-128. If the key is stored encrypted, then the passphrase may be provided in the sslpassword connection option. If an encrypted key is supplied and the `sslpassword` option is absent or blank, a password will be prompted for interactively by OpenSSL with a `Enter PEM pass phrase:` prompt if a TTY is available. Applications can override the client certificate prompt and the handling of the `sslpassword` parameter by supplying their own key password callback; see `PQsetSSLKeyPassHook_OpenSSL`.

For instructions on creating certificates, see Section 18.9.5.

36.19.3. Protection Provided in Different Modes

The different values for the `sslmode` parameter provide different levels of protection. SSL can provide protection against three types of attacks:

Eavesdropping

If a third party can examine the network traffic between the client and the server, it can read both connection information (including the user name and password) and the data that is passed. SSL uses encryption to prevent this.

Man-in-the-middle (MITM)

If a third party can modify the data while passing between the client and server, it can pretend to be the server and therefore see and modify data *even if it is encrypted*. The third party can then forward the connection information and data to the original server, making it impossible to detect this attack. Common vectors to do this include DNS poisoning and address hijacking, whereby the client is directed to a different server than intended. There are also several other attack methods that can accomplish this. SSL uses certificate verification to prevent this, by authenticating the server to the client.

Impersonation

If a third party can pretend to be an authorized client, it can simply access data it should not have access to. Typically this can happen through insecure password management. SSL uses client certificates to prevent this, by making sure that only holders of valid certificates can access the server.

For a connection to be known SSL-secured, SSL usage must be configured on *both the client and the server* before the connection is made. If it is only configured on the server, the client may end up sending sensitive information (e.g., passwords) before it knows that the server requires high security. In libpq, secure connections can be ensured by setting the `sslmode` parameter to `verify-full` or `verify-ca`, and providing the system with a root certificate to verify against. This is analogous to using an `https` URL for encrypted web browsing.

Once the server has been authenticated, the client can pass sensitive data. This means that up until this point, the client does not need to know if certificates will be used for authentication, making it safe to specify that only in the server configuration.

All SSL options carry overhead in the form of encryption and key-exchange, so there is a trade-off that has to be made between performance and security. Table 36.1 illustrates the risks the different `sslmode` values protect against, and what statement they make about security and overhead.

Table 36.1. SSL Mode Descriptions

`sslmode`	**Eavesdropping protection**	**MITM protection**	**Statement**
`disable`	No	No	I don't care about security, and I don't want to pay the overhead of encryption.

sslmode	Eavesdropping protection	MITM protection	Statement
allow	Maybe	No	I don't care about security, but I will pay the overhead of encryption if the server insists on it.
prefer	Maybe	No	I don't care about encryption, but I wish to pay the overhead of encryption if the server supports it.
require	Yes	No	I want my data to be encrypted, and I accept the overhead. I trust that the network will make sure I always connect to the server I want.
verify-ca	Yes	Depends on CA policy	I want my data encrypted, and I accept the overhead. I want to be sure that I connect to a server that I trust.
verify-full	Yes	Yes	I want my data encrypted, and I accept the overhead. I want to be sure that I connect to a server I trust, and that it's the one I specify.

The difference between `verify-ca` and `verify-full` depends on the policy of the root CA. If a public CA is used, `verify-ca` allows connections to a server that *somebody else* may have registered with the CA. In this case, `verify-full` should always be used. If a local CA is used, or even a self-signed certificate, using `verify-ca` often provides enough protection.

The default value for `sslmode` is `prefer`. As is shown in the table, this makes no sense from a security point of view, and it only promises performance overhead if possible. It is only provided as the default for backward compatibility, and is not recommended in secure deployments.

36.19.4. SSL Client File Usage

Table 36.2 summarizes the files that are relevant to the SSL setup on the client.

Table 36.2. Libpq/Client SSL File Usage

File	Contents	Effect
`~/.postgresql/postgresql.crt`	client certificate	sent to server
`~/.postgresql/postgresql.key`	client private key	proves client certificate sent by owner; does not indicate certificate owner is trustworthy
`~/.postgresql/root.crt`	trusted certificate authorities	checks that server certificate is signed by a trusted certificate authority
`~/.postgresql/root.crl`	certificates revoked by certificate authorities	server certificate must not be on this list

36.19.5. SSL Library Initialization

If your application initializes `libssl` and/or `libcrypto` libraries and libpq is built with SSL support, you should call `PQinitOpenSSL` to tell libpq that the `libssl` and/or `libcrypto` libraries have been initialized by your application, so that libpq will not also initialize those libraries. However, this is unnecessary when using OpenSSL version 1.1.0 or later, as duplicate initializations are no longer problematic.

`PQinitOpenSSL`

Allows applications to select which security libraries to initialize.

```
void PQinitOpenSSL(int do_ssl, int do_crypto);
```

When *do_ssl* is non-zero, libpq will initialize the OpenSSL library before first opening a database connection. When *do_crypto* is non-zero, the `libcrypto` library will be initialized. By default (if `PQinitOpenSSL` is not called), both libraries are initialized. When SSL support is not compiled in, this function is present but does nothing.

If your application uses and initializes either OpenSSL or its underlying `libcrypto` library, you *must* call this function with zeroes for the appropriate parameter(s) before first opening a database connection. Also be sure that you have done that initialization before opening a database connection.

`PQinitSSL`

Allows applications to select which security libraries to initialize.

```
void PQinitSSL(int do_ssl);
```

This function is equivalent to `PQinitOpenSSL(do_ssl, do_ssl)`. It is sufficient for applications that initialize both or neither of OpenSSL and `libcrypto`.

`PQinitSSL` has been present since PostgreSQL 8.0, while `PQinitOpenSSL` was added in PostgreSQL 8.4, so `PQinitSSL` might be preferable for applications that need to work with older versions of libpq.

36.20. Behavior in Threaded Programs

libpq is reentrant and thread-safe by default. You might need to use special compiler command-line options when you compile your application code. Refer to your system's documentation for information about how to build thread-enabled applications. This function allows the querying of libpq's thread-safe status:

`PQisthreadsafe`

Returns the thread safety status of the libpq library.

```
int PQisthreadsafe();
```

Returns 1 if the libpq is thread-safe and 0 if it is not.

One thread restriction is that no two threads attempt to manipulate the same `PGconn` object at the same time. In particular, you cannot issue concurrent commands from different threads through the same connection object. (If you need to run concurrent commands, use multiple connections.)

`PGresult` objects are normally read-only after creation, and so can be passed around freely between threads. However, if you use any of the `PGresult`-modifying functions described in Section 36.12 or Section 36.14, it's up to you to avoid concurrent operations on the same `PGresult`, too.

The deprecated functions `PQrequestCancel` and `PQoidStatus` are not thread-safe and should not be used in multithread programs. `PQrequestCancel` can be replaced by `PQcancel`. `PQoidStatus` can be replaced by `PQoidValue`.

If you are using Kerberos inside your application (in addition to inside libpq), you will need to do locking around Kerberos calls because Kerberos functions are not thread-safe.

36.21. Building libpq Programs

To build (i.e., compile and link) a program using libpq you need to do all of the following things:

- Include the `libpq-fe.h` header file:

  ```
  #include <libpq-fe.h>
  ```

  If you failed to do that then you will normally get error messages from your compiler similar to:

  ```
  foo.c: In function `main':
  foo.c:34: `PGconn' undeclared (first use in this function)
  foo.c:35: `PGresult' undeclared (first use in this function)
  foo.c:54: `CONNECTION_BAD' undeclared (first use in this function)
  foo.c:68: `PGRES_COMMAND_OK' undeclared (first use in this function)
  ```

```
foo.c:95: `PGRES_TUPLES_OK' undeclared (first use in this function)
```

- Point your compiler to the directory where the Postgres Pro header files were installed, by supplying the `-I`*directory* option to your compiler. (In some cases the compiler will look into the directory in question by default, so you can omit this option.) For instance, your compile command line could look like:

  ```
  cc -c -I/usr/local/pgsql/include testprog.c
  ```

  If you are using makefiles then add the option to the `CPPFLAGS` variable:

  ```
  CPPFLAGS += -I/usr/local/pgsql/include
  ```

  If there is any chance that your program might be compiled by other users then you should not hardcode the directory location like that. Instead, you can run the utility `pg_config`to find out where the header files are on the local system:

  ```
  $ pg_config --includedir
  /usr/local/include
  ```

  If you have `pkg-config`installed, you can run instead:

  ```
  $ pkg-config --cflags libpq
  -I/usr/local/include
  ```

  Note that this will already include the `-I` in front of the path.

  Failure to specify the correct option to the compiler will result in an error message such as:

  ```
  testlibpq.c:8:22: libpq-fe.h: No such file or directory
  ```

- When linking the final program, specify the option `-lpq` so that the libpq library gets pulled in, as well as the option `-L`*directory* to point the compiler to the directory where the libpq library resides. (Again, the compiler will search some directories by default.) For maximum portability, put the `-L` option before the `-lpq` option. For example:

  ```
  cc -o testprog testprog1.o testprog2.o -L/usr/local/pgsql/lib -lpq
  ```

  You can find out the library directory using `pg_config` as well:

  ```
  $ pg_config --libdir
  /usr/local/pgsql/lib
  ```

  Or again use `pkg-config`:

  ```
  $ pkg-config --libs libpq
  -L/usr/local/pgsql/lib -lpq
  ```

  Note again that this prints the full options, not only the path.

  Error messages that point to problems in this area could look like the following:

  ```
  testlibpq.o: In function `main':
  testlibpq.o(.text+0x60): undefined reference to `PQsetdbLogin'
  testlibpq.o(.text+0x71): undefined reference to `PQstatus'
  testlibpq.o(.text+0xa4): undefined reference to `PQerrorMessage'
  ```

  This means you forgot `-lpq`.

  ```
  /usr/bin/ld: cannot find -lpq
  ```

  This means you forgot the `-L` option or did not specify the right directory.

36.22. Example Programs

These examples and others can be found in the directory `src/test/examples` in the PostgreSQL source code distribution.

Example 36.1. libpq Example Program 1

```
/*
 * src/test/examples/testlibpq.c
 *
 *
 * testlibpq.c
 *
 *      Test the C version of libpq, the PostgreSQL frontend library.
 */
#include <stdio.h>
#include <stdlib.h>
#include "libpq-fe.h"

static void
exit_nicely(PGconn *conn)
{
    PQfinish(conn);
    exit(1);
}

int
main(int argc, char **argv)
{
    const char *conninfo;
    PGconn     *conn;
    PGresult   *res;
    int         nFields;
    int         i,
                j;

    /*
     * If the user supplies a parameter on the command line, use it as the
     * conninfo string; otherwise default to setting dbname=postgres and using
     * environment variables or defaults for all other connection parameters.
     */
    if (argc > 1)
        conninfo = argv[1];
    else
        conninfo = "dbname = postgres";

    /* Make a connection to the database */
    conn = PQconnectdb(conninfo);

    /* Check to see that the backend connection was successfully made */
    if (PQstatus(conn) != CONNECTION_OK)
    {
        fprintf(stderr, "%s", PQerrorMessage(conn));
        exit_nicely(conn);
    }

    /* Set always-secure search path, so malicious users can't take control. */
    res = PQexec(conn,
                 "SELECT pg_catalog.set_config('search_path', '', false)");
    if (PQresultStatus(res) != PGRES_TUPLES_OK)
    {
        fprintf(stderr, "SET failed: %s", PQerrorMessage(conn));
```

```
    PQclear(res);
    exit_nicely(conn);
}

/*
 * Should PQclear PGresult whenever it is no longer needed to avoid memory
 * leaks
 */
PQclear(res);

/*
 * Our test case here involves using a cursor, for which we must be inside
 * a transaction block.  We could do the whole thing with a single
 * PQexec() of "select * from pg_database", but that's too trivial to make
 * a good example.
 */

/* Start a transaction block */
res = PQexec(conn, "BEGIN");
if (PQresultStatus(res) != PGRES_COMMAND_OK)
{
    fprintf(stderr, "BEGIN command failed: %s", PQerrorMessage(conn));
    PQclear(res);
    exit_nicely(conn);
}
PQclear(res);

/*
 * Fetch rows from pg_database, the system catalog of databases
 */
res = PQexec(conn, "DECLARE myportal CURSOR FOR select * from pg_database");
if (PQresultStatus(res) != PGRES_COMMAND_OK)
{
    fprintf(stderr, "DECLARE CURSOR failed: %s", PQerrorMessage(conn));
    PQclear(res);
    exit_nicely(conn);
}
PQclear(res);

res = PQexec(conn, "FETCH ALL in myportal");
if (PQresultStatus(res) != PGRES_TUPLES_OK)
{
    fprintf(stderr, "FETCH ALL failed: %s", PQerrorMessage(conn));
    PQclear(res);
    exit_nicely(conn);
}

/* first, print out the attribute names */
nFields = PQnfields(res);
for (i = 0; i < nFields; i++)
    printf("%-15s", PQfname(res, i));
printf("\n\n");

/* next, print out the rows */
for (i = 0; i < PQntuples(res); i++)
{
    for (j = 0; j < nFields; j++)
        printf("%-15s", PQgetvalue(res, i, j));
```

```
        printf("\n");
    }

    PQclear(res);

    /* close the portal ... we don't bother to check for errors ... */
    res = PQexec(conn, "CLOSE myportal");
    PQclear(res);

    /* end the transaction */
    res = PQexec(conn, "END");
    PQclear(res);

    /* close the connection to the database and cleanup */
    PQfinish(conn);

    return 0;
}
```

Example 36.2. libpq Example Program 2

```
/*
 * src/test/examples/testlibpq2.c
 *
 *
 * testlibpq2.c
 *      Test of the asynchronous notification interface
 *
 * Start this program, then from psql in another window do
 *   NOTIFY TBL2;
 * Repeat four times to get this program to exit.
 *
 * Or, if you want to get fancy, try this:
 * populate a database with the following commands
 * (provided in src/test/examples/testlibpq2.sql):
 *
 *   CREATE SCHEMA TESTLIBPQ2;
 *   SET search_path = TESTLIBPQ2;
 *   CREATE TABLE TBL1 (i int4);
 *   CREATE TABLE TBL2 (i int4);
 *   CREATE RULE r1 AS ON INSERT TO TBL1 DO
 *     (INSERT INTO TBL2 VALUES (new.i); NOTIFY TBL2);
 *
 * Start this program, then from psql do this four times:
 *
 *   INSERT INTO TESTLIBPQ2.TBL1 VALUES (10);
 */

#ifdef WIN32
#include <windows.h>
#endif
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <errno.h>
#include <sys/time.h>
#include <sys/types.h>
```

```
#ifdef HAVE_SYS_SELECT_H
#include <sys/select.h>
#endif

#include "libpq-fe.h"

static void
exit_nicely(PGconn *conn)
{
    PQfinish(conn);
    exit(1);
}

int
main(int argc, char **argv)
{
    const char *conninfo;
    PGconn     *conn;
    PGresult   *res;
    PGnotify   *notify;
    int         nnotifies;

    /*
     * If the user supplies a parameter on the command line, use it as the
     * conninfo string; otherwise default to setting dbname=postgres and using
     * environment variables or defaults for all other connection parameters.
     */
    if (argc > 1)
        conninfo = argv[1];
    else
        conninfo = "dbname = postgres";

    /* Make a connection to the database */
    conn = PQconnectdb(conninfo);

    /* Check to see that the backend connection was successfully made */
    if (PQstatus(conn) != CONNECTION_OK)
    {
        fprintf(stderr, "%s", PQerrorMessage(conn));
        exit_nicely(conn);
    }

    /* Set always-secure search path, so malicious users can't take control. */
    res = PQexec(conn,
                 "SELECT pg_catalog.set_config('search_path', '', false)");
    if (PQresultStatus(res) != PGRES_TUPLES_OK)
    {
        fprintf(stderr, "SET failed: %s", PQerrorMessage(conn));
        PQclear(res);
        exit_nicely(conn);
    }

    /*
     * Should PQclear PGresult whenever it is no longer needed to avoid memory
     * leaks
     */
    PQclear(res);
```

```
    /*
     * Issue LISTEN command to enable notifications from the rule's NOTIFY.
     */
    res = PQexec(conn, "LISTEN TBL2");
    if (PQresultStatus(res) != PGRES_COMMAND_OK)
    {
        fprintf(stderr, "LISTEN command failed: %s", PQerrorMessage(conn));
        PQclear(res);
        exit_nicely(conn);
    }
    PQclear(res);

    /* Quit after four notifies are received. */
    nnotifies = 0;
    while (nnotifies < 4)
    {
        /*
         * Sleep until something happens on the connection.  We use select(2)
         * to wait for input, but you could also use poll() or similar
         * facilities.
         */
        int         sock;
        fd_set      input_mask;

        sock = PQsocket(conn);

        if (sock < 0)
            break;              /* shouldn't happen */

        FD_ZERO(&input_mask);
        FD_SET(sock, &input_mask);

        if (select(sock + 1, &input_mask, NULL, NULL, NULL) < 0)
        {
            fprintf(stderr, "select() failed: %s\n", strerror(errno));
            exit_nicely(conn);
        }

        /* Now check for input */
        PQconsumeInput(conn);
        while ((notify = PQnotifies(conn)) != NULL)
        {
            fprintf(stderr,
                    "ASYNC NOTIFY of '%s' received from backend PID %d\n",
                    notify->relname, notify->be_pid);
            PQfreemem(notify);
            nnotifies++;
            PQconsumeInput(conn);
        }
    }

    fprintf(stderr, "Done.\n");

    /* close the connection to the database and cleanup */
    PQfinish(conn);

    return 0;
}
```

Example 36.3. libpq Example Program 3

```
/*
 * src/test/examples/testlibpq3.c
 *
 *
 * testlibpq3.c
 *      Test out-of-line parameters and binary I/O.
 *
 * Before running this, populate a database with the following commands
 * (provided in src/test/examples/testlibpq3.sql):
 *
 * CREATE SCHEMA testlibpq3;
 * SET search_path = testlibpq3;
 * SET standard_conforming_strings = ON;
 * CREATE TABLE test1 (i int4, t text, b bytea);
 * INSERT INTO test1 values (1, 'joe''s place', '\000\001\002\003\004');
 * INSERT INTO test1 values (2, 'ho there', '\004\003\002\001\000');
 *
 * The expected output is:
 *
 * tuple 0: got
 *  i = (4 bytes) 1
 *  t = (11 bytes) 'joe's place'
 *  b = (5 bytes) \000\001\002\003\004
 *
 * tuple 0: got
 *  i = (4 bytes) 2
 *  t = (8 bytes) 'ho there'
 *  b = (5 bytes) \004\003\002\001\000
 */

#ifdef WIN32
#include <windows.h>
#endif

#include <stdio.h>
#include <stdlib.h>
#include <stdint.h>
#include <string.h>
#include <sys/types.h>
#include "libpq-fe.h"

/* for ntohl/htonl */
#include <netinet/in.h>
#include <arpa/inet.h>


static void
exit_nicely(PGconn *conn)
{
    PQfinish(conn);
    exit(1);
}

/*
```

```
 * This function prints a query result that is a binary-format fetch from
 * a table defined as in the comment above.  We split it out because the
 * main() function uses it twice.
 */
static void
show_binary_results(PGresult *res)
{
    int         i,
                j;
    int         i_fnum,
                t_fnum,
                b_fnum;

    /* Use PQfnumber to avoid assumptions about field order in result */
    i_fnum = PQfnumber(res, "i");
    t_fnum = PQfnumber(res, "t");
    b_fnum = PQfnumber(res, "b");

    for (i = 0; i < PQntuples(res); i++)
    {
        char       *iptr;
        char       *tptr;
        char       *bptr;
        int         blen;
        int         ival;

        /* Get the field values (we ignore possibility they are null!) */
        iptr = PQgetvalue(res, i, i_fnum);
        tptr = PQgetvalue(res, i, t_fnum);
        bptr = PQgetvalue(res, i, b_fnum);

        /*
         * The binary representation of INT4 is in network byte order, which
         * we'd better coerce to the local byte order.
         */
        ival = ntohl(*((uint32_t *) iptr));

        /*
         * The binary representation of TEXT is, well, text, and since libpq
         * was nice enough to append a zero byte to it, it'll work just fine
         * as a C string.
         *
         * The binary representation of BYTEA is a bunch of bytes, which could
         * include embedded nulls so we have to pay attention to field length.
         */
        blen = PQgetlength(res, i, b_fnum);

        printf("tuple %d: got\n", i);
        printf(" i = (%d bytes) %d\n",
               PQgetlength(res, i, i_fnum), ival);
        printf(" t = (%d bytes) '%s'\n",
               PQgetlength(res, i, t_fnum), tptr);
        printf(" b = (%d bytes) ", blen);
        for (j = 0; j < blen; j++)
            printf("\\%03o", bptr[j]);
        printf("\n\n");
    }
}
```

```
int
main(int argc, char **argv)
{
    const char *conninfo;
    PGconn     *conn;
    PGresult   *res;
    const char *paramValues[1];
    int         paramLengths[1];
    int         paramFormats[1];
    uint32_t    binaryIntVal;

    /*
     * If the user supplies a parameter on the command line, use it as the
     * conninfo string; otherwise default to setting dbname=postgres and using
     * environment variables or defaults for all other connection parameters.
     */
    if (argc > 1)
        conninfo = argv[1];
    else
        conninfo = "dbname = postgres";

    /* Make a connection to the database */
    conn = PQconnectdb(conninfo);

    /* Check to see that the backend connection was successfully made */
    if (PQstatus(conn) != CONNECTION_OK)
    {
        fprintf(stderr, "%s", PQerrorMessage(conn));
        exit_nicely(conn);
    }

    /* Set always-secure search path, so malicious users can't take control. */
    res = PQexec(conn, "SET search_path = testlibpq3");
    if (PQresultStatus(res) != PGRES_COMMAND_OK)
    {
        fprintf(stderr, "SET failed: %s", PQerrorMessage(conn));
        PQclear(res);
        exit_nicely(conn);
    }
    PQclear(res);

    /*
     * The point of this program is to illustrate use of PQexecParams() with
     * out-of-line parameters, as well as binary transmission of data.
     *
     * This first example transmits the parameters as text, but receives the
     * results in binary format.  By using out-of-line parameters we can avoid
     * a lot of tedious mucking about with quoting and escaping, even though
     * the data is text.  Notice how we don't have to do anything special with
     * the quote mark in the parameter value.
     */

    /* Here is our out-of-line parameter value */
    paramValues[0] = "joe's place";

    res = PQexecParams(conn,
                       "SELECT * FROM test1 WHERE t = $1",
```

```
                    1,       /* one param */
                    NULL,    /* let the backend deduce param type */
                    paramValues,
                    NULL,    /* don't need param lengths since text */
                    NULL,    /* default to all text params */
                    1);      /* ask for binary results */

if (PQresultStatus(res) != PGRES_TUPLES_OK)
{
    fprintf(stderr, "SELECT failed: %s", PQerrorMessage(conn));
    PQclear(res);
    exit_nicely(conn);
}

show_binary_results(res);

PQclear(res);

/*
 * In this second example we transmit an integer parameter in binary form,
 * and again retrieve the results in binary form.
 *
 * Although we tell PQexecParams we are letting the backend deduce
 * parameter type, we really force the decision by casting the parameter
 * symbol in the query text.  This is a good safety measure when sending
 * binary parameters.
 */

/* Convert integer value "2" to network byte order */
binaryIntVal = htonl((uint32_t) 2);

/* Set up parameter arrays for PQexecParams */
paramValues[0] = (char *) &binaryIntVal;
paramLengths[0] = sizeof(binaryIntVal);
paramFormats[0] = 1;        /* binary */

res = PQexecParams(conn,
                    "SELECT * FROM test1 WHERE i = $1::int4",
                    1,       /* one param */
                    NULL,    /* let the backend deduce param type */
                    paramValues,
                    paramLengths,
                    paramFormats,
                    1);      /* ask for binary results */

if (PQresultStatus(res) != PGRES_TUPLES_OK)
{
    fprintf(stderr, "SELECT failed: %s", PQerrorMessage(conn));
    PQclear(res);
    exit_nicely(conn);
}

show_binary_results(res);

PQclear(res);

/* close the connection to the database and cleanup */
PQfinish(conn);
```

```
    return 0;
}
```

Chapter 37. Large Objects

Postgres Pro has a *large object* facility, which provides stream-style access to user data that is stored in a special large-object structure. Streaming access is useful when working with data values that are too large to manipulate conveniently as a whole.

This chapter describes the implementation and the programming and query language interfaces to Postgres Pro large object data. We use the libpq C library for the examples in this chapter, but most programming interfaces native to Postgres Pro support equivalent functionality. Other interfaces might use the large object interface internally to provide generic support for large values. This is not described here.

37.1. Introduction

All large objects are stored in a single system table named `pg_largeobject`. Each large object also has an entry in the system table `pg_largeobject_metadata`. Large objects can be created, modified, and deleted using a read/write API that is similar to standard operations on files.

Postgres Pro also supports a storage system called "TOAST", which automatically stores values larger than a single database page into a secondary storage area per table. This makes the large object facility partially obsolete. One remaining advantage of the large object facility is that it allows values up to 4 TB in size, whereas TOASTed fields can be at most 1 GB. Also, reading and updating portions of a large object can be done efficiently, while most operations on a TOASTed field will read or write the whole value as a unit.

37.2. Implementation Features

The large object implementation breaks large objects up into "chunks" and stores the chunks in rows in the database. A B-tree index guarantees fast searches for the correct chunk number when doing random access reads and writes.

The chunks stored for a large object do not have to be contiguous. For example, if an application opens a new large object, seeks to offset 1000000, and writes a few bytes there, this does not result in allocation of 1000000 bytes worth of storage; only of chunks covering the range of data bytes actually written. A read operation will, however, read out zeroes for any unallocated locations preceding the last existing chunk. This corresponds to the common behavior of "sparsely allocated" files in Unix file systems.

As of PostgreSQL 9.0, large objects have an owner and a set of access permissions, which can be managed using GRANT and REVOKE. `SELECT` privileges are required to read a large object, and `UPDATE` privileges are required to write or truncate it. Only the large object's owner (or a database superuser) can delete, comment on, or change the owner of a large object. To adjust this behavior for compatibility with prior releases, see the lo_compat_privileges run-time parameter.

37.3. Client Interfaces

This section describes the facilities that Postgres Pro's libpq client interface library provides for accessing large objects. The Postgres Pro large object interface is modeled after the Unix file-system interface, with analogues of `open`, `read`, `write`, `lseek`, etc.

All large object manipulation using these functions *must* take place within an SQL transaction block, since large object file descriptors are only valid for the duration of a transaction.

If an error occurs while executing any one of these functions, the function will return an otherwise-impossible value, typically 0 or -1. A message describing the error is stored in the connection object and can be retrieved with `PQerrorMessage`.

Client applications that use these functions should include the header file `libpq/libpq-fs.h` and link with the libpq library.

Client applications cannot use these functions while a libpq connection is in pipeline mode.

37.3.1. Creating a Large Object

The function

```
Oid lo_creat(PGconn *conn, int mode);
```

creates a new large object. The return value is the OID that was assigned to the new large object, or `InvalidOid` (zero) on failure. *`mode`* is unused and ignored as of PostgreSQL 8.1; however, for backward compatibility with earlier releases it is best to set it to `INV_READ`, `INV_WRITE`, or `INV_READ | INV_WRITE`. (These symbolic constants are defined in the header file `libpq/libpq-fs.h`.)

An example:

```
inv_oid = lo_creat(conn, INV_READ|INV_WRITE);
```

The function

```
Oid lo_create(PGconn *conn, Oid lobjId);
```

also creates a new large object. The OID to be assigned can be specified by *`lobjId`*; if so, failure occurs if that OID is already in use for some large object. If *`lobjId`* is `InvalidOid` (zero) then `lo_create` assigns an unused OID (this is the same behavior as `lo_creat`). The return value is the OID that was assigned to the new large object, or `InvalidOid` (zero) on failure.

`lo_create` is new as of PostgreSQL 8.1; if this function is run against an older server version, it will fail and return `InvalidOid`.

An example:

```
inv_oid = lo_create(conn, desired_oid);
```

37.3.2. Importing a Large Object

To import an operating system file as a large object, call

```
Oid lo_import(PGconn *conn, const char *filename);
```

`filename` specifies the operating system name of the file to be imported as a large object. The return value is the OID that was assigned to the new large object, or `InvalidOid` (zero) on failure. Note that the file is read by the client interface library, not by the server; so it must exist in the client file system and be readable by the client application.

The function

```
Oid lo_import_with_oid(PGconn *conn, const char *filename, Oid lobjId);
```

also imports a new large object. The OID to be assigned can be specified by *`lobjId`*; if so, failure occurs if that OID is already in use for some large object. If *`lobjId`* is `InvalidOid` (zero) then `lo_import_with_oid` assigns an unused OID (this is the same behavior as `lo_import`). The return value is the OID that was assigned to the new large object, or `InvalidOid` (zero) on failure.

`lo_import_with_oid` is new as of PostgreSQL 8.4 and uses `lo_create` internally which is new in 8.1; if this function is run against 8.0 or before, it will fail and return `InvalidOid`.

37.3.3. Exporting a Large Object

To export a large object into an operating system file, call

```
int lo_export(PGconn *conn, Oid lobjId, const char *filename);
```

The *`lobjId`* argument specifies the OID of the large object to export and the *`filename`* argument specifies the operating system name of the file. Note that the file is written by the client interface library, not by the server. Returns 1 on success, -1 on failure.

37.3.4. Opening an Existing Large Object

To open an existing large object for reading or writing, call

```
int lo_open(PGconn *conn, Oid lobjId, int mode);
```

The *lobjId* argument specifies the OID of the large object to open. The *mode* bits control whether the object is opened for reading (INV_READ), writing (INV_WRITE), or both. (These symbolic constants are defined in the header file libpq/libpq-fs.h.) lo_open returns a (non-negative) large object descriptor for later use in lo_read, lo_write, lo_lseek, lo_lseek64, lo_tell, lo_tell64, lo_truncate, lo_truncate64, and lo_close. The descriptor is only valid for the duration of the current transaction. On failure, -1 is returned.

The server currently does not distinguish between modes INV_WRITE and INV_READ | INV_WRITE: you are allowed to read from the descriptor in either case. However there is a significant difference between these modes and INV_READ alone: with INV_READ you cannot write on the descriptor, and the data read from it will reflect the contents of the large object at the time of the transaction snapshot that was active when lo_open was executed, regardless of later writes by this or other transactions. Reading from a descriptor opened with INV_WRITE returns data that reflects all writes of other committed transactions as well as writes of the current transaction. This is similar to the behavior of REPEATABLE READ versus READ COMMITTED transaction modes for ordinary SQL SELECT commands.

lo_open will fail if SELECT privilege is not available for the large object, or if INV_WRITE is specified and UPDATE privilege is not available. (Prior to PostgreSQL 11, these privilege checks were instead performed at the first actual read or write call using the descriptor.) These privilege checks can be disabled with the lo_compat_privileges run-time parameter.

An example:

```
inv_fd = lo_open(conn, inv_oid, INV_READ|INV_WRITE);
```

37.3.5. Writing Data to a Large Object

The function

```
int lo_write(PGconn *conn, int fd, const char *buf, size_t len);
```

writes *len* bytes from *buf* (which must be of size *len*) to large object descriptor *fd*. The *fd* argument must have been returned by a previous lo_open. The number of bytes actually written is returned (in the current implementation, this will always equal *len* unless there is an error). In the event of an error, the return value is -1.

Although the *len* parameter is declared as size_t, this function will reject length values larger than INT_MAX. In practice, it's best to transfer data in chunks of at most a few megabytes anyway.

37.3.6. Reading Data from a Large Object

The function

```
int lo_read(PGconn *conn, int fd, char *buf, size_t len);
```

reads up to *len* bytes from large object descriptor *fd* into *buf* (which must be of size *len*). The *fd* argument must have been returned by a previous lo_open. The number of bytes actually read is returned; this will be less than *len* if the end of the large object is reached first. In the event of an error, the return value is -1.

Although the *len* parameter is declared as size_t, this function will reject length values larger than INT_MAX. In practice, it's best to transfer data in chunks of at most a few megabytes anyway.

37.3.7. Seeking in a Large Object

To change the current read or write location associated with a large object descriptor, call

```
int lo_lseek(PGconn *conn, int fd, int offset, int whence);
```

This function moves the current location pointer for the large object descriptor identified by *fd* to the new location specified by *offset*. The valid values for *whence* are SEEK_SET (seek from object start), SEEK_CUR (seek from current position), and SEEK_END (seek from object end). The return value is the new location pointer, or -1 on error.

When dealing with large objects that might exceed 2GB in size, instead use

```
pg_int64 lo_lseek64(PGconn *conn, int fd, pg_int64 offset, int whence);
```

This function has the same behavior as `lo_lseek`, but it can accept an *`offset`* larger than 2GB and/or deliver a result larger than 2GB. Note that `lo_lseek` will fail if the new location pointer would be greater than 2GB.

`lo_lseek64` is new as of PostgreSQL 9.3. If this function is run against an older server version, it will fail and return -1.

37.3.8. Obtaining the Seek Position of a Large Object

To obtain the current read or write location of a large object descriptor, call

```
int lo_tell(PGconn *conn, int fd);
```

If there is an error, the return value is -1.

When dealing with large objects that might exceed 2GB in size, instead use

```
pg_int64 lo_tell64(PGconn *conn, int fd);
```

This function has the same behavior as `lo_tell`, but it can deliver a result larger than 2GB. Note that `lo_tell` will fail if the current read/write location is greater than 2GB.

`lo_tell64` is new as of PostgreSQL 9.3. If this function is run against an older server version, it will fail and return -1.

37.3.9. Truncating a Large Object

To truncate a large object to a given length, call

```
int lo_truncate(PGconn *conn, int fd, size_t len);
```

This function truncates the large object descriptor *`fd`* to length *`len`*. The *`fd`* argument must have been returned by a previous `lo_open`. If *`len`* is greater than the large object's current length, the large object is extended to the specified length with null bytes ('\0'). On success, `lo_truncate` returns zero. On error, the return value is -1.

The read/write location associated with the descriptor *`fd`* is not changed.

Although the *`len`* parameter is declared as `size_t`, `lo_truncate` will reject length values larger than `INT_MAX`.

When dealing with large objects that might exceed 2GB in size, instead use

```
int lo_truncate64(PGconn *conn, int fd, pg_int64 len);
```

This function has the same behavior as `lo_truncate`, but it can accept a *`len`* value exceeding 2GB.

`lo_truncate` is new as of PostgreSQL 8.3; if this function is run against an older server version, it will fail and return -1.

`lo_truncate64` is new as of PostgreSQL 9.3; if this function is run against an older server version, it will fail and return -1.

37.3.10. Closing a Large Object Descriptor

A large object descriptor can be closed by calling

```
int lo_close(PGconn *conn, int fd);
```

where *`fd`* is a large object descriptor returned by `lo_open`. On success, `lo_close` returns zero. On error, the return value is -1.

Any large object descriptors that remain open at the end of a transaction will be closed automatically.

37.3.11. Removing a Large Object

To remove a large object from the database, call

```
int lo_unlink(PGconn *conn, Oid lobjId);
```

The *lobjId* argument specifies the OID of the large object to remove. Returns 1 if successful, -1 on failure.

37.4. Server-Side Functions

Server-side functions tailored for manipulating large objects from SQL are listed in Table 37.1.

Table 37.1. SQL-Oriented Large Object Functions

Function **Description** **Example(s)**

`lo_from_bytea` (*loid* `oid`, *data* `bytea`) → `oid`
Creates a large object and stores *data* in it. If *loid* is zero then the system will choose a free OID, otherwise that OID is used (with an error if some large object already has that OID). On success, the large object's OID is returned.
`lo_from_bytea(0, '\xffffff00')` → `24528`

`lo_put` (*loid* `oid`, *offset* `bigint`, *data* `bytea`) → `void` Writes *data* starting at the given offset within the large object; the large object is enlarged if necessary. `lo_put(24528, 1, '\xaa')` →

`lo_get` (*loid* `oid` [, *offset* `bigint`, *length* `integer`]) → `bytea`
Extracts the large object's contents, or a substring thereof.
`lo_get(24528, 0, 3)` → `\xffaaff`

There are additional server-side functions corresponding to each of the client-side functions described earlier; indeed, for the most part the client-side functions are simply interfaces to the equivalent server-side functions. The ones just as convenient to call via SQL commands are `lo_creat`, `lo_create`, `lo_unlink`, `lo_import`, and `lo_export`. Here are examples of their use:

```
CREATE TABLE image (
    name            text,
    raster          oid
);

SELECT lo_creat(-1);        -- returns OID of new, empty large object

SELECT lo_create(43213);    -- attempts to create large object with OID 43213

SELECT lo_unlink(173454);  -- deletes large object with OID 173454

INSERT INTO image (name, raster)
    VALUES ('beautiful image', lo_import('/etc/motd'));

INSERT INTO image (name, raster)  -- same as above, but specify OID to use
    VALUES ('beautiful image', lo_import('/etc/motd', 68583));

SELECT lo_export(image.raster, '/tmp/motd') FROM image
    WHERE name = 'beautiful image';
```

The server-side `lo_import` and `lo_export` functions behave considerably differently from their client-side analogs. These two functions read and write files in the server's file system, using the permissions of the database's owning user. Therefore, by default their use is restricted to superusers. In contrast, the client-side import and export functions read and write files in the client's file system, using the permissions of the client program. The client-side functions do not require any database privileges, except the privilege to read or write the large object in question.

> **Caution**
>
> It is possible to GRANT use of the server-side `lo_import` and `lo_export` functions to non-superusers, but careful consideration of the security implications is required. A malicious user of such privileges could easily parlay them into becoming superuser (for example by rewriting server configuration files), or could attack the rest of the server's file system without bothering to obtain database superuser privileges as such. *Access to roles having such privilege must therefore be guarded just as carefully as access to superuser roles.* Nonetheless, if use of server-side `lo_import` or `lo_export` is needed for some routine task, it's safer to use a role with such privileges than one with full superuser privileges, as that helps to reduce the risk of damage from accidental errors.

The functionality of `lo_read` and `lo_write` is also available via server-side calls, but the names of the server-side functions differ from the client side interfaces in that they do not contain underscores. You must call these functions as `loread` and `lowrite`.

37.5. Example Program

Example 37.1 is a sample program which shows how the large object interface in libpq can be used. Parts of the program are commented out for the reader's benefit.

Example 37.1. Large Objects with libpq Example Program

```
/*-------------------------------------------------------------------
 *
 * testlo.c
 *    test using large objects with libpq
 *
 * Portions Copyright (c) 1996-2021, PostgreSQL Global Development Group
 * Portions Copyright (c) 1994, Regents of the University of California
 *
 *
 * IDENTIFICATION
 *    src/test/examples/testlo.c
 *
 *-------------------------------------------------------------------
 */
#include <stdio.h>
#include <stdlib.h>

#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <unistd.h>

#include "libpq-fe.h"
#include "libpq/libpq-fs.h"

#define BUFSIZE         1024

/*
 * importFile -
 *    import file "in_filename" into database as large object "lobjOid"
 *
 */
static Oid
importFile(PGconn *conn, char *filename)
{
    Oid         lobjId;
```

```
    int         lobj_fd;
    char        buf[BUFSIZE];
    int         nbytes,
                tmp;
    int         fd;

    /*
     * open the file to be read in
     */
    fd = open(filename, O_RDONLY, 0666);
    if (fd < 0)
    {                           /* error */
        fprintf(stderr, "cannot open unix file\"%s\"\n", filename);
    }

    /*
     * create the large object
     */
    lobjId = lo_creat(conn, INV_READ | INV_WRITE);
    if (lobjId == 0)
        fprintf(stderr, "cannot create large object");

    lobj_fd = lo_open(conn, lobjId, INV_WRITE);

    /*
     * read in from the Unix file and write to the inversion file
     */
    while ((nbytes = read(fd, buf, BUFSIZE)) > 0)
    {
        tmp = lo_write(conn, lobj_fd, buf, nbytes);
        if (tmp < nbytes)
            fprintf(stderr, "error while reading \"%s\"", filename);
    }

    close(fd);
    lo_close(conn, lobj_fd);

    return lobjId;
}

static void
pickout(PGconn *conn, Oid lobjId, int start, int len)
{
    int         lobj_fd;
    char       *buf;
    int         nbytes;
    int         nread;

    lobj_fd = lo_open(conn, lobjId, INV_READ);
    if (lobj_fd < 0)
        fprintf(stderr, "cannot open large object %u", lobjId);

    lo_lseek(conn, lobj_fd, start, SEEK_SET);
    buf = malloc(len + 1);

    nread = 0;
    while (len - nread > 0)
    {
```

```
        nbytes = lo_read(conn, lobj_fd, buf, len - nread);
        buf[nbytes] = '\0';
        fprintf(stderr, ">>> %s", buf);
        nread += nbytes;
        if (nbytes <= 0)
            break;              /* no more data? */
    }
    free(buf);
    fprintf(stderr, "\n");
    lo_close(conn, lobj_fd);
}

static void
overwrite(PGconn *conn, Oid lobjId, int start, int len)
{
    int         lobj_fd;
    char       *buf;
    int         nbytes;
    int         nwritten;
    int         i;

    lobj_fd = lo_open(conn, lobjId, INV_WRITE);
    if (lobj_fd < 0)
        fprintf(stderr, "cannot open large object %u", lobjId);

    lo_lseek(conn, lobj_fd, start, SEEK_SET);
    buf = malloc(len + 1);

    for (i = 0; i < len; i++)
        buf[i] = 'X';
    buf[i] = '\0';

    nwritten = 0;
    while (len - nwritten > 0)
    {
        nbytes = lo_write(conn, lobj_fd, buf + nwritten, len - nwritten);
        nwritten += nbytes;
        if (nbytes <= 0)
        {
            fprintf(stderr, "\nWRITE FAILED!\n");
            break;
        }
    }
    free(buf);
    fprintf(stderr, "\n");
    lo_close(conn, lobj_fd);
}


/*
 * exportFile -
 *    export large object "lobjOid" to file "out_filename"
 *
 */
static void
exportFile(PGconn *conn, Oid lobjId, char *filename)
{
    int         lobj_fd;
```

```
    char        buf[BUFSIZE];
    int         nbytes,
                tmp;
    int         fd;

    /*
     * open the large object
     */
    lobj_fd = lo_open(conn, lobjId, INV_READ);
    if (lobj_fd < 0)
        fprintf(stderr, "cannot open large object %u", lobjId);

    /*
     * open the file to be written to
     */
    fd = open(filename, O_CREAT | O_WRONLY | O_TRUNC, 0666);
    if (fd < 0)
    {                           /* error */
        fprintf(stderr, "cannot open unix file\"%s\"",
                filename);
    }

    /*
     * read in from the inversion file and write to the Unix file
     */
    while ((nbytes = lo_read(conn, lobj_fd, buf, BUFSIZE)) > 0)
    {
        tmp = write(fd, buf, nbytes);
        if (tmp < nbytes)
        {
            fprintf(stderr, "error while writing \"%s\"",
                    filename);
        }
    }

    lo_close(conn, lobj_fd);
    close(fd);
}

static void
exit_nicely(PGconn *conn)
{
    PQfinish(conn);
    exit(1);
}

int
main(int argc, char **argv)
{
    char       *in_filename,
               *out_filename;
    char       *database;
    Oid         lobjOid;
    PGconn     *conn;
    PGresult   *res;

    if (argc != 4)
    {
```

```
        fprintf(stderr, "Usage: %s database_name in_filename out_filename\n",
                argv[0]);
        exit(1);
    }

    database = argv[1];
    in_filename = argv[2];
    out_filename = argv[3];

    /*
     * set up the connection
     */
    conn = PQsetdb(NULL, NULL, NULL, NULL, database);

    /* check to see that the backend connection was successfully made */
    if (PQstatus(conn) != CONNECTION_OK)
    {
        fprintf(stderr, "%s", PQerrorMessage(conn));
        exit_nicely(conn);
    }

    /* Set always-secure search path, so malicious users can't take control. */
    res = PQexec(conn,
                 "SELECT pg_catalog.set_config('search_path', '', false)");
    if (PQresultStatus(res) != PGRES_TUPLES_OK)
    {
        fprintf(stderr, "SET failed: %s", PQerrorMessage(conn));
        PQclear(res);
        exit_nicely(conn);
    }
    PQclear(res);

    res = PQexec(conn, "begin");
    PQclear(res);
    printf("importing file \"%s\" ...\n", in_filename);
/*  lobjOid = importFile(conn, in_filename); */
    lobjOid = lo_import(conn, in_filename);
    if (lobjOid == 0)
        fprintf(stderr, "%s\n", PQerrorMessage(conn));
    else
    {
        printf("\tas large object %u.\n", lobjOid);

        printf("picking out bytes 1000-2000 of the large object\n");
        pickout(conn, lobjOid, 1000, 1000);

        printf("overwriting bytes 1000-2000 of the large object with X's\n");
        overwrite(conn, lobjOid, 1000, 1000);

        printf("exporting large object to file \"%s\" ...\n", out_filename);
/*      exportFile(conn, lobjOid, out_filename); */
        if (lo_export(conn, lobjOid, out_filename) < 0)
            fprintf(stderr, "%s\n", PQerrorMessage(conn));
    }

    res = PQexec(conn, "end");
    PQclear(res);
    PQfinish(conn);
```

```
    return 0;
}
```

Chapter 38. ECPG — Embedded SQL in C

This chapter describes the embedded SQL package for Postgres Pro. It was written by Linus Tolke (<linus@epact.se>) and Michael Meskes (<meskes@postgresql.org>). Originally it was written to work with C. It also works with C++, but it does not recognize all C++ constructs yet.

This documentation is quite incomplete. But since this interface is standardized, additional information can be found in many resources about SQL.

38.1. The Concept

An embedded SQL program consists of code written in an ordinary programming language, in this case C, mixed with SQL commands in specially marked sections. To build the program, the source code (`*.pgc`) is first passed through the embedded SQL preprocessor, which converts it to an ordinary C program (`*.c`), and afterwards it can be processed by a C compiler. (For details about the compiling and linking see Section 38.10.) Converted ECPG applications call functions in the libpq library through the embedded SQL library (ecpglib), and communicate with the Postgres Pro server using the normal frontend-backend protocol.

Embedded SQL has advantages over other methods for handling SQL commands from C code. First, it takes care of the tedious passing of information to and from variables in your C program. Second, the SQL code in the program is checked at build time for syntactical correctness. Third, embedded SQL in C is specified in the SQL standard and supported by many other SQL database systems. The Postgres Pro implementation is designed to match this standard as much as possible, and it is usually possible to port embedded SQL programs written for other SQL databases to Postgres Pro with relative ease.

As already stated, programs written for the embedded SQL interface are normal C programs with special code inserted to perform database-related actions. This special code always has the form:

```
EXEC SQL ...;
```

These statements syntactically take the place of a C statement. Depending on the particular statement, they can appear at the global level or within a function.

Embedded SQL statements follow the case-sensitivity rules of normal SQL code, and not those of C. Also they allow nested C-style comments as per the SQL standard. The C part of the program, however, follows the C standard of not accepting nested comments. Embedded SQL statements likewise use SQL rules, not C rules, for parsing quoted strings and identifiers. (See Section 4.1.2.1 and Section 4.1.1 respectively. Note that ECPG assumes that `standard_conforming_strings` is `on`.) Of course, the C part of the program follows C quoting rules.

The following sections explain all the embedded SQL statements.

38.2. Managing Database Connections

This section describes how to open, close, and switch database connections.

38.2.1. Connecting to the Database Server

One connects to a database using the following statement:

```
EXEC SQL CONNECT TO target [AS connection-name] [USER user-name];
```

The *target* can be specified in the following ways:

- *dbname*[@*hostname*][:*port*]
- tcp:postgresql://*hostname*[:*port*][/*dbname*][?*options*]
- unix:postgresql://localhost[:*port*][/*dbname*][?*options*]
- an SQL string literal containing one of the above forms
- a reference to a character variable containing one of the above forms (see examples)

- `DEFAULT`

The connection target `DEFAULT` initiates a connection to the default database under the default user name. No separate user name or connection name can be specified in that case.

If you specify the connection target directly (that is, not as a string literal or variable reference), then the components of the target are passed through normal SQL parsing; this means that, for example, the *`hostname`* must look like one or more SQL identifiers separated by dots, and those identifiers will be case-folded unless double-quoted. Values of any *`options`* must be SQL identifiers, integers, or variable references. Of course, you can put nearly anything into an SQL identifier by double-quoting it. In practice, it is probably less error-prone to use a (single-quoted) string literal or a variable reference than to write the connection target directly.

There are also different ways to specify the user name:

- *`username`*
- *`username/password`*
- *`username`* `IDENTIFIED BY` *`password`*
- *`username`* `USING` *`password`*

As above, the parameters *`username`* and *`password`* can be an SQL identifier, an SQL string literal, or a reference to a character variable.

If the connection target includes any *`options`*, those consist of *`keyword=value`* specifications separated by ampersands (`&`). The allowed key words are the same ones recognized by libpq (see Section 36.1.2). Spaces are ignored before any *`keyword`* or *`value`*, though not within or after one. Note that there is no way to write `&` within a *`value`*.

Notice that when specifying a socket connection (with the `unix:` prefix), the host name must be exactly `localhost`. To select a non-default socket directory, write the directory's pathname as the value of a `host` option in the *`options`* part of the target.

The *`connection-name`* is used to handle multiple connections in one program. It can be omitted if a program uses only one connection. The most recently opened connection becomes the current connection, which is used by default when an SQL statement is to be executed (see later in this chapter).

Here are some examples of `CONNECT` statements:

```
EXEC SQL CONNECT TO mydb@sql.mydomain.com;

EXEC SQL CONNECT TO tcp:postgresql://sql.mydomain.com/mydb AS myconnection USER john;

EXEC SQL BEGIN DECLARE SECTION;
const char *target = "mydb@sql.mydomain.com";
const char *user = "john";
const char *passwd = "secret";
EXEC SQL END DECLARE SECTION;
 ...
EXEC SQL CONNECT TO :target USER :user USING :passwd;
/* or EXEC SQL CONNECT TO :target USER :user/:passwd; */
```

The last example makes use of the feature referred to above as character variable references. You will see in later sections how C variables can be used in SQL statements when you prefix them with a colon.

Be advised that the format of the connection target is not specified in the SQL standard. So if you want to develop portable applications, you might want to use something based on the last example above to encapsulate the connection target string somewhere.

If untrusted users have access to a database that has not adopted a secure schema usage pattern, begin each session by removing publicly-writable schemas from `search_path`. For example, add `options=-c`

`search_path=` to *`options`*, or issue `EXEC SQL SELECT pg_catalog.set_config('search_path', '', false);` after connecting. This consideration is not specific to ECPG; it applies to every interface for executing arbitrary SQL commands.

38.2.2. Choosing a Connection

SQL statements in embedded SQL programs are by default executed on the current connection, that is, the most recently opened one. If an application needs to manage multiple connections, then there are three ways to handle this.

The first option is to explicitly choose a connection for each SQL statement, for example:

```
EXEC SQL AT connection-name SELECT ...;
```

This option is particularly suitable if the application needs to use several connections in mixed order.

If your application uses multiple threads of execution, they cannot share a connection concurrently. You must either explicitly control access to the connection (using mutexes) or use a connection for each thread.

The second option is to execute a statement to switch the current connection. That statement is:

```
EXEC SQL SET CONNECTION connection-name;
```

This option is particularly convenient if many statements are to be executed on the same connection.

Here is an example program managing multiple database connections:

```
#include <stdio.h>

EXEC SQL BEGIN DECLARE SECTION;
    char dbname[1024];
EXEC SQL END DECLARE SECTION;

int
main()
{
    EXEC SQL CONNECT TO testdb1 AS con1 USER testuser;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;
    EXEC SQL CONNECT TO testdb2 AS con2 USER testuser;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;
    EXEC SQL CONNECT TO testdb3 AS con3 USER testuser;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    /* This query would be executed in the last opened database "testdb3". */
    EXEC SQL SELECT current_database() INTO :dbname;
    printf("current=%s (should be testdb3)\n", dbname);

    /* Using "AT" to run a query in "testdb2" */
    EXEC SQL AT con2 SELECT current_database() INTO :dbname;
    printf("current=%s (should be testdb2)\n", dbname);

    /* Switch the current connection to "testdb1". */
    EXEC SQL SET CONNECTION con1;

    EXEC SQL SELECT current_database() INTO :dbname;
    printf("current=%s (should be testdb1)\n", dbname);

    EXEC SQL DISCONNECT ALL;
    return 0;
}
```

This example would produce this output:

```
current=testdb3 (should be testdb3)
current=testdb2 (should be testdb2)
current=testdb1 (should be testdb1)
```

The third option is to declare an SQL identifier linked to the connection, for example:

```
EXEC SQL AT connection-name DECLARE statement-name STATEMENT;
EXEC SQL PREPARE statement-name FROM :dyn-string;
```

Once you link an SQL identifier to a connection, you execute dynamic SQL without an AT clause. Note that this option behaves like preprocessor directives, therefore the link is enabled only in the file.

Here is an example program using this option:

```
#include <stdio.h>

EXEC SQL BEGIN DECLARE SECTION;
char dbname[128];
char *dyn_sql = "SELECT current_database()";
EXEC SQL END DECLARE SECTION;

int main(){
  EXEC SQL CONNECT TO postgres AS con1;
  EXEC SQL CONNECT TO testdb AS con2;
  EXEC SQL AT con1 DECLARE stmt STATEMENT;
  EXEC SQL PREPARE stmt FROM :dyn_sql;
  EXEC SQL EXECUTE stmt INTO :dbname;
  printf("%s\n", dbname);

  EXEC SQL DISCONNECT ALL;
  return 0;
}
```

This example would produce this output, even if the default connection is testdb:

```
postgres
```

38.2.3. Closing a Connection

To close a connection, use the following statement:

```
EXEC SQL DISCONNECT [connection];
```

The *connection* can be specified in the following ways:

- *connection-name*
- CURRENT
- ALL

If no connection name is specified, the current connection is closed.

It is good style that an application always explicitly disconnect from every connection it opened.

38.3. Running SQL Commands

Any SQL command can be run from within an embedded SQL application. Below are some examples of how to do that.

38.3.1. Executing SQL Statements

Creating a table:

```
EXEC SQL CREATE TABLE foo (number integer, ascii char(16));
EXEC SQL CREATE UNIQUE INDEX num1 ON foo(number);
EXEC SQL COMMIT;
```

Inserting rows:

```
EXEC SQL INSERT INTO foo (number, ascii) VALUES (9999, 'doodad');
EXEC SQL COMMIT;
```

Deleting rows:

```
EXEC SQL DELETE FROM foo WHERE number = 9999;
EXEC SQL COMMIT;
```

Updates:

```
EXEC SQL UPDATE foo
    SET ascii = 'foobar'
    WHERE number = 9999;
EXEC SQL COMMIT;
```

`SELECT` statements that return a single result row can also be executed using `EXEC SQL` directly. To handle result sets with multiple rows, an application has to use a cursor; see Section 38.3.2 below. (As a special case, an application can fetch multiple rows at once into an array host variable; see Section 38.4.4.3.1.)

Single-row select:

```
EXEC SQL SELECT foo INTO :FooBar FROM table1 WHERE ascii = 'doodad';
```

Also, a configuration parameter can be retrieved with the `SHOW` command:

```
EXEC SQL SHOW search_path INTO :var;
```

The tokens of the form `:`*`something`* are *host variables*, that is, they refer to variables in the C program. They are explained in Section 38.4.

38.3.2. Using Cursors

To retrieve a result set holding multiple rows, an application has to declare a cursor and fetch each row from the cursor. The steps to use a cursor are the following: declare a cursor, open it, fetch a row from the cursor, repeat, and finally close it.

Select using cursors:

```
EXEC SQL DECLARE foo_bar CURSOR FOR
    SELECT number, ascii FROM foo
    ORDER BY ascii;
EXEC SQL OPEN foo_bar;
EXEC SQL FETCH foo_bar INTO :FooBar, DooDad;
...
EXEC SQL CLOSE foo_bar;
EXEC SQL COMMIT;
```

For more details about declaring a cursor, see DECLARE; for more details about fetching rows from a cursor, see FETCH.

> **Note**
>
> The ECPG `DECLARE` command does not actually cause a statement to be sent to the Postgres Pro backend. The cursor is opened in the backend (using the backend's `DECLARE` command) at the point when the `OPEN` command is executed.

38.3.3. Managing Transactions

In the default mode, statements are committed only when `EXEC SQL COMMIT` is issued. The embedded SQL interface also supports autocommit of transactions (similar to psql's default behavior) via the `-t` command-line option to `ecpg` (see ecpg) or via the `EXEC SQL SET AUTOCOMMIT TO ON` statement. In autocommit mode, each command is automatically committed unless it is inside an explicit transaction block. This mode can be explicitly turned off using `EXEC SQL SET AUTOCOMMIT TO OFF`.

The following transaction management commands are available:

`EXEC SQL COMMIT`

Commit an in-progress transaction.

`EXEC SQL ROLLBACK`

Roll back an in-progress transaction.

`EXEC SQL PREPARE TRANSACTION` *`transaction_id`*

Prepare the current transaction for two-phase commit.

`EXEC SQL COMMIT PREPARED` *`transaction_id`*

Commit a transaction that is in prepared state.

`EXEC SQL ROLLBACK PREPARED` *`transaction_id`*

Roll back a transaction that is in prepared state.

`EXEC SQL SET AUTOCOMMIT TO ON`

Enable autocommit mode.

`EXEC SQL SET AUTOCOMMIT TO OFF`

Disable autocommit mode. This is the default.

38.3.4. Prepared Statements

When the values to be passed to an SQL statement are not known at compile time, or the same statement is going to be used many times, then prepared statements can be useful.

The statement is prepared using the command `PREPARE`. For the values that are not known yet, use the placeholder "`?`":

```
EXEC SQL PREPARE stmt1 FROM "SELECT oid, datname FROM pg_database WHERE oid = ?";
```

If a statement returns a single row, the application can call `EXECUTE` after `PREPARE` to execute the statement, supplying the actual values for the placeholders with a `USING` clause:

```
EXEC SQL EXECUTE stmt1 INTO :dboid, :dbname USING 1;
```

If a statement returns multiple rows, the application can use a cursor declared based on the prepared statement. To bind input parameters, the cursor must be opened with a `USING` clause:

```
EXEC SQL PREPARE stmt1 FROM "SELECT oid,datname FROM pg_database WHERE oid > ?";
EXEC SQL DECLARE foo_bar CURSOR FOR stmt1;

/* when end of result set reached, break out of while loop */
EXEC SQL WHENEVER NOT FOUND DO BREAK;

EXEC SQL OPEN foo_bar USING 100;
...
while (1)
{
```

```
    EXEC SQL FETCH NEXT FROM foo_bar INTO :dboid, :dbname;
    ...
}
EXEC SQL CLOSE foo_bar;
```

When you don't need the prepared statement anymore, you should deallocate it:

```
EXEC SQL DEALLOCATE PREPARE name;
```

For more details about `PREPARE`, see PREPARE. Also see Section 38.5 for more details about using placeholders and input parameters.

38.4. Using Host Variables

In Section 38.3 you saw how you can execute SQL statements from an embedded SQL program. Some of those statements only used fixed values and did not provide a way to insert user-supplied values into statements or have the program process the values returned by the query. Those kinds of statements are not really useful in real applications. This section explains in detail how you can pass data between your C program and the embedded SQL statements using a simple mechanism called *host variables*. In an embedded SQL program we consider the SQL statements to be *guests* in the C program code which is the *host language*. Therefore the variables of the C program are called *host variables*.

Another way to exchange values between Postgres Pro backends and ECPG applications is the use of SQL descriptors, described in Section 38.7.

38.4.1. Overview

Passing data between the C program and the SQL statements is particularly simple in embedded SQL. Instead of having the program paste the data into the statement, which entails various complications, such as properly quoting the value, you can simply write the name of a C variable into the SQL statement, prefixed by a colon. For example:

```
EXEC SQL INSERT INTO sometable VALUES (:v1, 'foo', :v2);
```

This statement refers to two C variables named `v1` and `v2` and also uses a regular SQL string literal, to illustrate that you are not restricted to use one kind of data or the other.

This style of inserting C variables in SQL statements works anywhere a value expression is expected in an SQL statement.

38.4.2. Declare Sections

To pass data from the program to the database, for example as parameters in a query, or to pass data from the database back to the program, the C variables that are intended to contain this data need to be declared in specially marked sections, so the embedded SQL preprocessor is made aware of them.

This section starts with:

```
EXEC SQL BEGIN DECLARE SECTION;
```

and ends with:

```
EXEC SQL END DECLARE SECTION;
```

Between those lines, there must be normal C variable declarations, such as:

```
int    x = 4;
char   foo[16], bar[16];
```

As you can see, you can optionally assign an initial value to the variable. The variable's scope is determined by the location of its declaring section within the program. You can also declare variables with the following syntax which implicitly creates a declare section:

```
EXEC SQL int i = 4;
```

You can have as many declare sections in a program as you like.

The declarations are also echoed to the output file as normal C variables, so there's no need to declare them again. Variables that are not intended to be used in SQL commands can be declared normally outside these special sections.

The definition of a structure or union also must be listed inside a `DECLARE` section. Otherwise the pre-processor cannot handle these types since it does not know the definition.

38.4.3. Retrieving Query Results

Now you should be able to pass data generated by your program into an SQL command. But how do you retrieve the results of a query? For that purpose, embedded SQL provides special variants of the usual commands `SELECT` and `FETCH`. These commands have a special `INTO` clause that specifies which host variables the retrieved values are to be stored in. `SELECT` is used for a query that returns only single row, and `FETCH` is used for a query that returns multiple rows, using a cursor.

Here is an example:

```
/*
 * assume this table:
 * CREATE TABLE test1 (a int, b varchar(50));
 */

EXEC SQL BEGIN DECLARE SECTION;
int v1;
VARCHAR v2;
EXEC SQL END DECLARE SECTION;

 ...

EXEC SQL SELECT a, b INTO :v1, :v2 FROM test;
```

So the `INTO` clause appears between the select list and the `FROM` clause. The number of elements in the select list and the list after `INTO` (also called the target list) must be equal.

Here is an example using the command `FETCH`:

```
EXEC SQL BEGIN DECLARE SECTION;
int v1;
VARCHAR v2;
EXEC SQL END DECLARE SECTION;

 ...

EXEC SQL DECLARE foo CURSOR FOR SELECT a, b FROM test;

 ...

do
{
    ...
    EXEC SQL FETCH NEXT FROM foo INTO :v1, :v2;
    ...
} while (...);
```

Here the `INTO` clause appears after all the normal clauses.

38.4.4. Type Mapping

When ECPG applications exchange values between the Postgres Pro server and the C application, such as when retrieving query results from the server or executing SQL statements with input parameters, the values need to be converted between Postgres Pro data types and host language variable types (C

language data types, concretely). One of the main points of ECPG is that it takes care of this automatically in most cases.

In this respect, there are two kinds of data types: Some simple Postgres Pro data types, such as `integer` and `text`, can be read and written by the application directly. Other Postgres Pro data types, such as `timestamp` and `numeric` can only be accessed through special library functions; see Section 38.4.4.2.

Table 38.1 shows which Postgres Pro data types correspond to which C data types. When you wish to send or receive a value of a given Postgres Pro data type, you should declare a C variable of the corresponding C data type in the declare section.

Table 38.1. Mapping Between Postgres Pro Data Types and C Variable Types

Postgres Pro data type	Host variable type
`smallint`	`short`
`integer`	`int`
`bigint`	`long long int`
`decimal`	`decimal`[a]
`numeric`	`numeric`[a]
`real`	`float`
`double precision`	`double`
`smallserial`	`short`
`serial`	`int`
`bigserial`	`long long int`
`oid`	`unsigned int`
`character(` *n*`)`, `varchar(` *n*`)`, `text`	`char[`*n*`+1]`, `VARCHAR[`*n*`+1]`
`name`	`char[NAMEDATALEN]`
`timestamp`	`timestamp`[a]
`interval`	`interval`[a]
`date`	`date`[a]
`boolean`	`bool`[b]
`bytea`	`char *`, `bytea[`*n*`]`

[a] This type can only be accessed through special library functions; see Section 38.4.4.2.
[b] declared in `ecpglib.h` if not native

38.4.4.1. Handling Character Strings

To handle SQL character string data types, such as `varchar` and `text`, there are two possible ways to declare the host variables.

One way is using `char[]`, an array of `char`, which is the most common way to handle character data in C.

```
EXEC SQL BEGIN DECLARE SECTION;
    char str[50];
EXEC SQL END DECLARE SECTION;
```

Note that you have to take care of the length yourself. If you use this host variable as the target variable of a query which returns a string with more than 49 characters, a buffer overflow occurs.

The other way is using the `VARCHAR` type, which is a special type provided by ECPG. The definition on an array of type `VARCHAR` is converted into a named `struct` for every variable. A declaration like:

```
VARCHAR var[180];
```

is converted into:

```
struct varchar_var { int len; char arr[180]; } var;
```

The member `arr` hosts the string including a terminating zero byte. Thus, to store a string in a `VARCHAR` host variable, the host variable has to be declared with the length including the zero byte terminator. The member `len` holds the length of the string stored in the `arr` without the terminating zero byte. When a host variable is used as input for a query, if `strlen(arr)` and `len` are different, the shorter one is used.

`VARCHAR` can be written in upper or lower case, but not in mixed case.

`char` and `VARCHAR` host variables can also hold values of other SQL types, which will be stored in their string forms.

38.4.4.2. Accessing Special Data Types

ECPG contains some special types that help you to interact easily with some special data types from the Postgres Pro server. In particular, it has implemented support for the `numeric`, `decimal`, `date`, `timestamp`, and `interval` types. These data types cannot usefully be mapped to primitive host variable types (such as `int`, `long long int`, or `char[]`), because they have a complex internal structure. Applications deal with these types by declaring host variables in special types and accessing them using functions in the pgtypes library. The pgtypes library, described in detail in Section 38.6 contains basic functions to deal with those types, such that you do not need to send a query to the SQL server just for adding an interval to a time stamp for example.

The follow subsections describe these special data types. For more details about pgtypes library functions, see Section 38.6.

38.4.4.2.1. timestamp, date

Here is a pattern for handling `timestamp` variables in the ECPG host application.

First, the program has to include the header file for the `timestamp` type:

```
#include <pgtypes_timestamp.h>
```

Next, declare a host variable as type `timestamp` in the declare section:

```
EXEC SQL BEGIN DECLARE SECTION;
timestamp ts;
EXEC SQL END DECLARE SECTION;
```

And after reading a value into the host variable, process it using pgtypes library functions. In following example, the `timestamp` value is converted into text (ASCII) form with the `PGTYPEStimestamp_to_asc()` function:

```
EXEC SQL SELECT now()::timestamp INTO :ts;

printf("ts = %s\n", PGTYPEStimestamp_to_asc(ts));
```

This example will show some result like following:

```
ts = 2010-06-27 18:03:56.949343
```

In addition, the DATE type can be handled in the same way. The program has to include `pgtypes_date.h`, declare a host variable as the date type and convert a DATE value into a text form using `PGTYPESdate_to_asc()` function. For more details about the pgtypes library functions, see Section 38.6.

38.4.4.2.2. interval

The handling of the `interval` type is also similar to the `timestamp` and `date` types. It is required, however, to allocate memory for an `interval` type value explicitly. In other words, the memory space for the variable has to be allocated in the heap memory, not in the stack memory.

Here is an example program:

```
#include <stdio.h>
#include <stdlib.h>
```

```
#include <pgtypes_interval.h>

int
main(void)
{
EXEC SQL BEGIN DECLARE SECTION;
    interval *in;
EXEC SQL END DECLARE SECTION;

    EXEC SQL CONNECT TO testdb;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    in = PGTYPESinterval_new();
    EXEC SQL SELECT '1 min'::interval INTO :in;
    printf("interval = %s\n", PGTYPESinterval_to_asc(in));
    PGTYPESinterval_free(in);

    EXEC SQL COMMIT;
    EXEC SQL DISCONNECT ALL;
    return 0;
}
```

38.4.4.2.3. numeric, decimal

The handling of the `numeric` and `decimal` types is similar to the `interval` type: It requires defining a pointer, allocating some memory space on the heap, and accessing the variable using the pgtypes library functions. For more details about the pgtypes library functions, see Section 38.6.

No functions are provided specifically for the `decimal` type. An application has to convert it to a `numeric` variable using a pgtypes library function to do further processing.

Here is an example program handling `numeric` and `decimal` type variables.

```
#include <stdio.h>
#include <stdlib.h>
#include <pgtypes_numeric.h>

EXEC SQL WHENEVER SQLERROR STOP;

int
main(void)
{
EXEC SQL BEGIN DECLARE SECTION;
    numeric *num;
    numeric *num2;
    decimal *dec;
EXEC SQL END DECLARE SECTION;

    EXEC SQL CONNECT TO testdb;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    num = PGTYPESnumeric_new();
    dec = PGTYPESdecimal_new();

    EXEC SQL SELECT 12.345::numeric(4,2), 23.456::decimal(4,2) INTO :num, :dec;

    printf("numeric = %s\n", PGTYPESnumeric_to_asc(num, 0));
    printf("numeric = %s\n", PGTYPESnumeric_to_asc(num, 1));
    printf("numeric = %s\n", PGTYPESnumeric_to_asc(num, 2));
```

```
    /* Convert decimal to numeric to show a decimal value. */
    num2 = PGTYPESnumeric_new();
    PGTYPESnumeric_from_decimal(dec, num2);

    printf("decimal = %s\n", PGTYPESnumeric_to_asc(num2, 0));
    printf("decimal = %s\n", PGTYPESnumeric_to_asc(num2, 1));
    printf("decimal = %s\n", PGTYPESnumeric_to_asc(num2, 2));

    PGTYPESnumeric_free(num2);
    PGTYPESdecimal_free(dec);
    PGTYPESnumeric_free(num);

    EXEC SQL COMMIT;
    EXEC SQL DISCONNECT ALL;
    return 0;
}
```

38.4.4.2.4. bytea

The handling of the `bytea` type is similar to that of `VARCHAR`. The definition on an array of type `bytea` is converted into a named struct for every variable. A declaration like:

```
bytea var[180];
```

is converted into:

```
struct bytea_var { int len; char arr[180]; } var;
```

The member `arr` hosts binary format data. It can also handle `'\0'` as part of data, unlike `VARCHAR`. The data is converted from/to hex format and sent/received by ecpglib.

> **Note**
>
> `bytea` variable can be used only when bytea_output is set to `hex`.

38.4.4.3. Host Variables with Nonprimitive Types

As a host variable you can also use arrays, typedefs, structs, and pointers.

38.4.4.3.1. Arrays

There are two use cases for arrays as host variables. The first is a way to store some text string in `char[]` or `VARCHAR[]`, as explained in Section 38.4.4.1. The second use case is to retrieve multiple rows from a query result without using a cursor. Without an array, to process a query result consisting of multiple rows, it is required to use a cursor and the `FETCH` command. But with array host variables, multiple rows can be received at once. The length of the array has to be defined to be able to accommodate all rows, otherwise a buffer overflow will likely occur.

Following example scans the `pg_database` system table and shows all OIDs and names of the available databases:

```
int
main(void)
{
EXEC SQL BEGIN DECLARE SECTION;
    int dbid[8];
    char dbname[8][16];
    int i;
EXEC SQL END DECLARE SECTION;

    memset(dbname, 0, sizeof(char)* 16 * 8);
    memset(dbid, 0, sizeof(int) * 8);
```

```
    EXEC SQL CONNECT TO testdb;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    /* Retrieve multiple rows into arrays at once. */
    EXEC SQL SELECT oid,datname INTO :dbid, :dbname FROM pg_database;

    for (i = 0; i < 8; i++)
        printf("oid=%d, dbname=%s\n", dbid[i], dbname[i]);

    EXEC SQL COMMIT;
    EXEC SQL DISCONNECT ALL;
    return 0;
}
```

This example shows following result. (The exact values depend on local circumstances.)

```
oid=1, dbname=template1
oid=11510, dbname=template0
oid=11511, dbname=postgres
oid=313780, dbname=testdb
oid=0, dbname=
oid=0, dbname=
oid=0, dbname=
```

38.4.4.3.2. Structures

A structure whose member names match the column names of a query result, can be used to retrieve multiple columns at once. The structure enables handling multiple column values in a single host variable.

The following example retrieves OIDs, names, and sizes of the available databases from the `pg_database` system table and using the `pg_database_size()` function. In this example, a structure variable `dbinfo_t` with members whose names match each column in the `SELECT` result is used to retrieve one result row without putting multiple host variables in the `FETCH` statement.

```
EXEC SQL BEGIN DECLARE SECTION;
    typedef struct
    {
       int oid;
       char datname[65];
       long long int size;
    } dbinfo_t;

    dbinfo_t dbval;
EXEC SQL END DECLARE SECTION;

    memset(&dbval, 0, sizeof(dbinfo_t));

    EXEC SQL DECLARE cur1 CURSOR FOR SELECT oid, datname, pg_database_size(oid) AS size
 FROM pg_database;
    EXEC SQL OPEN cur1;

    /* when end of result set reached, break out of while loop */
    EXEC SQL WHENEVER NOT FOUND DO BREAK;

    while (1)
    {
        /* Fetch multiple columns into one structure. */
        EXEC SQL FETCH FROM cur1 INTO :dbval;
```

```
        /* Print members of the structure. */
        printf("oid=%d, datname=%s, size=%lld\n", dbval.oid, dbval.datname,
 dbval.size);
    }

    EXEC SQL CLOSE cur1;
```

This example shows following result. (The exact values depend on local circumstances.)

```
oid=1, datname=template1, size=4324580
oid=11510, datname=template0, size=4243460
oid=11511, datname=postgres, size=4324580
oid=313780, datname=testdb, size=8183012
```

Structure host variables “absorb” as many columns as the structure as fields. Additional columns can be assigned to other host variables. For example, the above program could also be restructured like this, with the `size` variable outside the structure:

```
EXEC SQL BEGIN DECLARE SECTION;
    typedef struct
    {
       int oid;
       char datname[65];
    } dbinfo_t;

    dbinfo_t dbval;
    long long int size;
EXEC SQL END DECLARE SECTION;

    memset(&dbval, 0, sizeof(dbinfo_t));

    EXEC SQL DECLARE cur1 CURSOR FOR SELECT oid, datname, pg_database_size(oid) AS size
 FROM pg_database;
    EXEC SQL OPEN cur1;

    /* when end of result set reached, break out of while loop */
    EXEC SQL WHENEVER NOT FOUND DO BREAK;

    while (1)
    {
        /* Fetch multiple columns into one structure. */
        EXEC SQL FETCH FROM cur1 INTO :dbval, :size;

        /* Print members of the structure. */
        printf("oid=%d, datname=%s, size=%lld\n", dbval.oid, dbval.datname, size);
    }

    EXEC SQL CLOSE cur1;
```

38.4.4.3.3. Typedefs

Use the `typedef` keyword to map new types to already existing types.

```
EXEC SQL BEGIN DECLARE SECTION;
    typedef char mychartype[40];
    typedef long serial_t;
EXEC SQL END DECLARE SECTION;
```

Note that you could also use:

```
EXEC SQL TYPE serial_t IS long;
```

This declaration does not need to be part of a declare section.

38.4.4.3.4. Pointers

You can declare pointers to the most common types. Note however that you cannot use pointers as target variables of queries without auto-allocation. See Section 38.7 for more information on auto-allocation.

```
EXEC SQL BEGIN DECLARE SECTION;
    int   *intp;
    char **charp;
EXEC SQL END DECLARE SECTION;
```

38.4.5. Handling Nonprimitive SQL Data Types

This section contains information on how to handle nonscalar and user-defined SQL-level data types in ECPG applications. Note that this is distinct from the handling of host variables of nonprimitive types, described in the previous section.

38.4.5.1. Arrays

Multi-dimensional SQL-level arrays are not directly supported in ECPG. One-dimensional SQL-level arrays can be mapped into C array host variables and vice-versa. However, when creating a statement ecpg does not know the types of the columns, so that it cannot check if a C array is input into a corresponding SQL-level array. When processing the output of an SQL statement, ecpg has the necessary information and thus checks if both are arrays.

If a query accesses *elements* of an array separately, then this avoids the use of arrays in ECPG. Then, a host variable with a type that can be mapped to the element type should be used. For example, if a column type is array of `integer`, a host variable of type `int` can be used. Also if the element type is `varchar` or `text`, a host variable of type `char[]` or `VARCHAR[]` can be used.

Here is an example. Assume the following table:

```
CREATE TABLE t3 (
    ii integer[]
);

testdb=> SELECT * FROM t3;
     ii
-------------
 {1,2,3,4,5}
(1 row)
```

The following example program retrieves the 4th element of the array and stores it into a host variable of type `int`:

```
EXEC SQL BEGIN DECLARE SECTION;
int ii;
EXEC SQL END DECLARE SECTION;

EXEC SQL DECLARE cur1 CURSOR FOR SELECT ii[4] FROM t3;
EXEC SQL OPEN cur1;

EXEC SQL WHENEVER NOT FOUND DO BREAK;

while (1)
{
    EXEC SQL FETCH FROM cur1 INTO :ii ;
    printf("ii=%d\n", ii);
}

EXEC SQL CLOSE cur1;
```

This example shows the following result:

```
ii=4
```

To map multiple array elements to the multiple elements in an array type host variables each element of array column and each element of the host variable array have to be managed separately, for example:

```
EXEC SQL BEGIN DECLARE SECTION;
int ii_a[8];
EXEC SQL END DECLARE SECTION;

EXEC SQL DECLARE cur1 CURSOR FOR SELECT ii[1], ii[2], ii[3], ii[4] FROM t3;
EXEC SQL OPEN cur1;

EXEC SQL WHENEVER NOT FOUND DO BREAK;

while (1)
{
    EXEC SQL FETCH FROM cur1 INTO :ii_a[0], :ii_a[1], :ii_a[2], :ii_a[3];
    ...
}
```

Note again that

```
EXEC SQL BEGIN DECLARE SECTION;
int ii_a[8];
EXEC SQL END DECLARE SECTION;

EXEC SQL DECLARE cur1 CURSOR FOR SELECT ii FROM t3;
EXEC SQL OPEN cur1;

EXEC SQL WHENEVER NOT FOUND DO BREAK;

while (1)
{
    /* WRONG */
    EXEC SQL FETCH FROM cur1 INTO :ii_a;
    ...
}
```

would not work correctly in this case, because you cannot map an array type column to an array host variable directly.

Another workaround is to store arrays in their external string representation in host variables of type `char[]` or `VARCHAR[]`. For more details about this representation, see Section 8.15.2. Note that this means that the array cannot be accessed naturally as an array in the host program (without further processing that parses the text representation).

38.4.5.2. Composite Types

Composite types are not directly supported in ECPG, but an easy workaround is possible. The available workarounds are similar to the ones described for arrays above: Either access each attribute separately or use the external string representation.

For the following examples, assume the following type and table:

```
CREATE TYPE comp_t AS (intval integer, textval varchar(32));
CREATE TABLE t4 (compval comp_t);
INSERT INTO t4 VALUES ( (256, 'Postgres Pro') );
```

The most obvious solution is to access each attribute separately. The following program retrieves data from the example table by selecting each attribute of the type `comp_t` separately:

```
EXEC SQL BEGIN DECLARE SECTION;
int intval;
varchar textval[33];
EXEC SQL END DECLARE SECTION;

/* Put each element of the composite type column in the SELECT list. */
EXEC SQL DECLARE cur1 CURSOR FOR SELECT (compval).intval, (compval).textval FROM t4;
EXEC SQL OPEN cur1;

EXEC SQL WHENEVER NOT FOUND DO BREAK;

while (1)
{
    /* Fetch each element of the composite type column into host variables. */
    EXEC SQL FETCH FROM cur1 INTO :intval, :textval;

    printf("intval=%d, textval=%s\n", intval, textval.arr);
}

EXEC SQL CLOSE cur1;
```

To enhance this example, the host variables to store values in the `FETCH` command can be gathered into one structure. For more details about the host variable in the structure form, see Section 38.4.4.3.2. To switch to the structure, the example can be modified as below. The two host variables, `intval` and `textval`, become members of the `comp_t` structure, and the structure is specified on the `FETCH` command.

```
EXEC SQL BEGIN DECLARE SECTION;
typedef struct
{
    int intval;
    varchar textval[33];
} comp_t;

comp_t compval;
EXEC SQL END DECLARE SECTION;

/* Put each element of the composite type column in the SELECT list. */
EXEC SQL DECLARE cur1 CURSOR FOR SELECT (compval).intval, (compval).textval FROM t4;
EXEC SQL OPEN cur1;

EXEC SQL WHENEVER NOT FOUND DO BREAK;

while (1)
{
    /* Put all values in the SELECT list into one structure. */
    EXEC SQL FETCH FROM cur1 INTO :compval;

    printf("intval=%d, textval=%s\n", compval.intval, compval.textval.arr);
}

EXEC SQL CLOSE cur1;
```

Although a structure is used in the `FETCH` command, the attribute names in the `SELECT` clause are specified one by one. This can be enhanced by using a `*` to ask for all attributes of the composite type value.

```
...
EXEC SQL DECLARE cur1 CURSOR FOR SELECT (compval).* FROM t4;
EXEC SQL OPEN cur1;

EXEC SQL WHENEVER NOT FOUND DO BREAK;
```

```
while (1)
{
    /* Put all values in the SELECT list into one structure. */
    EXEC SQL FETCH FROM cur1 INTO :compval;

    printf("intval=%d, textval=%s\n", compval.intval, compval.textval.arr);
}
...
```

This way, composite types can be mapped into structures almost seamlessly, even though ECPG does not understand the composite type itself.

Finally, it is also possible to store composite type values in their external string representation in host variables of type `char[]` or `VARCHAR[]`. But that way, it is not easily possible to access the fields of the value from the host program.

38.4.5.3. User-Defined Base Types

New user-defined base types are not directly supported by ECPG. You can use the external string representation and host variables of type `char[]` or `VARCHAR[]`, and this solution is indeed appropriate and sufficient for many types.

Here is an example using the data type `complex` from the example in Section 40.13. The external string representation of that type is `(%f,%f)`, which is defined in the functions `complex_in()` and `complex_out()` functions in Section 40.13. The following example inserts the complex type values `(1,1)` and `(3,3)` into the columns `a` and `b`, and select them from the table after that.

```
EXEC SQL BEGIN DECLARE SECTION;
    varchar a[64];
    varchar b[64];
EXEC SQL END DECLARE SECTION;

    EXEC SQL INSERT INTO test_complex VALUES ('(1,1)', '(3,3)');

    EXEC SQL DECLARE cur1 CURSOR FOR SELECT a, b FROM test_complex;
    EXEC SQL OPEN cur1;

    EXEC SQL WHENEVER NOT FOUND DO BREAK;

    while (1)
    {
        EXEC SQL FETCH FROM cur1 INTO :a, :b;
        printf("a=%s, b=%s\n", a.arr, b.arr);
    }

    EXEC SQL CLOSE cur1;
```

This example shows following result:

```
a=(1,1), b=(3,3)
```

Another workaround is avoiding the direct use of the user-defined types in ECPG and instead create a function or cast that converts between the user-defined type and a primitive type that ECPG can handle. Note, however, that type casts, especially implicit ones, should be introduced into the type system very carefully.

For example,

```
CREATE FUNCTION create_complex(r double, i double) RETURNS complex
LANGUAGE SQL
IMMUTABLE
```

```
AS $$ SELECT $1 * complex '(1,0)' + $2 * complex '(0,1)' $$;
```

After this definition, the following

```
EXEC SQL BEGIN DECLARE SECTION;
double a, b, c, d;
EXEC SQL END DECLARE SECTION;

a = 1;
b = 2;
c = 3;
d = 4;

EXEC SQL INSERT INTO test_complex VALUES (create_complex(:a, :b),
 create_complex(:c, :d));
```

has the same effect as

```
EXEC SQL INSERT INTO test_complex VALUES ('(1,2)', '(3,4)');
```

38.4.6. Indicators

The examples above do not handle null values. In fact, the retrieval examples will raise an error if they fetch a null value from the database. To be able to pass null values to the database or retrieve null values from the database, you need to append a second host variable specification to each host variable that contains data. This second host variable is called the *indicator* and contains a flag that tells whether the datum is null, in which case the value of the real host variable is ignored. Here is an example that handles the retrieval of null values correctly:

```
EXEC SQL BEGIN DECLARE SECTION;
VARCHAR val;
int val_ind;
EXEC SQL END DECLARE SECTION:

 ...

EXEC SQL SELECT b INTO :val :val_ind FROM test1;
```

The indicator variable `val_ind` will be zero if the value was not null, and it will be negative if the value was null. (See Section 38.16 to enable Oracle-specific behavior.)

The indicator has another function: if the indicator value is positive, it means that the value is not null, but it was truncated when it was stored in the host variable.

If the argument `-r no_indicator` is passed to the preprocessor `ecpg`, it works in “no-indicator” mode. In no-indicator mode, if no indicator variable is specified, null values are signaled (on input and output) for character string types as empty string and for integer types as the lowest possible value for type (for example, `INT_MIN` for `int`).

38.5. Dynamic SQL

In many cases, the particular SQL statements that an application has to execute are known at the time the application is written. In some cases, however, the SQL statements are composed at run time or provided by an external source. In these cases you cannot embed the SQL statements directly into the C source code, but there is a facility that allows you to call arbitrary SQL statements that you provide in a string variable.

38.5.1. Executing Statements without a Result Set

The simplest way to execute an arbitrary SQL statement is to use the command `EXECUTE IMMEDIATE`. For example:

```
EXEC SQL BEGIN DECLARE SECTION;
```

```
const char *stmt = "CREATE TABLE test1 (...);";
EXEC SQL END DECLARE SECTION;

EXEC SQL EXECUTE IMMEDIATE :stmt;
```

`EXECUTE IMMEDIATE` can be used for SQL statements that do not return a result set (e.g., DDL, `INSERT`, `UPDATE`, `DELETE`). You cannot execute statements that retrieve data (e.g., `SELECT`) this way. The next section describes how to do that.

38.5.2. Executing a Statement with Input Parameters

A more powerful way to execute arbitrary SQL statements is to prepare them once and execute the prepared statement as often as you like. It is also possible to prepare a generalized version of a statement and then execute specific versions of it by substituting parameters. When preparing the statement, write question marks where you want to substitute parameters later. For example:

```
EXEC SQL BEGIN DECLARE SECTION;
const char *stmt = "INSERT INTO test1 VALUES(?, ?);";
EXEC SQL END DECLARE SECTION;

EXEC SQL PREPARE mystmt FROM :stmt;
 ...
EXEC SQL EXECUTE mystmt USING 42, 'foobar';
```

When you don't need the prepared statement anymore, you should deallocate it:

```
EXEC SQL DEALLOCATE PREPARE name;
```

38.5.3. Executing a Statement with a Result Set

To execute an SQL statement with a single result row, `EXECUTE` can be used. To save the result, add an `INTO` clause.

```
EXEC SQL BEGIN DECLARE SECTION;
const char *stmt = "SELECT a, b, c FROM test1 WHERE a > ?";
int v1, v2;
VARCHAR v3[50];
EXEC SQL END DECLARE SECTION;

EXEC SQL PREPARE mystmt FROM :stmt;
 ...
EXEC SQL EXECUTE mystmt INTO :v1, :v2, :v3 USING 37;
```

An `EXECUTE` command can have an `INTO` clause, a `USING` clause, both, or neither.

If a query is expected to return more than one result row, a cursor should be used, as in the following example. (See Section 38.3.2 for more details about the cursor.)

```
EXEC SQL BEGIN DECLARE SECTION;
char dbaname[128];
char datname[128];
char *stmt = "SELECT u.usename as dbaname, d.datname "
             "  FROM pg_database d, pg_user u "
             "  WHERE d.datdba = u.usesysid";
EXEC SQL END DECLARE SECTION;

EXEC SQL CONNECT TO testdb AS con1 USER testuser;
EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

EXEC SQL PREPARE stmt1 FROM :stmt;
```

```
EXEC SQL DECLARE cursor1 CURSOR FOR stmt1;
EXEC SQL OPEN cursor1;

EXEC SQL WHENEVER NOT FOUND DO BREAK;

while (1)
{
    EXEC SQL FETCH cursor1 INTO :dbaname,:datname;
    printf("dbaname=%s, datname=%s\n", dbaname, datname);
}

EXEC SQL CLOSE cursor1;

EXEC SQL COMMIT;
EXEC SQL DISCONNECT ALL;
```

38.6. pgtypes Library

The pgtypes library maps Postgres Pro database types to C equivalents that can be used in C programs. It also offers functions to do basic calculations with those types within C, i.e., without the help of the Postgres Pro server. See the following example:

```
EXEC SQL BEGIN DECLARE SECTION;
   date date1;
   timestamp ts1, tsout;
   interval iv1;
   char *out;
EXEC SQL END DECLARE SECTION;

PGTYPESdate_today(&date1);
EXEC SQL SELECT started, duration INTO :ts1, :iv1 FROM datetbl WHERE d=:date1;
PGTYPEStimestamp_add_interval(&ts1, &iv1, &tsout);
out = PGTYPEStimestamp_to_asc(&tsout);
printf("Started + duration: %s\n", out);
PGTYPESchar_free(out);
```

38.6.1. Character Strings

Some functions such as `PGTYPESnumeric_to_asc` return a pointer to a freshly allocated character string. These results should be freed with `PGTYPESchar_free` instead of `free`. (This is important only on Windows, where memory allocation and release sometimes need to be done by the same library.)

38.6.2. The numeric Type

The numeric type offers to do calculations with arbitrary precision. See Section 8.1 for the equivalent type in the Postgres Pro server. Because of the arbitrary precision this variable needs to be able to expand and shrink dynamically. That's why you can only create numeric variables on the heap, by means of the `PGTYPESnumeric_new` and `PGTYPESnumeric_free` functions. The decimal type, which is similar but limited in precision, can be created on the stack as well as on the heap.

The following functions can be used to work with the numeric type:

`PGTYPESnumeric_new`

Request a pointer to a newly allocated numeric variable.

```
numeric *PGTYPESnumeric_new(void);
```

`PGTYPESnumeric_free`

Free a numeric type, release all of its memory.

```
void PGTYPESnumeric_free(numeric *var);
```

PGTYPESnumeric_from_asc

Parse a numeric type from its string notation.

```
numeric *PGTYPESnumeric_from_asc(char *str, char **endptr);
```

Valid formats are for example: `-2`, `.794`, `+3.44`, `592.49E07` or `-32.84e-4`. If the value could be parsed successfully, a valid pointer is returned, else the NULL pointer. At the moment ECPG always parses the complete string and so it currently does not support to store the address of the first invalid character in `*endptr`. You can safely set `endptr` to NULL.

PGTYPESnumeric_to_asc

Returns a pointer to a string allocated by `malloc` that contains the string representation of the numeric type `num`.

```
char *PGTYPESnumeric_to_asc(numeric *num, int dscale);
```

The numeric value will be printed with `dscale` decimal digits, with rounding applied if necessary. The result must be freed with `PGTYPESchar_free()`.

PGTYPESnumeric_add

Add two numeric variables into a third one.

```
int PGTYPESnumeric_add(numeric *var1, numeric *var2, numeric *result);
```

The function adds the variables `var1` and `var2` into the result variable `result`. The function returns 0 on success and -1 in case of error.

PGTYPESnumeric_sub

Subtract two numeric variables and return the result in a third one.

```
int PGTYPESnumeric_sub(numeric *var1, numeric *var2, numeric *result);
```

The function subtracts the variable `var2` from the variable `var1`. The result of the operation is stored in the variable `result`. The function returns 0 on success and -1 in case of error.

PGTYPESnumeric_mul

Multiply two numeric variables and return the result in a third one.

```
int PGTYPESnumeric_mul(numeric *var1, numeric *var2, numeric *result);
```

The function multiplies the variables `var1` and `var2`. The result of the operation is stored in the variable `result`. The function returns 0 on success and -1 in case of error.

PGTYPESnumeric_div

Divide two numeric variables and return the result in a third one.

```
int PGTYPESnumeric_div(numeric *var1, numeric *var2, numeric *result);
```

The function divides the variables `var1` by `var2`. The result of the operation is stored in the variable `result`. The function returns 0 on success and -1 in case of error.

PGTYPESnumeric_cmp

Compare two numeric variables.

```
int PGTYPESnumeric_cmp(numeric *var1, numeric *var2)
```

This function compares two numeric variables. In case of error, `INT_MAX` is returned. On success, the function returns one of three possible results:

- 1, if `var1` is bigger than `var2`
- -1, if `var1` is smaller than `var2`
- 0, if `var1` and `var2` are equal

`PGTYPESnumeric_from_int`

Convert an int variable to a numeric variable.

```
int PGTYPESnumeric_from_int(signed int int_val, numeric *var);
```

This function accepts a variable of type signed int and stores it in the numeric variable `var`. Upon success, 0 is returned and -1 in case of a failure.

`PGTYPESnumeric_from_long`

Convert a long int variable to a numeric variable.

```
int PGTYPESnumeric_from_long(signed long int long_val, numeric *var);
```

This function accepts a variable of type signed long int and stores it in the numeric variable `var`. Upon success, 0 is returned and -1 in case of a failure.

`PGTYPESnumeric_copy`

Copy over one numeric variable into another one.

```
int PGTYPESnumeric_copy(numeric *src, numeric *dst);
```

This function copies over the value of the variable that `src` points to into the variable that `dst` points to. It returns 0 on success and -1 if an error occurs.

`PGTYPESnumeric_from_double`

Convert a variable of type double to a numeric.

```
int  PGTYPESnumeric_from_double(double d, numeric *dst);
```

This function accepts a variable of type double and stores the result in the variable that `dst` points to. It returns 0 on success and -1 if an error occurs.

`PGTYPESnumeric_to_double`

Convert a variable of type numeric to double.

```
int PGTYPESnumeric_to_double(numeric *nv, double *dp)
```

The function converts the numeric value from the variable that `nv` points to into the double variable that `dp` points to. It returns 0 on success and -1 if an error occurs, including overflow. On overflow, the global variable `errno` will be set to `PGTYPES_NUM_OVERFLOW` additionally.

`PGTYPESnumeric_to_int`

Convert a variable of type numeric to int.

```
int PGTYPESnumeric_to_int(numeric *nv, int *ip);
```

The function converts the numeric value from the variable that `nv` points to into the integer variable that `ip` points to. It returns 0 on success and -1 if an error occurs, including overflow. On overflow, the global variable `errno` will be set to `PGTYPES_NUM_OVERFLOW` additionally.

`PGTYPESnumeric_to_long`

Convert a variable of type numeric to long.

```
int PGTYPESnumeric_to_long(numeric *nv, long *lp);
```

The function converts the numeric value from the variable that `nv` points to into the long integer variable that `lp` points to. It returns 0 on success and -1 if an error occurs, including overflow. On overflow, the global variable `errno` will be set to `PGTYPES_NUM_OVERFLOW` additionally.

`PGTYPESnumeric_to_decimal`

Convert a variable of type numeric to decimal.

```
int PGTYPESnumeric_to_decimal(numeric *src, decimal *dst);
```

The function converts the numeric value from the variable that `src` points to into the decimal variable that `dst` points to. It returns 0 on success and -1 if an error occurs, including overflow. On overflow, the global variable `errno` will be set to `PGTYPES_NUM_OVERFLOW` additionally.

`PGTYPESnumeric_from_decimal`

Convert a variable of type decimal to numeric.

```
int PGTYPESnumeric_from_decimal(decimal *src, numeric *dst);
```

The function converts the decimal value from the variable that `src` points to into the numeric variable that `dst` points to. It returns 0 on success and -1 if an error occurs. Since the decimal type is implemented as a limited version of the numeric type, overflow cannot occur with this conversion.

38.6.3. The date Type

The date type in C enables your programs to deal with data of the SQL type date. See Section 8.5 for the equivalent type in the Postgres Pro server.

The following functions can be used to work with the date type:

`PGTYPESdate_from_timestamp`

Extract the date part from a timestamp.

```
date PGTYPESdate_from_timestamp(timestamp dt);
```

The function receives a timestamp as its only argument and returns the extracted date part from this timestamp.

`PGTYPESdate_from_asc`

Parse a date from its textual representation.

```
date PGTYPESdate_from_asc(char *str, char **endptr);
```

The function receives a C char* string `str` and a pointer to a C char* string `endptr`. At the moment ECPG always parses the complete string and so it currently does not support to store the address of the first invalid character in `*endptr`. You can safely set `endptr` to NULL.

Note that the function always assumes MDY-formatted dates and there is currently no variable to change that within ECPG.

Table 38.2 shows the allowed input formats.

Table 38.2. Valid Input Formats for `PGTYPESdate_from_asc`

Input	Result
January 8, 1999	January 8, 1999
1999-01-08	January 8, 1999
1/8/1999	January 8, 1999
1/18/1999	January 18, 1999
01/02/03	February 1, 2003
1999-Jan-08	January 8, 1999
Jan-08-1999	January 8, 1999
08-Jan-1999	January 8, 1999
99-Jan-08	January 8, 1999
08-Jan-99	January 8, 1999
08-Jan-06	January 8, 2006
Jan-08-99	January 8, 1999

Input	Result
19990108	ISO 8601; January 8, 1999
990108	ISO 8601; January 8, 1999
1999.008	year and day of year
J2451187	Julian day
January 8, 99 BC	year 99 before the Common Era

PGTYPESdate_to_asc

Return the textual representation of a date variable.

```
char *PGTYPESdate_to_asc(date dDate);
```

The function receives the date dDate as its only parameter. It will output the date in the form 1999-01-18, i.e., in the YYYY-MM-DD format. The result must be freed with PGTYPESchar_free().

PGTYPESdate_julmdy

Extract the values for the day, the month and the year from a variable of type date.

```
void PGTYPESdate_julmdy(date d, int *mdy);
```

The function receives the date d and a pointer to an array of 3 integer values mdy. The variable name indicates the sequential order: mdy[0] will be set to contain the number of the month, mdy[1] will be set to the value of the day and mdy[2] will contain the year.

PGTYPESdate_mdyjul

Create a date value from an array of 3 integers that specify the day, the month and the year of the date.

```
void PGTYPESdate_mdyjul(int *mdy, date *jdate);
```

The function receives the array of the 3 integers (mdy) as its first argument and as its second argument a pointer to a variable of type date that should hold the result of the operation.

PGTYPESdate_dayofweek

Return a number representing the day of the week for a date value.

```
int PGTYPESdate_dayofweek(date d);
```

The function receives the date variable d as its only argument and returns an integer that indicates the day of the week for this date.

- 0 - Sunday
- 1 - Monday
- 2 - Tuesday
- 3 - Wednesday
- 4 - Thursday
- 5 - Friday
- 6 - Saturday

PGTYPESdate_today

Get the current date.

```
void PGTYPESdate_today(date *d);
```

The function receives a pointer to a date variable (d) that it sets to the current date.

PGTYPESdate_fmt_asc

Convert a variable of type date to its textual representation using a format mask.

```
int PGTYPESdate_fmt_asc(date dDate, char *fmtstring, char *outbuf);
```

The function receives the date to convert (`dDate`), the format mask (`fmtstring`) and the string that will hold the textual representation of the date (`outbuf`).

On success, 0 is returned and a negative value if an error occurred.

The following literals are the field specifiers you can use:

- `dd` - The number of the day of the month.
- `mm` - The number of the month of the year.
- `yy` - The number of the year as a two digit number.
- `yyyy` - The number of the year as a four digit number.
- `ddd` - The name of the day (abbreviated).
- `mmm` - The name of the month (abbreviated).

All other characters are copied 1:1 to the output string.

Table 38.3 indicates a few possible formats. This will give you an idea of how to use this function. All output lines are based on the same date: November 23, 1959.

Table 38.3. Valid Input Formats for `PGTYPESdate_fmt_asc`

Format	Result
mmddyy	112359
ddmmyy	231159
yymmdd	591123
yy/mm/dd	59/11/23
yy mm dd	59 11 23
yy.mm.dd	59.11.23
.mm.yyyy.dd.	.11.1959.23.
mmm. dd, yyyy	Nov. 23, 1959
mmm dd yyyy	Nov 23 1959
yyyy dd mm	1959 23 11
ddd, mmm. dd, yyyy	Mon, Nov. 23, 1959
(ddd) mmm. dd, yyyy	(Mon) Nov. 23, 1959

`PGTYPESdate_defmt_asc`

Use a format mask to convert a C `char*` string to a value of type date.

```
int PGTYPESdate_defmt_asc(date *d, char *fmt, char *str);
```

The function receives a pointer to the date value that should hold the result of the operation (`d`), the format mask to use for parsing the date (`fmt`) and the C char* string containing the textual representation of the date (`str`). The textual representation is expected to match the format mask. However you do not need to have a 1:1 mapping of the string to the format mask. The function only analyzes the sequential order and looks for the literals `yy` or `yyyy` that indicate the position of the year, `mm` to indicate the position of the month and `dd` to indicate the position of the day.

Table 38.4 indicates a few possible formats. This will give you an idea of how to use this function.

Table 38.4. Valid Input Formats for `rdefmtdate`

Format	String	Result
ddmmyy	21-2-54	1954-02-21

Format	String	Result
ddmmyy	2-12-54	1954-12-02
ddmmyy	20111954	1954-11-20
ddmmyy	130464	1964-04-13
mmm.dd.yyyy	MAR-12-1967	1967-03-12
yy/mm/dd	1954, February 3rd	1954-02-03
mmm.dd.yyyy	041269	1969-04-12
yy/mm/dd	In the year 2525, in the month of July, mankind will be alive on the 28th day	2525-07-28
dd-mm-yy	I said on the 28th of July in the year 2525	2525-07-28
mmm.dd.yyyy	9/14/58	1958-09-14
yy/mm/dd	47/03/29	1947-03-29
mmm.dd.yyyy	oct 28 1975	1975-10-28
mmddyy	Nov 14th, 1985	1985-11-14

38.6.4. The timestamp Type

The timestamp type in C enables your programs to deal with data of the SQL type timestamp. See Section 8.5 for the equivalent type in the Postgres Pro server.

The following functions can be used to work with the timestamp type:

`PGTYPEStimestamp_from_asc`

Parse a timestamp from its textual representation into a timestamp variable.

```
timestamp PGTYPEStimestamp_from_asc(char *str, char **endptr);
```

The function receives the string to parse (`str`) and a pointer to a C char* (`endptr`). At the moment ECPG always parses the complete string and so it currently does not support to store the address of the first invalid character in `*endptr`. You can safely set `endptr` to NULL.

The function returns the parsed timestamp on success. On error, `PGTYPESInvalidTimestamp` is returned and `errno` is set to `PGTYPES_TS_BAD_TIMESTAMP`. See `PGTYPESInvalidTimestamp` for important notes on this value.

In general, the input string can contain any combination of an allowed date specification, a white-space character and an allowed time specification. Note that time zones are not supported by ECPG. It can parse them but does not apply any calculation as the Postgres Pro server does for example. Timezone specifiers are silently discarded.

Table 38.5 contains a few examples for input strings.

Table 38.5. Valid Input Formats for `PGTYPEStimestamp_from_asc`

Input	Result
1999-01-08 04:05:06	1999-01-08 04:05:06
January 8 04:05:06 1999 PST	1999-01-08 04:05:06
1999-Jan-08 04:05:06.789-8	1999-01-08 04:05:06.789 (time zone specifier ignored)
J2451187 04:05-08:00	1999-01-08 04:05:00 (time zone specifier ignored)

`PGTYPEStimestamp_to_asc`

Converts a date to a C char* string.

```
char *PGTYPEStimestamp_to_asc(timestamp tstamp);
```

The function receives the timestamp `tstamp` as its only argument and returns an allocated string that contains the textual representation of the timestamp. The result must be freed with `PGTYPESchar_free()`.

`PGTYPEStimestamp_current`

Retrieve the current timestamp.

```
void PGTYPEStimestamp_current(timestamp *ts);
```

The function retrieves the current timestamp and saves it into the timestamp variable that `ts` points to.

`PGTYPEStimestamp_fmt_asc`

Convert a timestamp variable to a C char* using a format mask.

```
int PGTYPEStimestamp_fmt_asc(timestamp *ts, char *output, int str_len, char
 *fmtstr);
```

The function receives a pointer to the timestamp to convert as its first argument (`ts`), a pointer to the output buffer (`output`), the maximal length that has been allocated for the output buffer (`str_len`) and the format mask to use for the conversion (`fmtstr`).

Upon success, the function returns 0 and a negative value if an error occurred.

You can use the following format specifiers for the format mask. The format specifiers are the same ones that are used in the `strftime` function in libc. Any non-format specifier will be copied into the output buffer.

- `%A` - is replaced by national representation of the full weekday name.
- `%a` - is replaced by national representation of the abbreviated weekday name.
- `%B` - is replaced by national representation of the full month name.
- `%b` - is replaced by national representation of the abbreviated month name.
- `%C` - is replaced by (year / 100) as decimal number; single digits are preceded by a zero.
- `%c` - is replaced by national representation of time and date.
- `%D` - is equivalent to `%m/%d/%y`.
- `%d` - is replaced by the day of the month as a decimal number (01–31).
- `%E* %O*` - POSIX locale extensions. The sequences `%Ec %EC %Ex %EX %Ey %EY %Od %Oe %OH %OI %Om %OM %OS %Ou %OU %OV %Ow %OW %Oy` are supposed to provide alternative representations.

  Additionally `%OB` implemented to represent alternative months names (used standalone, without day mentioned).
- `%e` - is replaced by the day of month as a decimal number (1–31); single digits are preceded by a blank.
- `%F` - is equivalent to `%Y-%m-%d`.
- `%G` - is replaced by a year as a decimal number with century. This year is the one that contains the greater part of the week (Monday as the first day of the week).
- `%g` - is replaced by the same year as in `%G`, but as a decimal number without century (00–99).
- `%H` - is replaced by the hour (24-hour clock) as a decimal number (00–23).
- `%h` - the same as `%b`.

- `%I` - is replaced by the hour (12-hour clock) as a decimal number (01–12).
- `%j` - is replaced by the day of the year as a decimal number (001–366).
- `%k` - is replaced by the hour (24-hour clock) as a decimal number (0–23); single digits are preceded by a blank.
- `%l` - is replaced by the hour (12-hour clock) as a decimal number (1–12); single digits are preceded by a blank.
- `%M` - is replaced by the minute as a decimal number (00–59).
- `%m` - is replaced by the month as a decimal number (01–12).
- `%n` - is replaced by a newline.
- `%O*` - the same as `%E*`.
- `%p` - is replaced by national representation of either “ante meridiem” or “post meridiem” as appropriate.
- `%R` - is equivalent to `%H:%M`.
- `%r` - is equivalent to `%I:%M:%S %p`.
- `%S` - is replaced by the second as a decimal number (00–60).
- `%s` - is replaced by the number of seconds since the Epoch, UTC.
- `%T` - is equivalent to `%H:%M:%S`
- `%t` - is replaced by a tab.
- `%U` - is replaced by the week number of the year (Sunday as the first day of the week) as a decimal number (00–53).
- `%u` - is replaced by the weekday (Monday as the first day of the week) as a decimal number (1–7).
- `%V` - is replaced by the week number of the year (Monday as the first day of the week) as a decimal number (01–53). If the week containing January 1 has four or more days in the new year, then it is week 1; otherwise it is the last week of the previous year, and the next week is week 1.
- `%v` - is equivalent to `%e-%b-%Y`.
- `%W` - is replaced by the week number of the year (Monday as the first day of the week) as a decimal number (00–53).
- `%w` - is replaced by the weekday (Sunday as the first day of the week) as a decimal number (0–6).
- `%X` - is replaced by national representation of the time.
- `%x` - is replaced by national representation of the date.
- `%Y` - is replaced by the year with century as a decimal number.
- `%y` - is replaced by the year without century as a decimal number (00–99).
- `%Z` - is replaced by the time zone name.
- `%z` - is replaced by the time zone offset from UTC; a leading plus sign stands for east of UTC, a minus sign for west of UTC, hours and minutes follow with two digits each and no delimiter between them (common form for *RFC 822* date headers).
- `%+` - is replaced by national representation of the date and time.
- `%-*` - GNU libc extension. Do not do any padding when performing numerical outputs.
- $_* - GNU libc extension. Explicitly specify space for padding.
- `%0*` - GNU libc extension. Explicitly specify zero for padding.
- `%%` - is replaced by `%`.

`PGTYPEStimestamp_sub`

Subtract one timestamp from another one and save the result in a variable of type interval.

```
int PGTYPEStimestamp_sub(timestamp *ts1, timestamp *ts2, interval *iv);
```

The function will subtract the timestamp variable that `ts2` points to from the timestamp variable that `ts1` points to and will store the result in the interval variable that `iv` points to.

Upon success, the function returns 0 and a negative value if an error occurred.

`PGTYPEStimestamp_defmt_asc`

Parse a timestamp value from its textual representation using a formatting mask.

```
int PGTYPEStimestamp_defmt_asc(char *str, char *fmt, timestamp *d);
```

The function receives the textual representation of a timestamp in the variable `str` as well as the formatting mask to use in the variable `fmt`. The result will be stored in the variable that `d` points to.

If the formatting mask `fmt` is NULL, the function will fall back to the default formatting mask which is `%Y-%m-%d %H:%M:%S`.

This is the reverse function to `PGTYPEStimestamp_fmt_asc`. See the documentation there in order to find out about the possible formatting mask entries.

`PGTYPEStimestamp_add_interval`

Add an interval variable to a timestamp variable.

```
int PGTYPEStimestamp_add_interval(timestamp *tin, interval *span, timestamp *tout);
```

The function receives a pointer to a timestamp variable `tin` and a pointer to an interval variable `span`. It adds the interval to the timestamp and saves the resulting timestamp in the variable that `tout` points to.

Upon success, the function returns 0 and a negative value if an error occurred.

`PGTYPEStimestamp_sub_interval`

Subtract an interval variable from a timestamp variable.

```
int PGTYPEStimestamp_sub_interval(timestamp *tin, interval *span, timestamp *tout);
```

The function subtracts the interval variable that `span` points to from the timestamp variable that `tin` points to and saves the result into the variable that `tout` points to.

Upon success, the function returns 0 and a negative value if an error occurred.

38.6.5. The interval Type

The interval type in C enables your programs to deal with data of the SQL type interval. See Section 8.5 for the equivalent type in the Postgres Pro server.

The following functions can be used to work with the interval type:

`PGTYPESinterval_new`

Return a pointer to a newly allocated interval variable.

```
interval *PGTYPESinterval_new(void);
```

`PGTYPESinterval_free`

Release the memory of a previously allocated interval variable.

```
void PGTYPESinterval_free(interval *intvl);
```

`PGTYPESinterval_from_asc`

Parse an interval from its textual representation.

```
interval *PGTYPESinterval_from_asc(char *str, char **endptr);
```

The function parses the input string `str` and returns a pointer to an allocated interval variable. At the moment ECPG always parses the complete string and so it currently does not support to store the address of the first invalid character in `*endptr`. You can safely set `endptr` to NULL.

`PGTYPESinterval_to_asc`

Convert a variable of type interval to its textual representation.

```
char *PGTYPESinterval_to_asc(interval *span);
```

The function converts the interval variable that `span` points to into a C char*. The output looks like this example: `@ 1 day 12 hours 59 mins 10 secs`. The result must be freed with `PGTYPESchar_free()`.

`PGTYPESinterval_copy`

Copy a variable of type interval.

```
int PGTYPESinterval_copy(interval *intvlsrc, interval *intvldest);
```

The function copies the interval variable that `intvlsrc` points to into the variable that `intvldest` points to. Note that you need to allocate the memory for the destination variable before.

38.6.6. The decimal Type

The decimal type is similar to the numeric type. However it is limited to a maximum precision of 30 significant digits. In contrast to the numeric type which can be created on the heap only, the decimal type can be created either on the stack or on the heap (by means of the functions `PGTYPESdecimal_new` and `PGTYPESdecimal_free`). There are a lot of other functions that deal with the decimal type in the Informix compatibility mode described in Section 38.15.

The following functions can be used to work with the decimal type and are not only contained in the `libcompat` library.

`PGTYPESdecimal_new`

Request a pointer to a newly allocated decimal variable.

```
decimal *PGTYPESdecimal_new(void);
```

`PGTYPESdecimal_free`

Free a decimal type, release all of its memory.

```
void PGTYPESdecimal_free(decimal *var);
```

38.6.7. errno Values of pgtypeslib

`PGTYPES_NUM_BAD_NUMERIC`

An argument should contain a numeric variable (or point to a numeric variable) but in fact its in-memory representation was invalid.

`PGTYPES_NUM_OVERFLOW`

An overflow occurred. Since the numeric type can deal with almost arbitrary precision, converting a numeric variable into other types might cause overflow.

`PGTYPES_NUM_UNDERFLOW`

An underflow occurred. Since the numeric type can deal with almost arbitrary precision, converting a numeric variable into other types might cause underflow.

`PGTYPES_NUM_DIVIDE_ZERO`

A division by zero has been attempted.

PGTYPES_DATE_BAD_DATE

An invalid date string was passed to the PGTYPESdate_from_asc function.

PGTYPES_DATE_ERR_EARGS

Invalid arguments were passed to the PGTYPESdate_defmt_asc function.

PGTYPES_DATE_ERR_ENOSHORTDATE

An invalid token in the input string was found by the PGTYPESdate_defmt_asc function.

PGTYPES_INTVL_BAD_INTERVAL

An invalid interval string was passed to the PGTYPESinterval_from_asc function, or an invalid interval value was passed to the PGTYPESinterval_to_asc function.

PGTYPES_DATE_ERR_ENOTDMY

There was a mismatch in the day/month/year assignment in the PGTYPESdate_defmt_asc function.

PGTYPES_DATE_BAD_DAY

An invalid day of the month value was found by the PGTYPESdate_defmt_asc function.

PGTYPES_DATE_BAD_MONTH

An invalid month value was found by the PGTYPESdate_defmt_asc function.

PGTYPES_TS_BAD_TIMESTAMP

An invalid timestamp string pass passed to the PGTYPEStimestamp_from_asc function, or an invalid timestamp value was passed to the PGTYPEStimestamp_to_asc function.

PGTYPES_TS_ERR_EINFTIME

An infinite timestamp value was encountered in a context that cannot handle it.

38.6.8. Special Constants of pgtypeslib

PGTYPESInvalidTimestamp

A value of type timestamp representing an invalid time stamp. This is returned by the function PGTYPEStimestamp_from_asc on parse error. Note that due to the internal representation of the timestamp data type, PGTYPESInvalidTimestamp is also a valid timestamp at the same time. It is set to 1899-12-31 23:59:59. In order to detect errors, make sure that your application does not only test for PGTYPESInvalidTimestamp but also for errno != 0 after each call to PGTYPEStimestamp_from_asc.

38.7. Using Descriptor Areas

An SQL descriptor area is a more sophisticated method for processing the result of a SELECT, FETCH or a DESCRIBE statement. An SQL descriptor area groups the data of one row of data together with metadata items into one data structure. The metadata is particularly useful when executing dynamic SQL statements, where the nature of the result columns might not be known ahead of time. Postgres Pro provides two ways to use Descriptor Areas: the named SQL Descriptor Areas and the C-structure SQLDAs.

38.7.1. Named SQL Descriptor Areas

A named SQL descriptor area consists of a header, which contains information concerning the entire descriptor, and one or more item descriptor areas, which basically each describe one column in the result row.

Before you can use an SQL descriptor area, you need to allocate one:

```
EXEC SQL ALLOCATE DESCRIPTOR identifier;
```

The identifier serves as the "variable name" of the descriptor area. When you don't need the descriptor anymore, you should deallocate it:

```
EXEC SQL DEALLOCATE DESCRIPTOR identifier;
```

To use a descriptor area, specify it as the storage target in an `INTO` clause, instead of listing host variables:

```
EXEC SQL FETCH NEXT FROM mycursor INTO SQL DESCRIPTOR mydesc;
```

If the result set is empty, the Descriptor Area will still contain the metadata from the query, i.e., the field names.

For not yet executed prepared queries, the `DESCRIBE` statement can be used to get the metadata of the result set:

```
EXEC SQL BEGIN DECLARE SECTION;
char *sql_stmt = "SELECT * FROM table1";
EXEC SQL END DECLARE SECTION;

EXEC SQL PREPARE stmt1 FROM :sql_stmt;
EXEC SQL DESCRIBE stmt1 INTO SQL DESCRIPTOR mydesc;
```

Before PostgreSQL 9.0, the `SQL` keyword was optional, so using `DESCRIPTOR` and `SQL DESCRIPTOR` produced named SQL Descriptor Areas. Now it is mandatory, omitting the `SQL` keyword produces SQLDA Descriptor Areas, see Section 38.7.2.

In `DESCRIBE` and `FETCH` statements, the `INTO` and `USING` keywords can be used to similarly: they produce the result set and the metadata in a Descriptor Area.

Now how do you get the data out of the descriptor area? You can think of the descriptor area as a structure with named fields. To retrieve the value of a field from the header and store it into a host variable, use the following command:

```
EXEC SQL GET DESCRIPTOR name :hostvar = field;
```

Currently, there is only one header field defined: *`COUNT`*, which tells how many item descriptor areas exist (that is, how many columns are contained in the result). The host variable needs to be of an integer type. To get a field from the item descriptor area, use the following command:

```
EXEC SQL GET DESCRIPTOR name VALUE num :hostvar = field;
```

`num` can be a literal integer or a host variable containing an integer. Possible fields are:

`CARDINALITY` (integer)

number of rows in the result set

`DATA`

actual data item (therefore, the data type of this field depends on the query)

`DATETIME_INTERVAL_CODE` (integer)

When `TYPE` is `9`, `DATETIME_INTERVAL_CODE` will have a value of `1` for `DATE`, `2` for `TIME`, `3` for `TIMESTAMP`, `4` for `TIME WITH TIME ZONE`, or `5` for `TIMESTAMP WITH TIME ZONE`.

`DATETIME_INTERVAL_PRECISION` (integer)

not implemented

`INDICATOR` (integer)

the indicator (indicating a null value or a value truncation)

`KEY_MEMBER` (integer)

not implemented

`LENGTH` (integer)

length of the datum in characters

`NAME` (string)

name of the column

`NULLABLE` (integer)

not implemented

`OCTET_LENGTH` (integer)

length of the character representation of the datum in bytes

`PRECISION` (integer)

precision (for type `numeric`)

`RETURNED_LENGTH` (integer)

length of the datum in characters

`RETURNED_OCTET_LENGTH` (integer)

length of the character representation of the datum in bytes

`SCALE` (integer)

scale (for type `numeric`)

`TYPE` (integer)

numeric code of the data type of the column

In `EXECUTE`, `DECLARE` and `OPEN` statements, the effect of the `INTO` and `USING` keywords are different. A Descriptor Area can also be manually built to provide the input parameters for a query or a cursor and `USING SQL DESCRIPTOR` *`name`* is the way to pass the input parameters into a parameterized query. The statement to build a named SQL Descriptor Area is below:

```
EXEC SQL SET DESCRIPTOR name VALUE num field = :hostvar;
```

Postgres Pro supports retrieving more that one record in one `FETCH` statement and storing the data in host variables in this case assumes that the variable is an array. E.g.:

```
EXEC SQL BEGIN DECLARE SECTION;
int id[5];
EXEC SQL END DECLARE SECTION;

EXEC SQL FETCH 5 FROM mycursor INTO SQL DESCRIPTOR mydesc;

EXEC SQL GET DESCRIPTOR mydesc VALUE 1 :id = DATA;
```

38.7.2. SQLDA Descriptor Areas

An SQLDA Descriptor Area is a C language structure which can be also used to get the result set and the metadata of a query. One structure stores one record from the result set.

```
EXEC SQL include sqlda.h;
sqlda_t         *mysqlda;

EXEC SQL FETCH 3 FROM mycursor INTO DESCRIPTOR mysqlda;
```

Note that the `SQL` keyword is omitted. The paragraphs about the use cases of the `INTO` and `USING` keywords in Section 38.7.1 also apply here with an addition. In a `DESCRIBE` statement the `DESCRIPTOR` keyword can be completely omitted if the `INTO` keyword is used:

```
EXEC SQL DESCRIBE prepared_statement INTO mysqlda;
```

The general flow of a program that uses SQLDA is:

1. Prepare a query, and declare a cursor for it.
2. Declare an SQLDA for the result rows.
3. Declare an SQLDA for the input parameters, and initialize them (memory allocation, parameter settings).
4. Open a cursor with the input SQLDA.
5. Fetch rows from the cursor, and store them into an output SQLDA.
6. Read values from the output SQLDA into the host variables (with conversion if necessary).
7. Close the cursor.
8. Free the memory area allocated for the input SQLDA.

38.7.2.1. SQLDA Data Structure

SQLDA uses three data structure types: `sqlda_t`, `sqlvar_t`, and `struct sqlname`.

> **Tip**
>
> Postgres Pro's SQLDA has a similar data structure to the one in IBM DB2 Universal Database, so some technical information on DB2's SQLDA could help understanding Postgres Pro's one better.

38.7.2.1.1. sqlda_t Structure

The structure type `sqlda_t` is the type of the actual SQLDA. It holds one record. And two or more `sqlda_t` structures can be connected in a linked list with the pointer in the `desc_next` field, thus representing an ordered collection of rows. So, when two or more rows are fetched, the application can read them by following the `desc_next` pointer in each `sqlda_t` node.

The definition of `sqlda_t` is:

```
struct sqlda_struct
{
    char            sqldaid[8];
    long            sqldabc;
    short           sqln;
    short           sqld;
    struct sqlda_struct *desc_next;
    struct sqlvar_struct sqlvar[1];
};

typedef struct sqlda_struct sqlda_t;
```

The meaning of the fields is:

`sqldaid`

It contains the literal string `"SQLDA "`.

`sqldabc`

It contains the size of the allocated space in bytes.

`sqln`

It contains the number of input parameters for a parameterized query in case it's passed into `OPEN`, `DECLARE` or `EXECUTE` statements using the `USING` keyword. In case it's used as output of `SELECT`, `EXECUTE` or `FETCH` statements, its value is the same as `sqld` statement

`sqld`

It contains the number of fields in a result set.

`desc_next`

If the query returns more than one record, multiple linked SQLDA structures are returned, and `desc_next` holds a pointer to the next entry in the list.

`sqlvar`

This is the array of the columns in the result set.

38.7.2.1.2. sqlvar_t Structure

The structure type `sqlvar_t` holds a column value and metadata such as type and length. The definition of the type is:

```
struct sqlvar_struct
{
    short          sqltype;
    short          sqllen;
    char          *sqldata;
    short         *sqlind;
    struct sqlname sqlname;
};

typedef struct sqlvar_struct sqlvar_t;
```

The meaning of the fields is:

`sqltype`

Contains the type identifier of the field. For values, see `enum ECPGttype` in `ecpgtype.h`.

`sqllen`

Contains the binary length of the field. e.g., 4 bytes for `ECPGt_int`.

`sqldata`

Points to the data. The format of the data is described in Section 38.4.4.

`sqlind`

Points to the null indicator. 0 means not null, -1 means null.

`sqlname`

The name of the field.

38.7.2.1.3. struct sqlname Structure

A `struct sqlname` structure holds a column name. It is used as a member of the `sqlvar_t` structure. The definition of the structure is:

```
#define NAMEDATALEN 64

struct sqlname
{
        short           length;
        char            data[NAMEDATALEN];
};
```

The meaning of the fields is:

`length`

Contains the length of the field name.

`data`

Contains the actual field name.

38.7.2.2. Retrieving a Result Set Using an SQLDA

The general steps to retrieve a query result set through an SQLDA are:

1. Declare an `sqlda_t` structure to receive the result set.
2. Execute `FETCH`/`EXECUTE`/`DESCRIBE` commands to process a query specifying the declared SQLDA.
3. Check the number of records in the result set by looking at `sqln`, a member of the `sqlda_t` structure.
4. Get the values of each column from `sqlvar[0]`, `sqlvar[1]`, etc., members of the `sqlda_t` structure.
5. Go to next row (`sqlda_t` structure) by following the `desc_next` pointer, a member of the `sqlda_t` structure.
6. Repeat above as you need.

Here is an example retrieving a result set through an SQLDA.

First, declare a `sqlda_t` structure to receive the result set.

```
sqlda_t *sqlda1;
```

Next, specify the SQLDA in a command. This is a `FETCH` command example.

```
EXEC SQL FETCH NEXT FROM cur1 INTO DESCRIPTOR sqlda1;
```

Run a loop following the linked list to retrieve the rows.

```
sqlda_t *cur_sqlda;

for (cur_sqlda = sqlda1;
     cur_sqlda != NULL;
     cur_sqlda = cur_sqlda->desc_next)
{
    ...
}
```

Inside the loop, run another loop to retrieve each column data (`sqlvar_t` structure) of the row.

```
for (i = 0; i < cur_sqlda->sqld; i++)
{
    sqlvar_t v = cur_sqlda->sqlvar[i];
    char *sqldata = v.sqldata;
    short sqllen  = v.sqllen;
    ...
}
```

To get a column value, check the `sqltype` value, a member of the `sqlvar_t` structure. Then, switch to an appropriate way, depending on the column type, to copy data from the `sqlvar` field to a host variable.

```
char var_buf[1024];

switch (v.sqltype)
{
    case ECPGt_char:
        memset(&var_buf, 0, sizeof(var_buf));
        memcpy(&var_buf, sqldata, (sizeof(var_buf) <= sqllen ? sizeof(var_buf) - 1 :
 sqllen));
        break;

    case ECPGt_int: /* integer */
```

```
        memcpy(&intval, sqldata, sqllen);
        snprintf(var_buf, sizeof(var_buf), "%d", intval);
        break;

    ...
}
```

38.7.2.3. Passing Query Parameters Using an SQLDA

The general steps to use an SQLDA to pass input parameters to a prepared query are:

1. Create a prepared query (prepared statement)
2. Declare an sqlda_t structure as an input SQLDA.
3. Allocate memory area (as sqlda_t structure) for the input SQLDA.
4. Set (copy) input values in the allocated memory.
5. Open a cursor with specifying the input SQLDA.

Here is an example.

First, create a prepared statement.

```
EXEC SQL BEGIN DECLARE SECTION;
char query[1024] = "SELECT d.oid, * FROM pg_database d, pg_stat_database s WHERE d.oid
 = s.datid AND (d.datname = ? OR d.oid = ?)";
EXEC SQL END DECLARE SECTION;

EXEC SQL PREPARE stmt1 FROM :query;
```

Next, allocate memory for an SQLDA, and set the number of input parameters in `sqln`, a member variable of the `sqlda_t` structure. When two or more input parameters are required for the prepared query, the application has to allocate additional memory space which is calculated by (nr. of params - 1) * sizeof(sqlvar_t). The example shown here allocates memory space for two input parameters.

```
sqlda_t *sqlda2;

sqlda2 = (sqlda_t *) malloc(sizeof(sqlda_t) + sizeof(sqlvar_t));
memset(sqlda2, 0, sizeof(sqlda_t) + sizeof(sqlvar_t));

sqlda2->sqln = 2; /* number of input variables */
```

After memory allocation, store the parameter values into the `sqlvar[]` array. (This is same array used for retrieving column values when the SQLDA is receiving a result set.) In this example, the input parameters are `"postgres"`, having a string type, and `1`, having an integer type.

```
sqlda2->sqlvar[0].sqltype = ECPGt_char;
sqlda2->sqlvar[0].sqldata = "postgres";
sqlda2->sqlvar[0].sqllen  = 8;

int intval = 1;
sqlda2->sqlvar[1].sqltype = ECPGt_int;
sqlda2->sqlvar[1].sqldata = (char *) &intval;
sqlda2->sqlvar[1].sqllen  = sizeof(intval);
```

By opening a cursor and specifying the SQLDA that was set up beforehand, the input parameters are passed to the prepared statement.

```
EXEC SQL OPEN cur1 USING DESCRIPTOR sqlda2;
```

Finally, after using input SQLDAs, the allocated memory space must be freed explicitly, unlike SQLDAs used for receiving query results.

```
free(sqlda2);
```

38.7.2.4. A Sample Application Using SQLDA

Here is an example program, which describes how to fetch access statistics of the databases, specified by the input parameters, from the system catalogs.

This application joins two system tables, pg_database and pg_stat_database on the database OID, and also fetches and shows the database statistics which are retrieved by two input parameters (a database `postgres`, and OID `1`).

First, declare an SQLDA for input and an SQLDA for output.

```
EXEC SQL include sqlda.h;

sqlda_t *sqlda1; /* an output descriptor */
sqlda_t *sqlda2; /* an input descriptor  */
```

Next, connect to the database, prepare a statement, and declare a cursor for the prepared statement.

```
int
main(void)
{
    EXEC SQL BEGIN DECLARE SECTION;
    char query[1024] = "SELECT d.oid,* FROM pg_database d, pg_stat_database s WHERE
 d.oid=s.datid AND ( d.datname=? OR d.oid=? )";
    EXEC SQL END DECLARE SECTION;

    EXEC SQL CONNECT TO testdb AS con1 USER testuser;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    EXEC SQL PREPARE stmt1 FROM :query;
    EXEC SQL DECLARE cur1 CURSOR FOR stmt1;
```

Next, put some values in the input SQLDA for the input parameters. Allocate memory for the input SQLDA, and set the number of input parameters to `sqln`. Store type, value, and value length into `sqltype`, `sqldata`, and `sqllen` in the `sqlvar` structure.

```
    /* Create SQLDA structure for input parameters. */
    sqlda2 = (sqlda_t *) malloc(sizeof(sqlda_t) + sizeof(sqlvar_t));
    memset(sqlda2, 0, sizeof(sqlda_t) + sizeof(sqlvar_t));
    sqlda2->sqln = 2; /* number of input variables */

    sqlda2->sqlvar[0].sqltype = ECPGt_char;
    sqlda2->sqlvar[0].sqldata = "postgres";
    sqlda2->sqlvar[0].sqllen  = 8;

    intval = 1;
    sqlda2->sqlvar[1].sqltype = ECPGt_int;
    sqlda2->sqlvar[1].sqldata = (char *)&intval;
    sqlda2->sqlvar[1].sqllen  = sizeof(intval);
```

After setting up the input SQLDA, open a cursor with the input SQLDA.

```
    /* Open a cursor with input parameters. */
    EXEC SQL OPEN cur1 USING DESCRIPTOR sqlda2;
```

Fetch rows into the output SQLDA from the opened cursor. (Generally, you have to call `FETCH` repeatedly in the loop, to fetch all rows in the result set.)

```
    while (1)
    {
        sqlda_t *cur_sqlda;
```

```
        /* Assign descriptor to the cursor  */
        EXEC SQL FETCH NEXT FROM cur1 INTO DESCRIPTOR sqlda1;
```

Next, retrieve the fetched records from the SQLDA, by following the linked list of the `sqlda_t` structure.

```
    for (cur_sqlda = sqlda1 ;
         cur_sqlda != NULL ;
         cur_sqlda = cur_sqlda->desc_next)
    {
        ...
```

Read each columns in the first record. The number of columns is stored in `sqld`, the actual data of the first column is stored in `sqlvar[0]`, both members of the `sqlda_t` structure.

```
        /* Print every column in a row. */
        for (i = 0; i < sqlda1->sqld; i++)
        {
            sqlvar_t v = sqlda1->sqlvar[i];
            char *sqldata = v.sqldata;
            short sqllen  = v.sqllen;

            strncpy(name_buf, v.sqlname.data, v.sqlname.length);
            name_buf[v.sqlname.length] = '\0';
```

Now, the column data is stored in the variable `v`. Copy every datum into host variables, looking at `v.sqltype` for the type of the column.

```
            switch (v.sqltype) {
                int intval;
                double doubleval;
                unsigned long long int longlongval;

                case ECPGt_char:
                    memset(&var_buf, 0, sizeof(var_buf));
                    memcpy(&var_buf, sqldata, (sizeof(var_buf) <= sqllen ?
 sizeof(var_buf)-1 : sqllen));
                    break;

                case ECPGt_int: /* integer */
                    memcpy(&intval, sqldata, sqllen);
                    snprintf(var_buf, sizeof(var_buf), "%d", intval);
                    break;

                ...

                default:
                    ...
            }

            printf("%s = %s (type: %d)\n", name_buf, var_buf, v.sqltype);
        }
```

Close the cursor after processing all of records, and disconnect from the database.

```
    EXEC SQL CLOSE cur1;
    EXEC SQL COMMIT;

    EXEC SQL DISCONNECT ALL;
```

The whole program is shown in Example 38.1.

Example 38.1. Example SQLDA Program

```
#include <stdlib.h>
#include <string.h>
#include <stdlib.h>
#include <stdio.h>
#include <unistd.h>

EXEC SQL include sqlda.h;

sqlda_t *sqlda1; /* descriptor for output */
sqlda_t *sqlda2; /* descriptor for input */

EXEC SQL WHENEVER NOT FOUND DO BREAK;
EXEC SQL WHENEVER SQLERROR STOP;

int
main(void)
{
    EXEC SQL BEGIN DECLARE SECTION;
    char query[1024] = "SELECT d.oid,* FROM pg_database d, pg_stat_database s WHERE
 d.oid=s.datid AND ( d.datname=? OR d.oid=? )";

    int intval;
    unsigned long long int longlongval;
    EXEC SQL END DECLARE SECTION;

    EXEC SQL CONNECT TO uptimedb AS con1 USER uptime;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    EXEC SQL PREPARE stmt1 FROM :query;
    EXEC SQL DECLARE cur1 CURSOR FOR stmt1;

    /* Create an SQLDA structure for an input parameter */
    sqlda2 = (sqlda_t *)malloc(sizeof(sqlda_t) + sizeof(sqlvar_t));
    memset(sqlda2, 0, sizeof(sqlda_t) + sizeof(sqlvar_t));
    sqlda2->sqln = 2; /* a number of input variables */

    sqlda2->sqlvar[0].sqltype = ECPGt_char;
    sqlda2->sqlvar[0].sqldata = "postgres";
    sqlda2->sqlvar[0].sqllen  = 8;

    intval = 1;
    sqlda2->sqlvar[1].sqltype = ECPGt_int;
    sqlda2->sqlvar[1].sqldata = (char *) &intval;
    sqlda2->sqlvar[1].sqllen  = sizeof(intval);

    /* Open a cursor with input parameters. */
    EXEC SQL OPEN cur1 USING DESCRIPTOR sqlda2;

    while (1)
    {
        sqlda_t *cur_sqlda;

        /* Assign descriptor to the cursor  */
        EXEC SQL FETCH NEXT FROM cur1 INTO DESCRIPTOR sqlda1;

        for (cur_sqlda = sqlda1 ;
```

```
             cur_sqlda != NULL ;
             cur_sqlda = cur_sqlda->desc_next)
        {
            int i;
            char name_buf[1024];
            char var_buf[1024];

            /* Print every column in a row. */
            for (i=0 ; i<cur_sqlda->sqld ; i++)
            {
                sqlvar_t v = cur_sqlda->sqlvar[i];
                char *sqldata = v.sqldata;
                short sqllen  = v.sqllen;

                strncpy(name_buf, v.sqlname.data, v.sqlname.length);
                name_buf[v.sqlname.length] = '\0';

                switch (v.sqltype)
                {
                    case ECPGt_char:
                        memset(&var_buf, 0, sizeof(var_buf));
                        memcpy(&var_buf, sqldata, (sizeof(var_buf)<=sqllen ?
sizeof(var_buf)-1 : sqllen) );
                        break;

                    case ECPGt_int: /* integer */
                        memcpy(&intval, sqldata, sqllen);
                        snprintf(var_buf, sizeof(var_buf), "%d", intval);
                        break;

                    case ECPGt_long_long: /* bigint */
                        memcpy(&longlongval, sqldata, sqllen);
                        snprintf(var_buf, sizeof(var_buf), "%lld", longlongval);
                        break;

                    default:
                    {
                        int i;
                        memset(var_buf, 0, sizeof(var_buf));
                        for (i = 0; i < sqllen; i++)
                        {
                            char tmpbuf[16];
                            snprintf(tmpbuf, sizeof(tmpbuf), "%02x ", (unsigned char)
sqldata[i]);
                            strncat(var_buf, tmpbuf, sizeof(var_buf));
                        }
                    }
                        break;
                }

                printf("%s = %s (type: %d)\n", name_buf, var_buf, v.sqltype);
            }

            printf("\n");
        }
    }

    EXEC SQL CLOSE cur1;
```

```
    EXEC SQL COMMIT;

    EXEC SQL DISCONNECT ALL;

    return 0;
}
```

The output of this example should look something like the following (some numbers will vary).

```
oid = 1 (type: 1)
datname = template1 (type: 1)
datdba = 10 (type: 1)
encoding = 0 (type: 5)
datistemplate = t (type: 1)
datallowconn = t (type: 1)
dathasloginevt = f (type: 1)
datconnlimit = -1 (type: 5)
datlastsysoid = 11510 (type: 1)
datfrozenxid = 379 (type: 1)
dattablespace = 1663 (type: 1)
datconfig =  (type: 1)
datacl = {=c/uptime,uptime=CTc/uptime} (type: 1)
datid = 1 (type: 1)
datname = template1 (type: 1)
numbackends = 0 (type: 5)
xact_commit = 113606 (type: 9)
xact_rollback = 0 (type: 9)
blks_read = 130 (type: 9)
blks_hit = 7341714 (type: 9)
tup_returned = 38262679 (type: 9)
tup_fetched = 1836281 (type: 9)
tup_inserted = 0 (type: 9)
tup_updated = 0 (type: 9)
tup_deleted = 0 (type: 9)

oid = 11511 (type: 1)
datname = postgres (type: 1)
datdba = 10 (type: 1)
encoding = 0 (type: 5)
datistemplate = f (type: 1)
datallowconn = t (type: 1)
dathasloginevt = f (type: 1)
datconnlimit = -1 (type: 5)
datlastsysoid = 11510 (type: 1)
datfrozenxid = 379 (type: 1)
dattablespace = 1663 (type: 1)
datconfig =  (type: 1)
datacl =  (type: 1)
datid = 11511 (type: 1)
datname = postgres (type: 1)
numbackends = 0 (type: 5)
xact_commit = 221069 (type: 9)
xact_rollback = 18 (type: 9)
blks_read = 1176 (type: 9)
blks_hit = 13943750 (type: 9)
tup_returned = 77410091 (type: 9)
tup_fetched = 3253694 (type: 9)
tup_inserted = 0 (type: 9)
tup_updated = 0 (type: 9)
```

```
tup_deleted = 0 (type: 9)
```

38.8. Error Handling

This section describes how you can handle exceptional conditions and warnings in an embedded SQL program. There are two nonexclusive facilities for this.

- Callbacks can be configured to handle warning and error conditions using the `WHENEVER` command.
- Detailed information about the error or warning can be obtained from the `sqlca` variable.

38.8.1. Setting Callbacks

One simple method to catch errors and warnings is to set a specific action to be executed whenever a particular condition occurs. In general:

```
EXEC SQL WHENEVER condition action;
```

condition can be one of the following:

`SQLERROR`

The specified action is called whenever an error occurs during the execution of an SQL statement.

`SQLWARNING`

The specified action is called whenever a warning occurs during the execution of an SQL statement.

`NOT FOUND`

The specified action is called whenever an SQL statement retrieves or affects zero rows. (This condition is not an error, but you might be interested in handling it specially.)

action can be one of the following:

`CONTINUE`

This effectively means that the condition is ignored. This is the default.

`GOTO label`
`GO TO label`

Jump to the specified label (using a C `goto` statement).

`SQLPRINT`

Print a message to standard error. This is useful for simple programs or during prototyping. The details of the message cannot be configured.

`STOP`

Call `exit(1)`, which will terminate the program.

`DO BREAK`

Execute the C statement `break`. This should only be used in loops or `switch` statements.

`DO CONTINUE`

Execute the C statement `continue`. This should only be used in loops statements. if executed, will cause the flow of control to return to the top of the loop.

`CALL name (args)`
`DO name (args)`

Call the specified C functions with the specified arguments. (This use is different from the meaning of `CALL` and `DO` in the normal Postgres Pro grammar.)

The SQL standard only provides for the actions `CONTINUE` and `GOTO` (and `GO TO`).

Here is an example that you might want to use in a simple program. It prints a simple message when a warning occurs and aborts the program when an error happens:

```
EXEC SQL WHENEVER SQLWARNING SQLPRINT;
EXEC SQL WHENEVER SQLERROR STOP;
```

The statement `EXEC SQL WHENEVER` is a directive of the SQL preprocessor, not a C statement. The error or warning actions that it sets apply to all embedded SQL statements that appear below the point where the handler is set, unless a different action was set for the same condition between the first `EXEC SQL WHENEVER` and the SQL statement causing the condition, regardless of the flow of control in the C program. So neither of the two following C program excerpts will have the desired effect:

```
/*
 * WRONG
 */
int main(int argc, char *argv[])
{
    ...
    if (verbose) {
        EXEC SQL WHENEVER SQLWARNING SQLPRINT;
    }
    ...
    EXEC SQL SELECT ...;
    ...
}
```

```
/*
 * WRONG
 */
int main(int argc, char *argv[])
{
    ...
    set_error_handler();
    ...
    EXEC SQL SELECT ...;
    ...
}

static void set_error_handler(void)
{
    EXEC SQL WHENEVER SQLERROR STOP;
}
```

38.8.2. sqlca

For more powerful error handling, the embedded SQL interface provides a global variable with the name `sqlca` (SQL communication area) that has the following structure:

```
struct
{
    char sqlcaid[8];
    long sqlabc;
    long sqlcode;
    struct
    {
        int sqlerrml;
        char sqlerrmc[SQLERRMC_LEN];
    } sqlerrm;
    char sqlerrp[8];
```

```
    long sqlerrd[6];
    char sqlwarn[8];
    char sqlstate[5];
} sqlca;
```

(In a multithreaded program, every thread automatically gets its own copy of `sqlca`. This works similarly to the handling of the standard C global variable `errno`.)

`sqlca` covers both warnings and errors. If multiple warnings or errors occur during the execution of a statement, then `sqlca` will only contain information about the last one.

If no error occurred in the last SQL statement, `sqlca.sqlcode` will be 0 and `sqlca.sqlstate` will be `"00000"`. If a warning or error occurred, then `sqlca.sqlcode` will be negative and `sqlca.sqlstate` will be different from `"00000"`. A positive `sqlca.sqlcode` indicates a harmless condition, such as that the last query returned zero rows. `sqlcode` and `sqlstate` are two different error code schemes; details appear below.

If the last SQL statement was successful, then `sqlca.sqlerrd[1]` contains the OID of the processed row, if applicable, and `sqlca.sqlerrd[2]` contains the number of processed or returned rows, if applicable to the command.

In case of an error or warning, `sqlca.sqlerrm.sqlerrmc` will contain a string that describes the error. The field `sqlca.sqlerrm.sqlerrml` contains the length of the error message that is stored in `sqlca.sqlerrm.sqlerrmc` (the result of `strlen()`, not really interesting for a C programmer). Note that some messages are too long to fit in the fixed-size `sqlerrmc` array; they will be truncated.

In case of a warning, `sqlca.sqlwarn[2]` is set to `W`. (In all other cases, it is set to something different from `W`.) If `sqlca.sqlwarn[1]` is set to `W`, then a value was truncated when it was stored in a host variable. `sqlca.sqlwarn[0]` is set to `W` if any of the other elements are set to indicate a warning.

The fields `sqlcaid`, `sqlabc`, `sqlerrp`, and the remaining elements of `sqlerrd` and `sqlwarn` currently contain no useful information.

The structure `sqlca` is not defined in the SQL standard, but is implemented in several other SQL database systems. The definitions are similar at the core, but if you want to write portable applications, then you should investigate the different implementations carefully.

Here is one example that combines the use of `WHENEVER` and `sqlca`, printing out the contents of `sqlca` when an error occurs. This is perhaps useful for debugging or prototyping applications, before installing a more “user-friendly” error handler.

```
EXEC SQL WHENEVER SQLERROR CALL print_sqlca();

void
print_sqlca()
{
    fprintf(stderr, "==== sqlca ====\n");
    fprintf(stderr, "sqlcode: %ld\n", sqlca.sqlcode);
    fprintf(stderr, "sqlerrm.sqlerrml: %d\n", sqlca.sqlerrm.sqlerrml);
    fprintf(stderr, "sqlerrm.sqlerrmc: %s\n", sqlca.sqlerrm.sqlerrmc);
    fprintf(stderr, "sqlerrd: %ld %ld %ld %ld %ld %ld\n",
 sqlca.sqlerrd[0],sqlca.sqlerrd[1],sqlca.sqlerrd[2],

 sqlca.sqlerrd[3],sqlca.sqlerrd[4],sqlca.sqlerrd[5]);
    fprintf(stderr, "sqlwarn: %d %d %d %d %d %d %d %d\n", sqlca.sqlwarn[0],
 sqlca.sqlwarn[1], sqlca.sqlwarn[2],
                                                          sqlca.sqlwarn[3],
 sqlca.sqlwarn[4], sqlca.sqlwarn[5],
                                                          sqlca.sqlwarn[6],
 sqlca.sqlwarn[7]);
```

```
    fprintf(stderr, "sqlstate: %5s\n", sqlca.sqlstate);
    fprintf(stderr, "===============\n");
}
```

The result could look as follows (here an error due to a misspelled table name):

```
==== sqlca ====
sqlcode: -400
sqlerrm.sqlerrml: 49
sqlerrm.sqlerrmc: relation "pg_databasep" does not exist on line 38
sqlerrd: 0 0 0 0 0 0
sqlwarn: 0 0 0 0 0 0 0 0
sqlstate: 42P01
===============
```

38.8.3. SQLSTATE vs. SQLCODE

The fields `sqlca.sqlstate` and `sqlca.sqlcode` are two different schemes that provide error codes. Both are derived from the SQL standard, but `SQLCODE` has been marked deprecated in the SQL-92 edition of the standard and has been dropped in later editions. Therefore, new applications are strongly encouraged to use `SQLSTATE`.

`SQLSTATE` is a five-character array. The five characters contain digits or upper-case letters that represent codes of various error and warning conditions. `SQLSTATE` has a hierarchical scheme: the first two characters indicate the general class of the condition, the last three characters indicate a subclass of the general condition. A successful state is indicated by the code `00000`. The `SQLSTATE` codes are for the most part defined in the SQL standard. The Postgres Pro server natively supports `SQLSTATE` error codes; therefore a high degree of consistency can be achieved by using this error code scheme throughout all applications. For further information see Appendix A.

`SQLCODE`, the deprecated error code scheme, is a simple integer. A value of 0 indicates success, a positive value indicates success with additional information, a negative value indicates an error. The SQL standard only defines the positive value +100, which indicates that the last command returned or affected zero rows, and no specific negative values. Therefore, this scheme can only achieve poor portability and does not have a hierarchical code assignment. Historically, the embedded SQL processor for Postgres Pro has assigned some specific `SQLCODE` values for its use, which are listed below with their numeric value and their symbolic name. Remember that these are not portable to other SQL implementations. To simplify the porting of applications to the `SQLSTATE` scheme, the corresponding `SQLSTATE` is also listed. There is, however, no one-to-one or one-to-many mapping between the two schemes (indeed it is many-to-many), so you should consult the global `SQLSTATE` listing in Appendix A in each case.

These are the assigned `SQLCODE` values:

0 (`ECPG_NO_ERROR`)

Indicates no error. (SQLSTATE 00000)

100 (`ECPG_NOT_FOUND`)

This is a harmless condition indicating that the last command retrieved or processed zero rows, or that you are at the end of the cursor. (SQLSTATE 02000)

When processing a cursor in a loop, you could use this code as a way to detect when to abort the loop, like this:

```
while (1)
{
    EXEC SQL FETCH ... ;
    if (sqlca.sqlcode == ECPG_NOT_FOUND)
        break;
}
```

But `WHENEVER NOT FOUND DO BREAK` effectively does this internally, so there is usually no advantage in writing this out explicitly.

-12 (`ECPG_OUT_OF_MEMORY`)

Indicates that your virtual memory is exhausted. The numeric value is defined as `-ENOMEM`. (SQLSTATE YE001)

-200 (`ECPG_UNSUPPORTED`)

Indicates the preprocessor has generated something that the library does not know about. Perhaps you are running incompatible versions of the preprocessor and the library. (SQLSTATE YE002)

-201 (`ECPG_TOO_MANY_ARGUMENTS`)

This means that the command specified more host variables than the command expected. (SQLSTATE 07001 or 07002)

-202 (`ECPG_TOO_FEW_ARGUMENTS`)

This means that the command specified fewer host variables than the command expected. (SQLSTATE 07001 or 07002)

-203 (`ECPG_TOO_MANY_MATCHES`)

This means a query has returned multiple rows but the statement was only prepared to store one result row (for example, because the specified variables are not arrays). (SQLSTATE 21000)

-204 (`ECPG_INT_FORMAT`)

The host variable is of type `int` and the datum in the database is of a different type and contains a value that cannot be interpreted as an `int`. The library uses `strtol()` for this conversion. (SQLSTATE 42804)

-205 (`ECPG_UINT_FORMAT`)

The host variable is of type `unsigned int` and the datum in the database is of a different type and contains a value that cannot be interpreted as an `unsigned int`. The library uses `strtoul()` for this conversion. (SQLSTATE 42804)

-206 (`ECPG_FLOAT_FORMAT`)

The host variable is of type `float` and the datum in the database is of another type and contains a value that cannot be interpreted as a `float`. The library uses `strtod()` for this conversion. (SQLSTATE 42804)

-207 (`ECPG_NUMERIC_FORMAT`)

The host variable is of type `numeric` and the datum in the database is of another type and contains a value that cannot be interpreted as a `numeric` value. (SQLSTATE 42804)

-208 (`ECPG_INTERVAL_FORMAT`)

The host variable is of type `interval` and the datum in the database is of another type and contains a value that cannot be interpreted as an `interval` value. (SQLSTATE 42804)

-209 (`ECPG_DATE_FORMAT`)

The host variable is of type `date` and the datum in the database is of another type and contains a value that cannot be interpreted as a `date` value. (SQLSTATE 42804)

-210 (`ECPG_TIMESTAMP_FORMAT`)

The host variable is of type `timestamp` and the datum in the database is of another type and contains a value that cannot be interpreted as a `timestamp` value. (SQLSTATE 42804)

-211 (ECPG_CONVERT_BOOL)

This means the host variable is of type `bool` and the datum in the database is neither `'t'` nor `'f'`. (SQLSTATE 42804)

-212 (ECPG_EMPTY)

The statement sent to the Postgres Pro server was empty. (This cannot normally happen in an embedded SQL program, so it might point to an internal error.) (SQLSTATE YE002)

-213 (ECPG_MISSING_INDICATOR)

A null value was returned and no null indicator variable was supplied. (SQLSTATE 22002)

-214 (ECPG_NO_ARRAY)

An ordinary variable was used in a place that requires an array. (SQLSTATE 42804)

-215 (ECPG_DATA_NOT_ARRAY)

The database returned an ordinary variable in a place that requires array value. (SQLSTATE 42804)

-216 (ECPG_ARRAY_INSERT)

The value could not be inserted into the array. (SQLSTATE 42804)

-220 (ECPG_NO_CONN)

The program tried to access a connection that does not exist. (SQLSTATE 08003)

-221 (ECPG_NOT_CONN)

The program tried to access a connection that does exist but is not open. (This is an internal error.) (SQLSTATE YE002)

-230 (ECPG_INVALID_STMT)

The statement you are trying to use has not been prepared. (SQLSTATE 26000)

-239 (ECPG_INFORMIX_DUPLICATE_KEY)

Duplicate key error, violation of unique constraint (Informix compatibility mode). (SQLSTATE 23505)

-240 (ECPG_UNKNOWN_DESCRIPTOR)

The descriptor specified was not found. The statement you are trying to use has not been prepared. (SQLSTATE 33000)

-241 (ECPG_INVALID_DESCRIPTOR_INDEX)

The descriptor index specified was out of range. (SQLSTATE 07009)

-242 (ECPG_UNKNOWN_DESCRIPTOR_ITEM)

An invalid descriptor item was requested. (This is an internal error.) (SQLSTATE YE002)

-243 (ECPG_VAR_NOT_NUMERIC)

During the execution of a dynamic statement, the database returned a numeric value and the host variable was not numeric. (SQLSTATE 07006)

-244 (ECPG_VAR_NOT_CHAR)

During the execution of a dynamic statement, the database returned a non-numeric value and the host variable was numeric. (SQLSTATE 07006)

-284 (ECPG_INFORMIX_SUBSELECT_NOT_ONE)

A result of the subquery is not single row (Informix compatibility mode). (SQLSTATE 21000)

-400 (ECPG_PGSQL)

Some error caused by the Postgres Pro server. The message contains the error message from the Postgres Pro server.

-401 (ECPG_TRANS)

The Postgres Pro server signaled that we cannot start, commit, or rollback the transaction. (SQLSTATE 08007)

-402 (ECPG_CONNECT)

The connection attempt to the database did not succeed. (SQLSTATE 08001)

-403 (ECPG_DUPLICATE_KEY)

Duplicate key error, violation of unique constraint. (SQLSTATE 23505)

-404 (ECPG_SUBSELECT_NOT_ONE)

A result for the subquery is not single row. (SQLSTATE 21000)

-602 (ECPG_WARNING_UNKNOWN_PORTAL)

An invalid cursor name was specified. (SQLSTATE 34000)

-603 (ECPG_WARNING_IN_TRANSACTION)

Transaction is in progress. (SQLSTATE 25001)

-604 (ECPG_WARNING_NO_TRANSACTION)

There is no active (in-progress) transaction. (SQLSTATE 25P01)

-605 (ECPG_WARNING_PORTAL_EXISTS)

An existing cursor name was specified. (SQLSTATE 42P03)

38.9. Preprocessor Directives

Several preprocessor directives are available that modify how the ecpg preprocessor parses and processes a file.

38.9.1. Including Files

To include an external file into your embedded SQL program, use:

```
EXEC SQL INCLUDE filename;
EXEC SQL INCLUDE <filename>;
EXEC SQL INCLUDE "filename";
```

The embedded SQL preprocessor will look for a file named *filename*.h, preprocess it, and include it in the resulting C output. Thus, embedded SQL statements in the included file are handled correctly.

The ecpg preprocessor will search a file at several directories in following order:

- current directory
- /usr/local/include
- Postgres Pro include directory, defined at build time (e.g., /usr/local/pgsql/include)
- /usr/include

But when EXEC SQL INCLUDE "*filename*" is used, only the current directory is searched.

In each directory, the preprocessor will first look for the file name as given, and if not found will append .h to the file name and try again (unless the specified file name already has that suffix).

Note that `EXEC SQL INCLUDE` is *not* the same as:

```
#include <filename.h>
```

because this file would not be subject to SQL command preprocessing. Naturally, you can continue to use the C `#include` directive to include other header files.

> **Note**
>
> The include file name is case-sensitive, even though the rest of the `EXEC SQL INCLUDE` command follows the normal SQL case-sensitivity rules.

38.9.2. The define and undef Directives

Similar to the directive `#define` that is known from C, embedded SQL has a similar concept:

```
EXEC SQL DEFINE name;
EXEC SQL DEFINE name value;
```

So you can define a name:

```
EXEC SQL DEFINE HAVE_FEATURE;
```

And you can also define constants:

```
EXEC SQL DEFINE MYNUMBER 12;
EXEC SQL DEFINE MYSTRING 'abc';
```

Use `undef` to remove a previous definition:

```
EXEC SQL UNDEF MYNUMBER;
```

Of course you can continue to use the C versions `#define` and `#undef` in your embedded SQL program. The difference is where your defined values get evaluated. If you use `EXEC SQL DEFINE` then the `ecpg` preprocessor evaluates the defines and substitutes the values. For example if you write:

```
EXEC SQL DEFINE MYNUMBER 12;
...
EXEC SQL UPDATE Tbl SET col = MYNUMBER;
```

then `ecpg` will already do the substitution and your C compiler will never see any name or identifier `MYNUMBER`. Note that you cannot use `#define` for a constant that you are going to use in an embedded SQL query because in this case the embedded SQL precompiler is not able to see this declaration.

If multiple input files are named on the `ecpg` preprocessor's command line, the effects of `EXEC SQL DEFINE` and `EXEC SQL UNDEF` do not carry across files: each file starts with only the symbols defined by `-D` switches on the command line.

38.9.3. ifdef, ifndef, elif, else, and endif Directives

You can use the following directives to compile code sections conditionally:

`EXEC SQL ifdef name;`

Checks a *name* and processes subsequent lines if *name* has been defined via `EXEC SQL define name`.

`EXEC SQL ifndef name;`

Checks a *name* and processes subsequent lines if *name* has *not* been defined via `EXEC SQL define name`.

`EXEC SQL elif name;`

Begins an optional alternative section after an `EXEC SQL ifdef name` or `EXEC SQL ifndef name` directive. Any number of `elif` sections can appear. Lines following an `elif` will be processed if

name has been defined *and* no previous section of the same ifdef/ifndef...endif construct has been processed.

EXEC SQL else;

Begins an optional, final alternative section after an EXEC SQL ifdef *name* or EXEC SQL ifndef *name* directive. Subsequent lines will be processed if no previous section of the same ifdef/ifndef...endif construct has been processed.

EXEC SQL endif;

Ends an ifdef/ifndef...endif construct. Subsequent lines are processed normally.

ifdef/ifndef...endif constructs can be nested, up to 127 levels deep.

This example will compile exactly one of the three SET TIMEZONE commands:

```
EXEC SQL ifdef TZVAR;
EXEC SQL SET TIMEZONE TO TZVAR;
EXEC SQL elif TZNAME;
EXEC SQL SET TIMEZONE TO TZNAME;
EXEC SQL else;
EXEC SQL SET TIMEZONE TO 'GMT';
EXEC SQL endif;
```

38.10. Processing Embedded SQL Programs

Now that you have an idea how to form embedded SQL C programs, you probably want to know how to compile them. Before compiling you run the file through the embedded SQL C preprocessor, which converts the SQL statements you used to special function calls. After compiling, you must link with a special library that contains the needed functions. These functions fetch information from the arguments, perform the SQL command using the libpq interface, and put the result in the arguments specified for output.

The preprocessor program is called ecpg and is included in a normal Postgres Pro installation. Embedded SQL programs are typically named with an extension .pgc. If you have a program file called prog1.pgc, you can preprocess it by simply calling:

```
ecpg prog1.pgc
```

This will create a file called prog1.c. If your input files do not follow the suggested naming pattern, you can specify the output file explicitly using the -o option.

The preprocessed file can be compiled normally, for example:

```
cc -c prog1.c
```

The generated C source files include header files from the Postgres Pro installation, so if you installed Postgres Pro in a location that is not searched by default, you have to add an option such as -I/usr/local/pgsql/include to the compilation command line.

To link an embedded SQL program, you need to include the libecpg library, like so:

```
cc -o myprog prog1.o prog2.o ... -lecpg
```

Again, you might have to add an option like -L/usr/local/pgsql/lib to that command line.

You can use pg_configor pkg-configwith package name libecpg to get the paths for your installation.

If you manage the build process of a larger project using make, it might be convenient to include the following implicit rule to your makefiles:

```
ECPG = ecpg
```

```
%.c: %.pgc
        $(ECPG) $<
```

The complete syntax of the `ecpg` command is detailed in ecpg.

The ecpg library is thread-safe by default. However, you might need to use some threading command-line options to compile your client code.

38.11. Library Functions

The `libecpg` library primarily contains “hidden” functions that are used to implement the functionality expressed by the embedded SQL commands. But there are some functions that can usefully be called directly. Note that this makes your code unportable.

- `ECPGdebug(int on, FILE *stream)` turns on debug logging if called with the first argument non-zero. Debug logging is done on *stream*. The log contains all SQL statements with all the input variables inserted, and the results from the Postgres Pro server. This can be very useful when searching for errors in your SQL statements.

  > **Note**
  >
  > On Windows, if the ecpg libraries and an application are compiled with different flags, this function call will crash the application because the internal representation of the `FILE` pointers differ. Specifically, multithreaded/single-threaded, release/debug, and static/dynamic flags should be the same for the library and all applications using that library.

- `ECPGget_PGconn(const char *connection_name)` returns the library database connection handle identified by the given name. If *connection_name* is set to `NULL`, the current connection handle is returned. If no connection handle can be identified, the function returns `NULL`. The returned connection handle can be used to call any other functions from libpq, if necessary.

  > **Note**
  >
  > It is a bad idea to manipulate database connection handles made from ecpg directly with libpq routines.

- `ECPGtransactionStatus(const char *connection_name)` returns the current transaction status of the given connection identified by *connection_name*. See Section 36.2 and libpq's `PQtransactionStatus` for details about the returned status codes.

- `ECPGstatus(int lineno, const char* connection_name)` returns true if you are connected to a database and false if not. *connection_name* can be `NULL` if a single connection is being used.

38.12. Large Objects

Large objects are not directly supported by ECPG, but ECPG application can manipulate large objects through the libpq large object functions, obtaining the necessary `PGconn` object by calling the `ECPGget_PGconn()` function. (However, use of the `ECPGget_PGconn()` function and touching `PGconn` objects directly should be done very carefully and ideally not mixed with other ECPG database access calls.)

For more details about the `ECPGget_PGconn()`, see Section 38.11. For information about the large object function interface, see Chapter 37.

Large object functions have to be called in a transaction block, so when autocommit is off, `BEGIN` commands have to be issued explicitly.

Example 38.2 shows an example program that illustrates how to create, write, and read a large object in an ECPG application.

Example 38.2. ECPG Program Accessing Large Objects

```
#include <stdio.h>
#include <stdlib.h>
#include <libpq-fe.h>
#include <libpq/libpq-fs.h>

EXEC SQL WHENEVER SQLERROR STOP;

int
main(void)
{
    PGconn     *conn;
    Oid         loid;
    int         fd;
    char        buf[256];
    int         buflen = 256;
    char        buf2[256];
    int         rc;

    memset(buf, 1, buflen);

    EXEC SQL CONNECT TO testdb AS con1;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    conn = ECPGget_PGconn("con1");
    printf("conn = %p\n", conn);

    /* create */
    loid = lo_create(conn, 0);
    if (loid &lt; 0)
        printf("lo_create() failed: %s", PQerrorMessage(conn));

    printf("loid = %d\n", loid);

    /* write test */
    fd = lo_open(conn, loid, INV_READ|INV_WRITE);
    if (fd &lt; 0)
        printf("lo_open() failed: %s", PQerrorMessage(conn));

    printf("fd = %d\n", fd);

    rc = lo_write(conn, fd, buf, buflen);
    if (rc &lt; 0)
        printf("lo_write() failed\n");

    rc = lo_close(conn, fd);
    if (rc &lt; 0)
        printf("lo_close() failed: %s", PQerrorMessage(conn));

    /* read test */
    fd = lo_open(conn, loid, INV_READ);
    if (fd &lt; 0)
        printf("lo_open() failed: %s", PQerrorMessage(conn));

    printf("fd = %d\n", fd);
```

```
    rc = lo_read(conn, fd, buf2, buflen);
    if (rc &lt; 0)
        printf("lo_read() failed\n");

    rc = lo_close(conn, fd);
    if (rc &lt; 0)
        printf("lo_close() failed: %s", PQerrorMessage(conn));

    /* check */
    rc = memcmp(buf, buf2, buflen);
    printf("memcmp() = %d\n", rc);

    /* cleanup */
    rc = lo_unlink(conn, loid);
    if (rc &lt; 0)
        printf("lo_unlink() failed: %s", PQerrorMessage(conn));

    EXEC SQL COMMIT;
    EXEC SQL DISCONNECT ALL;
    return 0;
}
```

38.13. C++ Applications

ECPG has some limited support for C++ applications. This section describes some caveats.

The `ecpg` preprocessor takes an input file written in C (or something like C) and embedded SQL commands, converts the embedded SQL commands into C language chunks, and finally generates a `.c` file. The header file declarations of the library functions used by the C language chunks that `ecpg` generates are wrapped in `extern "C" { ... }` blocks when used under C++, so they should work seamlessly in C++.

In general, however, the `ecpg` preprocessor only understands C; it does not handle the special syntax and reserved words of the C++ language. So, some embedded SQL code written in C++ application code that uses complicated features specific to C++ might fail to be preprocessed correctly or might not work as expected.

A safe way to use the embedded SQL code in a C++ application is hiding the ECPG calls in a C module, which the C++ application code calls into to access the database, and linking that together with the rest of the C++ code. See Section 38.13.2 about that.

38.13.1. Scope for Host Variables

The `ecpg` preprocessor understands the scope of variables in C. In the C language, this is rather simple because the scopes of variables is based on their code blocks. In C++, however, the class member variables are referenced in a different code block from the declared position, so the `ecpg` preprocessor will not understand the scope of the class member variables.

For example, in the following case, the `ecpg` preprocessor cannot find any declaration for the variable `dbname` in the `test` method, so an error will occur.

```
class TestCpp
{
    EXEC SQL BEGIN DECLARE SECTION;
    char dbname[1024];
    EXEC SQL END DECLARE SECTION;

  public:
```

```
    TestCpp();
    void test();
    ~TestCpp();
};

TestCpp::TestCpp()
{
    EXEC SQL CONNECT TO testdb1;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;
}

void Test::test()
{
    EXEC SQL SELECT current_database() INTO :dbname;
    printf("current_database = %s\n", dbname);
}

TestCpp::~TestCpp()
{
    EXEC SQL DISCONNECT ALL;
}
```

This code will result in an error like this:

```
ecpg test_cpp.pgc
test_cpp.pgc:28: ERROR: variable "dbname" is not declared
```

To avoid this scope issue, the `test` method could be modified to use a local variable as intermediate storage. But this approach is only a poor workaround, because it uglifies the code and reduces performance.

```
void TestCpp::test()
{
    EXEC SQL BEGIN DECLARE SECTION;
    char tmp[1024];
    EXEC SQL END DECLARE SECTION;

    EXEC SQL SELECT current_database() INTO :tmp;
    strlcpy(dbname, tmp, sizeof(tmp));

    printf("current_database = %s\n", dbname);
}
```

38.13.2. C++ Application Development with External C Module

If you understand these technical limitations of the `ecpg` preprocessor in C++, you might come to the conclusion that linking C objects and C++ objects at the link stage to enable C++ applications to use ECPG features could be better than writing some embedded SQL commands in C++ code directly. This section describes a way to separate some embedded SQL commands from C++ application code with a simple example. In this example, the application is implemented in C++, while C and ECPG is used to connect to the Postgres Pro server.

Three kinds of files have to be created: a C file (`*.pgc`), a header file, and a C++ file:

`test_mod.pgc`

A sub-routine module to execute SQL commands embedded in C. It is going to be converted into `test_mod.c` by the preprocessor.

```
#include "test_mod.h"
#include <stdio.h>

void
```

```
db_connect()
{
    EXEC SQL CONNECT TO testdb1;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL
 COMMIT;
}

void
db_test()
{
    EXEC SQL BEGIN DECLARE SECTION;
    char dbname[1024];
    EXEC SQL END DECLARE SECTION;

    EXEC SQL SELECT current_database() INTO :dbname;
    printf("current_database = %s\n", dbname);
}

void
db_disconnect()
{
    EXEC SQL DISCONNECT ALL;
}
```

`test_mod.h`

A header file with declarations of the functions in the C module (`test_mod.pgc`). It is included by `test_cpp.cpp`. This file has to have an `extern "C"` block around the declarations, because it will be linked from the C++ module.

```
#ifdef __cplusplus
extern "C" {
#endif

void db_connect();
void db_test();
void db_disconnect();

#ifdef __cplusplus
}
#endif
```

`test_cpp.cpp`

The main code for the application, including the `main` routine, and in this example a C++ class.

```
#include "test_mod.h"

class TestCpp
{
  public:
    TestCpp();
    void test();
    ~TestCpp();
};

TestCpp::TestCpp()
{
    db_connect();
}
```

```
void
TestCpp::test()
{
    db_test();
}

TestCpp::~TestCpp()
{
    db_disconnect();
}

int
main(void)
{
    TestCpp *t = new TestCpp();

    t->test();
    return 0;
}
```

To build the application, proceed as follows. Convert `test_mod.pgc` into `test_mod.c` by running `ecpg`, and generate `test_mod.o` by compiling `test_mod.c` with the C compiler:

```
ecpg -o test_mod.c test_mod.pgc
cc -c test_mod.c -o test_mod.o
```

Next, generate `test_cpp.o` by compiling `test_cpp.cpp` with the C++ compiler:

```
c++ -c test_cpp.cpp -o test_cpp.o
```

Finally, link these object files, `test_cpp.o` and `test_mod.o`, into one executable, using the C++ compiler driver:

```
c++ test_cpp.o test_mod.o -lecpg -o test_cpp
```

38.14. Embedded SQL Commands

This section describes all SQL commands that are specific to embedded SQL. Also refer to the SQL commands listed in SQL Commands, which can also be used in embedded SQL, unless stated otherwise.

ALLOCATE DESCRIPTOR

ALLOCATE DESCRIPTOR — allocate an SQL descriptor area

Synopsis

```
ALLOCATE DESCRIPTOR name
```

Description

`ALLOCATE DESCRIPTOR` allocates a new named SQL descriptor area, which can be used to exchange data between the Postgres Pro server and the host program.

Descriptor areas should be freed after use using the `DEALLOCATE DESCRIPTOR` command.

Parameters

name

A name of SQL descriptor, case sensitive. This can be an SQL identifier or a host variable.

Examples

```
EXEC SQL ALLOCATE DESCRIPTOR mydesc;
```

Compatibility

`ALLOCATE DESCRIPTOR` is specified in the SQL standard.

See Also

DEALLOCATE DESCRIPTOR, GET DESCRIPTOR, SET DESCRIPTOR

CONNECT

CONNECT — establish a database connection

Synopsis

```
CONNECT TO connection_target [ AS connection_name ] [ USER connection_user ]
CONNECT TO DEFAULT
CONNECT connection_user
DATABASE connection_target
```

Description

The `CONNECT` command establishes a connection between the client and the Postgres Pro server.

Parameters

connection_target

connection_target specifies the target server of the connection on one of several forms.

[*database_name*] [`@`*host*] [`:`*port*]

Connect over TCP/IP

`unix:postgresql://`*host* [`:`*port*] `/` [*database_name*] [`?`*connection_option*]

Connect over Unix-domain sockets

`tcp:postgresql://`*host* [`:`*port*] `/` [*database_name*] [`?`*connection_option*]

Connect over TCP/IP

SQL string constant

containing a value in one of the above forms

host variable

host variable of type `char[]` or `VARCHAR[]` containing a value in one of the above forms

connection_name

An optional identifier for the connection, so that it can be referred to in other commands. This can be an SQL identifier or a host variable.

connection_user

The user name for the database connection.

This parameter can also specify user name and password, using one the forms *user_name*`/`*password*, *user_name* `IDENTIFIED BY` *password*, or *user_name* `USING` *password*.

User name and password can be SQL identifiers, string constants, or host variables.

`DEFAULT`

Use all default connection parameters, as defined by libpq.

Examples

Here a several variants for specifying connection parameters:

```
EXEC SQL CONNECT TO "connectdb" AS main;
EXEC SQL CONNECT TO "connectdb" AS second;
```

```
EXEC SQL CONNECT TO "unix:postgresql://200.46.204.71/connectdb" AS main USER
 connectuser;
EXEC SQL CONNECT TO "unix:postgresql://localhost/connectdb" AS main USER connectuser;
EXEC SQL CONNECT TO 'connectdb' AS main;
EXEC SQL CONNECT TO 'unix:postgresql://localhost/connectdb' AS main USER :user;
EXEC SQL CONNECT TO :db AS :id;
EXEC SQL CONNECT TO :db USER connectuser USING :pw;
EXEC SQL CONNECT TO @localhost AS main USER connectdb;
EXEC SQL CONNECT TO REGRESSDB1 as main;
EXEC SQL CONNECT TO AS main USER connectdb;
EXEC SQL CONNECT TO connectdb AS :id;
EXEC SQL CONNECT TO connectdb AS main USER connectuser/connectdb;
EXEC SQL CONNECT TO connectdb AS main;
EXEC SQL CONNECT TO connectdb@localhost AS main;
EXEC SQL CONNECT TO tcp:postgresql://localhost/ USER connectdb;
EXEC SQL CONNECT TO tcp:postgresql://localhost/connectdb USER connectuser IDENTIFIED BY
 connectpw;
EXEC SQL CONNECT TO tcp:postgresql://localhost:20/connectdb USER connectuser IDENTIFIED
 BY connectpw;
EXEC SQL CONNECT TO unix:postgresql://localhost/ AS main USER connectdb;
EXEC SQL CONNECT TO unix:postgresql://localhost/connectdb AS main USER connectuser;
EXEC SQL CONNECT TO unix:postgresql://localhost/connectdb USER connectuser IDENTIFIED
 BY "connectpw";
EXEC SQL CONNECT TO unix:postgresql://localhost/connectdb USER connectuser USING
 "connectpw";
EXEC SQL CONNECT TO unix:postgresql://localhost/connectdb?connect_timeout=14 USER
 connectuser;
```

Here is an example program that illustrates the use of host variables to specify connection parameters:

```
int
main(void)
{
EXEC SQL BEGIN DECLARE SECTION;
    char *dbname     = "testdb";    /* database name */
    char *user       = "testuser";  /* connection user name */
    char *connection = "tcp:postgresql://localhost:5432/testdb";
                                    /* connection string */
    char ver[256];                  /* buffer to store the version string */
EXEC SQL END DECLARE SECTION;

    ECPGdebug(1, stderr);

    EXEC SQL CONNECT TO :dbname USER :user;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;
    EXEC SQL SELECT pgpro_version() INTO :ver;
    EXEC SQL DISCONNECT;

    printf("version: %s\n", ver);

    EXEC SQL CONNECT TO :connection USER :user;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;
    EXEC SQL SELECT pgpro_version() INTO :ver;
    EXEC SQL DISCONNECT;

    printf("version: %s\n", ver);

    return 0;
}
```

Compatibility

`CONNECT` is specified in the SQL standard, but the format of the connection parameters is implementation-specific.

See Also

DISCONNECT, SET CONNECTION

DEALLOCATE DESCRIPTOR

DEALLOCATE DESCRIPTOR — deallocate an SQL descriptor area

Synopsis

```
DEALLOCATE DESCRIPTOR name
```

Description

`DEALLOCATE DESCRIPTOR` deallocates a named SQL descriptor area.

Parameters

name

The name of the descriptor which is going to be deallocated. It is case sensitive. This can be an SQL identifier or a host variable.

Examples

```
EXEC SQL DEALLOCATE DESCRIPTOR mydesc;
```

Compatibility

`DEALLOCATE DESCRIPTOR` is specified in the SQL standard.

See Also

ALLOCATE DESCRIPTOR, GET DESCRIPTOR, SET DESCRIPTOR

DECLARE

DECLARE — define a cursor

Synopsis

```
DECLARE cursor_name [ BINARY ] [ ASENSITIVE | INSENSITIVE ] [ [ NO ] SCROLL ] CURSOR
  [ { WITH | WITHOUT } HOLD ] FOR prepared_name
DECLARE cursor_name [ BINARY ] [ ASENSITIVE | INSENSITIVE ] [ [ NO ] SCROLL ] CURSOR
  [ { WITH | WITHOUT } HOLD ] FOR query
```

Description

`DECLARE` declares a cursor for iterating over the result set of a prepared statement. This command has slightly different semantics from the direct SQL command `DECLARE`: Whereas the latter executes a query and prepares the result set for retrieval, this embedded SQL command merely declares a name as a "loop variable" for iterating over the result set of a query; the actual execution happens when the cursor is opened with the `OPEN` command.

Parameters

cursor_name

A cursor name, case sensitive. This can be an SQL identifier or a host variable.

prepared_name

The name of a prepared query, either as an SQL identifier or a host variable.

query

A SELECT or VALUES command which will provide the rows to be returned by the cursor.

For the meaning of the cursor options, see DECLARE.

Examples

Examples declaring a cursor for a query:

```
EXEC SQL DECLARE C CURSOR FOR SELECT * FROM My_Table;
EXEC SQL DECLARE C CURSOR FOR SELECT Item1 FROM T;
EXEC SQL DECLARE cur1 CURSOR FOR SELECT pgpro_version();
```

An example declaring a cursor for a prepared statement:

```
EXEC SQL PREPARE stmt1 AS SELECT pgpro_version();
EXEC SQL DECLARE cur1 CURSOR FOR stmt1;
```

Compatibility

`DECLARE` is specified in the SQL standard.

See Also

OPEN, CLOSE, DECLARE

DECLARE STATEMENT

DECLARE STATEMENT — declare SQL statement identifier

Synopsis

```
EXEC SQL [ AT connection_name ] DECLARE statement_name STATEMENT
```

Description

`DECLARE STATEMENT` declares an SQL statement identifier. SQL statement identifier can be associated with the connection. When the identifier is used by dynamic SQL statements, the statements are executed using the associated connection. The namespace of the declaration is the precompile unit, and multiple declarations to the same SQL statement identifier are not allowed. Note that if the precompiler runs in Informix compatibility mode and some SQL statement is declared, "database" can not be used as a cursor name.

Parameters

connection_name

A database connection name established by the `CONNECT` command.

AT clause can be omitted, but such statement has no meaning.

statement_name

The name of an SQL statement identifier, either as an SQL identifier or a host variable.

Notes

This association is valid only if the declaration is physically placed on top of a dynamic statement.

Examples

```
EXEC SQL CONNECT TO postgres AS con1;
EXEC SQL AT con1 DECLARE sql_stmt STATEMENT;
EXEC SQL DECLARE cursor_name CURSOR FOR sql_stmt;
EXEC SQL PREPARE sql_stmt FROM :dyn_string;
EXEC SQL OPEN cursor_name;
EXEC SQL FETCH cursor_name INTO :column1;
EXEC SQL CLOSE cursor_name;
```

Compatibility

`DECLARE STATEMENT` is an extension of the SQL standard, but can be used in famous DBMSs.

See Also

CONNECT, DECLARE, OPEN

DESCRIBE

DESCRIBE — obtain information about a prepared statement or result set

Synopsis

```
DESCRIBE [ OUTPUT ] prepared_name USING [ SQL ] DESCRIPTOR descriptor_name
DESCRIBE [ OUTPUT ] prepared_name INTO [ SQL ] DESCRIPTOR descriptor_name
DESCRIBE [ OUTPUT ] prepared_name INTO sqlda_name
```

Description

`DESCRIBE` retrieves metadata information about the result columns contained in a prepared statement, without actually fetching a row.

Parameters

prepared_name

The name of a prepared statement. This can be an SQL identifier or a host variable.

descriptor_name

A descriptor name. It is case sensitive. It can be an SQL identifier or a host variable.

sqlda_name

The name of an SQLDA variable.

Examples

```
EXEC SQL ALLOCATE DESCRIPTOR mydesc;
EXEC SQL PREPARE stmt1 FROM :sql_stmt;
EXEC SQL DESCRIBE stmt1 INTO SQL DESCRIPTOR mydesc;
EXEC SQL GET DESCRIPTOR mydesc VALUE 1 :charvar = NAME;
EXEC SQL DEALLOCATE DESCRIPTOR mydesc;
```

Compatibility

`DESCRIBE` is specified in the SQL standard.

See Also

ALLOCATE DESCRIPTOR, GET DESCRIPTOR

DISCONNECT

DISCONNECT — terminate a database connection

Synopsis

```
DISCONNECT connection_name
DISCONNECT [ CURRENT ]
DISCONNECT ALL
```

Description

`DISCONNECT` closes a connection (or all connections) to the database.

Parameters

connection_name

A database connection name established by the `CONNECT` command.

`CURRENT`

Close the "current" connection, which is either the most recently opened connection, or the connection set by the `SET CONNECTION` command. This is also the default if no argument is given to the `DISCONNECT` command.

`ALL`

Close all open connections.

Examples

```
int
main(void)
{
    EXEC SQL CONNECT TO testdb AS con1 USER testuser;
    EXEC SQL CONNECT TO testdb AS con2 USER testuser;
    EXEC SQL CONNECT TO testdb AS con3 USER testuser;

    EXEC SQL DISCONNECT CURRENT;  /* close con3          */
    EXEC SQL DISCONNECT ALL;      /* close con2 and con1 */

    return 0;
}
```

Compatibility

`DISCONNECT` is specified in the SQL standard.

See Also

CONNECT, SET CONNECTION

EXECUTE IMMEDIATE

EXECUTE IMMEDIATE — dynamically prepare and execute a statement

Synopsis

```
EXECUTE IMMEDIATE string
```

Description

`EXECUTE IMMEDIATE` immediately prepares and executes a dynamically specified SQL statement, without retrieving result rows.

Parameters

string

A literal string or a host variable containing the SQL statement to be executed.

Notes

In typical usage, the *string* is a host variable reference to a string containing a dynamically-constructed SQL statement. The case of a literal string is not very useful; you might as well just write the SQL statement directly, without the extra typing of `EXECUTE IMMEDIATE`.

If you do use a literal string, keep in mind that any double quotes you might wish to include in the SQL statement must be written as octal escapes (`\042`) not the usual C idiom `\"`. This is because the string is inside an `EXEC SQL` section, so the ECPG lexer parses it according to SQL rules not C rules. Any embedded backslashes will later be handled according to C rules; but `\"` causes an immediate syntax error because it is seen as ending the literal.

Examples

Here is an example that executes an `INSERT` statement using `EXECUTE IMMEDIATE` and a host variable named `command`:

```
sprintf(command, "INSERT INTO test (name, amount, letter) VALUES ('db: ''r1''', 1,
 'f')");
EXEC SQL EXECUTE IMMEDIATE :command;
```

Compatibility

`EXECUTE IMMEDIATE` is specified in the SQL standard.

GET DESCRIPTOR

GET DESCRIPTOR — get information from an SQL descriptor area

Synopsis

```
GET DESCRIPTOR descriptor_name :cvariable = descriptor_header_item [, ... ]
GET DESCRIPTOR descriptor_name VALUE column_number :cvariable = descriptor_item
 [, ... ]
```

Description

`GET DESCRIPTOR` retrieves information about a query result set from an SQL descriptor area and stores it into host variables. A descriptor area is typically populated using `FETCH` or `SELECT` before using this command to transfer the information into host language variables.

This command has two forms: The first form retrieves descriptor "header" items, which apply to the result set in its entirety. One example is the row count. The second form, which requires the column number as additional parameter, retrieves information about a particular column. Examples are the column name and the actual column value.

Parameters

descriptor_name

A descriptor name.

descriptor_header_item

A token identifying which header information item to retrieve. Only `COUNT`, to get the number of columns in the result set, is currently supported.

column_number

The number of the column about which information is to be retrieved. The count starts at 1.

descriptor_item

A token identifying which item of information about a column to retrieve. See Section 38.7.1 for a list of supported items.

cvariable

A host variable that will receive the data retrieved from the descriptor area.

Examples

An example to retrieve the number of columns in a result set:

```
EXEC SQL GET DESCRIPTOR d :d_count = COUNT;
```

An example to retrieve a data length in the first column:

```
EXEC SQL GET DESCRIPTOR d VALUE 1 :d_returned_octet_length = RETURNED_OCTET_LENGTH;
```

An example to retrieve the data body of the second column as a string:

```
EXEC SQL GET DESCRIPTOR d VALUE 2 :d_data = DATA;
```

Here is an example for a whole procedure of executing `SELECT current_database();` and showing the number of columns, the column data length, and the column data:

```
int
main(void)
{
```

```
EXEC SQL BEGIN DECLARE SECTION;
    int  d_count;
    char d_data[1024];
    int  d_returned_octet_length;
EXEC SQL END DECLARE SECTION;

    EXEC SQL CONNECT TO testdb AS con1 USER testuser;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;
    EXEC SQL ALLOCATE DESCRIPTOR d;

    /* Declare, open a cursor, and assign a descriptor to the cursor  */
    EXEC SQL DECLARE cur CURSOR FOR SELECT current_database();
    EXEC SQL OPEN cur;
    EXEC SQL FETCH NEXT FROM cur INTO SQL DESCRIPTOR d;

    /* Get a number of total columns */
    EXEC SQL GET DESCRIPTOR d :d_count = COUNT;
    printf("d_count                 = %d\n", d_count);

    /* Get length of a returned column */
    EXEC SQL GET DESCRIPTOR d VALUE 1 :d_returned_octet_length = RETURNED_OCTET_LENGTH;
    printf("d_returned_octet_length = %d\n", d_returned_octet_length);

    /* Fetch the returned column as a string */
    EXEC SQL GET DESCRIPTOR d VALUE 1 :d_data = DATA;
    printf("d_data                  = %s\n", d_data);

    /* Closing */
    EXEC SQL CLOSE cur;
    EXEC SQL COMMIT;

    EXEC SQL DEALLOCATE DESCRIPTOR d;
    EXEC SQL DISCONNECT ALL;

    return 0;
}
```

When the example is executed, the result will look like this:

```
d_count                 = 1
d_returned_octet_length = 6
d_data                  = testdb
```

Compatibility

`GET DESCRIPTOR` is specified in the SQL standard.

See Also

ALLOCATE DESCRIPTOR, SET DESCRIPTOR

OPEN

OPEN — open a dynamic cursor

Synopsis

```
OPEN cursor_name
OPEN cursor_name USING value [, ... ]
OPEN cursor_name USING SQL DESCRIPTOR descriptor_name
```

Description

`OPEN` opens a cursor and optionally binds actual values to the placeholders in the cursor's declaration. The cursor must previously have been declared with the `DECLARE` command. The execution of `OPEN` causes the query to start executing on the server.

Parameters

cursor_name

The name of the cursor to be opened. This can be an SQL identifier or a host variable.

value

A value to be bound to a placeholder in the cursor. This can be an SQL constant, a host variable, or a host variable with indicator.

descriptor_name

The name of a descriptor containing values to be bound to the placeholders in the cursor. This can be an SQL identifier or a host variable.

Examples

```
EXEC SQL OPEN a;
EXEC SQL OPEN d USING 1, 'test';
EXEC SQL OPEN c1 USING SQL DESCRIPTOR mydesc;
EXEC SQL OPEN :curname1;
```

Compatibility

`OPEN` is specified in the SQL standard.

See Also

DECLARE, CLOSE

PREPARE

PREPARE — prepare a statement for execution

Synopsis

```
PREPARE prepared_name FROM string
```

Description

`PREPARE` prepares a statement dynamically specified as a string for execution. This is different from the direct SQL statement PREPARE, which can also be used in embedded programs. The EXECUTE command is used to execute either kind of prepared statement.

Parameters

prepared_name

An identifier for the prepared query.

string

A literal string or a host variable containing a preparable SQL statement, one of SELECT, INSERT, UPDATE, or DELETE. Use question marks (`?`) for parameter values to be supplied at execution.

Notes

In typical usage, the *string* is a host variable reference to a string containing a dynamically-constructed SQL statement. The case of a literal string is not very useful; you might as well just write a direct SQL `PREPARE` statement.

If you do use a literal string, keep in mind that any double quotes you might wish to include in the SQL statement must be written as octal escapes (`\042`) not the usual C idiom `\"`. This is because the string is inside an `EXEC SQL` section, so the ECPG lexer parses it according to SQL rules not C rules. Any embedded backslashes will later be handled according to C rules; but `\"` causes an immediate syntax error because it is seen as ending the literal.

Examples

```
char *stmt = "SELECT * FROM test1 WHERE a = ? AND b = ?";

EXEC SQL ALLOCATE DESCRIPTOR outdesc;
EXEC SQL PREPARE foo FROM :stmt;

EXEC SQL EXECUTE foo USING SQL DESCRIPTOR indesc INTO SQL DESCRIPTOR outdesc;
```

Compatibility

`PREPARE` is specified in the SQL standard.

See Also

EXECUTE

SET AUTOCOMMIT

SET AUTOCOMMIT — set the autocommit behavior of the current session

Synopsis

```
SET AUTOCOMMIT { = | TO } { ON | OFF }
```

Description

`SET AUTOCOMMIT` sets the autocommit behavior of the current database session. By default, embedded SQL programs are *not* in autocommit mode, so `COMMIT` needs to be issued explicitly when desired. This command can change the session to autocommit mode, where each individual statement is committed implicitly.

Compatibility

`SET AUTOCOMMIT` is an extension of Postgres Pro ECPG.

SET CONNECTION

SET CONNECTION — select a database connection

Synopsis

```
SET CONNECTION [ TO | = ] connection_name
```

Description

`SET CONNECTION` sets the “current” database connection, which is the one that all commands use unless overridden.

Parameters

`connection_name`

A database connection name established by the `CONNECT` command.

`CURRENT`

Set the connection to the current connection (thus, nothing happens).

Examples

```
EXEC SQL SET CONNECTION TO con2;
EXEC SQL SET CONNECTION = con1;
```

Compatibility

`SET CONNECTION` is specified in the SQL standard.

See Also

CONNECT, DISCONNECT

SET DESCRIPTOR

SET DESCRIPTOR — set information in an SQL descriptor area

Synopsis

```
SET DESCRIPTOR descriptor_name descriptor_header_item = value [, ... ]
SET DESCRIPTOR descriptor_name VALUE number descriptor_item = value [, ...]
```

Description

`SET DESCRIPTOR` populates an SQL descriptor area with values. The descriptor area is then typically used to bind parameters in a prepared query execution.

This command has two forms: The first form applies to the descriptor “header”, which is independent of a particular datum. The second form assigns values to particular datums, identified by number.

Parameters

descriptor_name

A descriptor name.

descriptor_header_item

A token identifying which header information item to set. Only `COUNT`, to set the number of descriptor items, is currently supported.

number

The number of the descriptor item to set. The count starts at 1.

descriptor_item

A token identifying which item of information to set in the descriptor. See Section 38.7.1 for a list of supported items.

value

A value to store into the descriptor item. This can be an SQL constant or a host variable.

Examples

```
EXEC SQL SET DESCRIPTOR indesc COUNT = 1;
EXEC SQL SET DESCRIPTOR indesc VALUE 1 DATA = 2;
EXEC SQL SET DESCRIPTOR indesc VALUE 1 DATA = :val1;
EXEC SQL SET DESCRIPTOR indesc VALUE 2 INDICATOR = :val1, DATA = 'some string';
EXEC SQL SET DESCRIPTOR indesc VALUE 2 INDICATOR = :val2null, DATA = :val2;
```

Compatibility

`SET DESCRIPTOR` is specified in the SQL standard.

See Also

ALLOCATE DESCRIPTOR, GET DESCRIPTOR

TYPE

TYPE — define a new data type

Synopsis

```
TYPE type_name IS ctype
```

Description

The `TYPE` command defines a new C type. It is equivalent to putting a `typedef` into a declare section.

This command is only recognized when `ecpg` is run with the `-c` option.

Parameters

type_name

The name for the new type. It must be a valid C type name.

ctype

A C type specification.

Examples

```
EXEC SQL TYPE customer IS
    struct
    {
        varchar name[50];
        int     phone;
    };

EXEC SQL TYPE cust_ind IS
    struct ind
    {
        short   name_ind;
        short   phone_ind;
    };

EXEC SQL TYPE c IS char reference;
EXEC SQL TYPE ind IS union { int integer; short smallint; };
EXEC SQL TYPE intarray IS int[AMOUNT];
EXEC SQL TYPE str IS varchar[BUFFERSIZ];
EXEC SQL TYPE string IS char[11];
```

Here is an example program that uses `EXEC SQL TYPE`:

```
EXEC SQL WHENEVER SQLERROR SQLPRINT;

EXEC SQL TYPE tt IS
    struct
    {
        varchar v[256];
        int     i;
    };

EXEC SQL TYPE tt_ind IS
    struct ind {
        short   v_ind;
        short   i_ind;
    };
```

```
int
main(void)
{
EXEC SQL BEGIN DECLARE SECTION;
    tt t;
    tt_ind t_ind;
EXEC SQL END DECLARE SECTION;

    EXEC SQL CONNECT TO testdb AS con1;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;

    EXEC SQL SELECT current_database(), 256 INTO :t:t_ind LIMIT 1;

    printf("t.v = %s\n", t.v.arr);
    printf("t.i = %d\n", t.i);

    printf("t_ind.v_ind = %d\n", t_ind.v_ind);
    printf("t_ind.i_ind = %d\n", t_ind.i_ind);

    EXEC SQL DISCONNECT con1;

    return 0;
}
```

The output from this program looks like this:

```
t.v = testdb
t.i = 256
t_ind.v_ind = 0
t_ind.i_ind = 0
```

Compatibility

The `TYPE` command is a Postgres Pro extension.

VAR

VAR — define a variable

Synopsis

```
VAR varname IS ctype
```

Description

The `VAR` command assigns a new C data type to a host variable. The host variable must be previously declared in a declare section.

Parameters

varname

A C variable name.

ctype

A C type specification.

Examples

```
Exec sql begin declare section;
short a;
exec sql end declare section;
EXEC SQL VAR a IS int;
```

Compatibility

The `VAR` command is a Postgres Pro extension.

WHENEVER

WHENEVER — specify the action to be taken when an SQL statement causes a specific class condition to be raised

Synopsis

```
WHENEVER { NOT FOUND | SQLERROR | SQLWARNING } action
```

Description

Define a behavior which is called on the special cases (Rows not found, SQL warnings or errors) in the result of SQL execution.

Parameters

See Section 38.8.1 for a description of the parameters.

Examples

```
EXEC SQL WHENEVER NOT FOUND CONTINUE;
EXEC SQL WHENEVER NOT FOUND DO BREAK;
EXEC SQL WHENEVER NOT FOUND DO CONTINUE;
EXEC SQL WHENEVER SQLWARNING SQLPRINT;
EXEC SQL WHENEVER SQLWARNING DO warn();
EXEC SQL WHENEVER SQLERROR sqlprint;
EXEC SQL WHENEVER SQLERROR CALL print2();
EXEC SQL WHENEVER SQLERROR DO handle_error("select");
EXEC SQL WHENEVER SQLERROR DO sqlnotice(NULL, NONO);
EXEC SQL WHENEVER SQLERROR DO sqlprint();
EXEC SQL WHENEVER SQLERROR GOTO error_label;
EXEC SQL WHENEVER SQLERROR STOP;
```

A typical application is the use of `WHENEVER NOT FOUND BREAK` to handle looping through result sets:

```
int
main(void)
{
    EXEC SQL CONNECT TO testdb AS con1;
    EXEC SQL SELECT pg_catalog.set_config('search_path', '', false); EXEC SQL COMMIT;
    EXEC SQL ALLOCATE DESCRIPTOR d;
    EXEC SQL DECLARE cur CURSOR FOR SELECT current_database(), 'hoge', 256;
    EXEC SQL OPEN cur;

    /* when end of result set reached, break out of while loop */
    EXEC SQL WHENEVER NOT FOUND DO BREAK;

    while (1)
    {
        EXEC SQL FETCH NEXT FROM cur INTO SQL DESCRIPTOR d;
        ...
    }

    EXEC SQL CLOSE cur;
    EXEC SQL COMMIT;

    EXEC SQL DEALLOCATE DESCRIPTOR d;
    EXEC SQL DISCONNECT ALL;

    return 0;
}
```

Compatibility

`WHENEVER` is specified in the SQL standard, but most of the actions are Postgres Pro extensions.

38.15. Informix Compatibility Mode

`ecpg` can be run in a so-called *Informix compatibility mode*. If this mode is active, it tries to behave as if it were the Informix precompiler for Informix E/SQL. Generally spoken this will allow you to use the dollar sign instead of the `EXEC SQL` primitive to introduce embedded SQL commands:

```
$int j = 3;
$CONNECT TO :dbname;
$CREATE TABLE test(i INT PRIMARY KEY, j INT);
$INSERT INTO test(i, j) VALUES (7, :j);
$COMMIT;
```

> **Note**
>
> There must not be any white space between the `$` and a following preprocessor directive, that is, `include`, `define`, `ifdef`, etc. Otherwise, the preprocessor will parse the token as a host variable.

There are two compatibility modes: `INFORMIX`, `INFORMIX_SE`

When linking programs that use this compatibility mode, remember to link against `libcompat` that is shipped with ECPG.

Besides the previously explained syntactic sugar, the Informix compatibility mode ports some functions for input, output and transformation of data as well as embedded SQL statements known from E/SQL to ECPG.

Informix compatibility mode is closely connected to the pgtypeslib library of ECPG. pgtypeslib maps SQL data types to data types within the C host program and most of the additional functions of the Informix compatibility mode allow you to operate on those C host program types. Note however that the extent of the compatibility is limited. It does not try to copy Informix behavior; it allows you to do more or less the same operations and gives you functions that have the same name and the same basic behavior but it is no drop-in replacement if you are using Informix at the moment. Moreover, some of the data types are different. For example, Postgres Pro's datetime and interval types do not know about ranges like for example `YEAR TO MINUTE` so you won't find support in ECPG for that either.

38.15.1. Additional Types

The Informix-special "string" pseudo-type for storing right-trimmed character string data is now supported in Informix-mode without using `typedef`. In fact, in Informix-mode, ECPG refuses to process source files that contain `typedef sometype string;`

```
EXEC SQL BEGIN DECLARE SECTION;
string userid; /* this variable will contain trimmed data */
EXEC SQL END DECLARE SECTION;

EXEC SQL FETCH MYCUR INTO :userid;
```

38.15.2. Additional/Missing Embedded SQL Statements

`CLOSE DATABASE`

This statement closes the current connection. In fact, this is a synonym for ECPG's `DISCONNECT CURRENT`:

```
$CLOSE DATABASE;                /* close the current connection */
EXEC SQL CLOSE DATABASE;
```

`FREE cursor_name`

Due to the differences how ECPG works compared to Informix's ESQL/C (i.e., which steps are purely grammar transformations and which steps rely on the underlying run-time library) there is no `FREE cursor_name` statement in ECPG. This is because in ECPG, `DECLARE CURSOR` doesn't translate to a function call into the run-time library that uses to the cursor name. This means that there's no run-time bookkeeping of SQL cursors in the ECPG run-time library, only in the Postgres Pro server.

`FREE statement_name`

`FREE statement_name` is a synonym for `DEALLOCATE PREPARE statement_name`.

38.15.3. Informix-compatible SQLDA Descriptor Areas

Informix-compatible mode supports a different structure than the one described in Section 38.7.2. See below:

```
struct sqlvar_compat
{
    short   sqltype;
    int     sqllen;
    char   *sqldata;
    short  *sqlind;
    char   *sqlname;
    char   *sqlformat;
    short   sqlitype;
    short   sqlilen;
    char   *sqlidata;
    int     sqlxid;
    char   *sqltypename;
    short   sqltypelen;
    short   sqlownerlen;
    short   sqlsourcetype;
    char   *sqlownername;
    int     sqlsourceid;
    char   *sqlilongdata;
    int     sqlflags;
    void   *sqlreserved;
};

struct sqlda_compat
{
    short  sqld;
    struct sqlvar_compat *sqlvar;
    char   desc_name[19];
    short  desc_occ;
    struct sqlda_compat *desc_next;
    void  *reserved;
};

typedef struct sqlvar_compat    sqlvar_t;
typedef struct sqlda_compat     sqlda_t;
```

The global properties are:

`sqld`

The number of fields in the `SQLDA` descriptor.

`sqlvar`

Pointer to the per-field properties.

`desc_name`

Unused, filled with zero-bytes.

`desc_occ`

Size of the allocated structure.

`desc_next`

Pointer to the next SQLDA structure if the result set contains more than one record.

`reserved`

Unused pointer, contains NULL. Kept for Informix-compatibility.

The per-field properties are below, they are stored in the `sqlvar` array:

`sqltype`

Type of the field. Constants are in `sqltypes.h`

`sqllen`

Length of the field data.

`sqldata`

Pointer to the field data. The pointer is of `char *` type, the data pointed by it is in a binary format. Example:

```
int intval;

switch (sqldata->sqlvar[i].sqltype)
{
    case SQLINTEGER:
        intval = *(int *)sqldata->sqlvar[i].sqldata;
        break;
  ...
}
```

`sqlind`

Pointer to the NULL indicator. If returned by DESCRIBE or FETCH then it's always a valid pointer. If used as input for `EXECUTE ... USING sqlda;` then NULL-pointer value means that the value for this field is non-NULL. Otherwise a valid pointer and `sqlitype` has to be properly set. Example:

```
if (*(int2 *)sqldata->sqlvar[i].sqlind != 0)
    printf("value is NULL\n");
```

`sqlname`

Name of the field. 0-terminated string.

`sqlformat`

Reserved in Informix, value of `PQfformat` for the field.

`sqlitype`

Type of the NULL indicator data. It's always SQLSMINT when returning data from the server. When the `SQLDA` is used for a parameterized query, the data is treated according to the set type.

`sqlilen`

Length of the NULL indicator data.

`sqlxid`

Extended type of the field, result of `PQftype`.

`sqltypename`
`sqltypelen`
`sqlownerlen`
`sqlsourcetype`
`sqlownername`
`sqlsourceid`
`sqlflags`
`sqlreserved`

Unused.

`sqlilongdata`

It equals to `sqldata` if `sqllen` is larger than 32kB.

Example:

```
EXEC SQL INCLUDE sqlda.h;

    sqlda_t        *sqlda; /* This doesn't need to be under embedded DECLARE SECTION */

    EXEC SQL BEGIN DECLARE SECTION;
    char *prep_stmt = "select * from table1";
    int i;
    EXEC SQL END DECLARE SECTION;

    ...

    EXEC SQL PREPARE mystmt FROM :prep_stmt;

    EXEC SQL DESCRIBE mystmt INTO sqlda;

    printf("# of fields: %d\n", sqlda->sqld);
    for (i = 0; i < sqlda->sqld; i++)
      printf("field %d: \"%s\"\n", sqlda->sqlvar[i]->sqlname);

    EXEC SQL DECLARE mycursor CURSOR FOR mystmt;
    EXEC SQL OPEN mycursor;
    EXEC SQL WHENEVER NOT FOUND GOTO out;

    while (1)
    {
      EXEC SQL FETCH mycursor USING sqlda;
    }

    EXEC SQL CLOSE mycursor;

    free(sqlda); /* The main structure is all to be free(),
                  * sqlda and sqlda->sqlvar is in one allocated area */
```

38.15.4. Additional Functions

`decadd`

Add two decimal type values.

```
int decadd(decimal *arg1, decimal *arg2, decimal *sum);
```

The function receives a pointer to the first operand of type decimal (`arg1`), a pointer to the second operand of type decimal (`arg2`) and a pointer to a value of type decimal that will contain the sum (`sum`). On success, the function returns 0. `ECPG_INFORMIX_NUM_OVERFLOW` is returned in case of overflow and `ECPG_INFORMIX_NUM_UNDERFLOW` in case of underflow. -1 is returned for other failures and `errno` is set to the respective `errno` number of the pgtypeslib.

`deccmp`

Compare two variables of type decimal.

```
int deccmp(decimal *arg1, decimal *arg2);
```

The function receives a pointer to the first decimal value (`arg1`), a pointer to the second decimal value (`arg2`) and returns an integer value that indicates which is the bigger value.

- 1, if the value that `arg1` points to is bigger than the value that `var2` points to
- -1, if the value that `arg1` points to is smaller than the value that `arg2` points to
- 0, if the value that `arg1` points to and the value that `arg2` points to are equal

`deccopy`

Copy a decimal value.

```
void deccopy(decimal *src, decimal *target);
```

The function receives a pointer to the decimal value that should be copied as the first argument (`src`) and a pointer to the target structure of type decimal (`target`) as the second argument.

`deccvasc`

Convert a value from its ASCII representation into a decimal type.

```
int deccvasc(char *cp, int len, decimal *np);
```

The function receives a pointer to string that contains the string representation of the number to be converted (`cp`) as well as its length `len`. `np` is a pointer to the decimal value that saves the result of the operation.

Valid formats are for example: `-2`, `.794`, `+3.44`, `592.49E07` or `-32.84e-4`.

The function returns 0 on success. If overflow or underflow occurred, `ECPG_INFORMIX_NUM_OVERFLOW` or `ECPG_INFORMIX_NUM_UNDERFLOW` is returned. If the ASCII representation could not be parsed, `ECPG_INFORMIX_BAD_NUMERIC` is returned or `ECPG_INFORMIX_BAD_EXPONENT` if this problem occurred while parsing the exponent.

`deccvdbl`

Convert a value of type double to a value of type decimal.

```
int deccvdbl(double dbl, decimal *np);
```

The function receives the variable of type double that should be converted as its first argument (`dbl`). As the second argument (`np`), the function receives a pointer to the decimal variable that should hold the result of the operation.

The function returns 0 on success and a negative value if the conversion failed.

`deccvint`

Convert a value of type int to a value of type decimal.

```
int deccvint(int in, decimal *np);
```

The function receives the variable of type int that should be converted as its first argument (`in`). As the second argument (`np`), the function receives a pointer to the decimal variable that should hold the result of the operation.

The function returns 0 on success and a negative value if the conversion failed.

`deccvlong`

Convert a value of type long to a value of type decimal.

```
int deccvlong(long lng, decimal *np);
```

The function receives the variable of type long that should be converted as its first argument (`lng`). As the second argument (`np`), the function receives a pointer to the decimal variable that should hold the result of the operation.

The function returns 0 on success and a negative value if the conversion failed.

`decdiv`

Divide two variables of type decimal.

```
int decdiv(decimal *n1, decimal *n2, decimal *result);
```

The function receives pointers to the variables that are the first (`n1`) and the second (`n2`) operands and calculates `n1`/`n2`. `result` is a pointer to the variable that should hold the result of the operation.

On success, 0 is returned and a negative value if the division fails. If overflow or underflow occurred, the function returns `ECPG_INFORMIX_NUM_OVERFLOW` or `ECPG_INFORMIX_NUM_UNDERFLOW` respectively. If an attempt to divide by zero is observed, the function returns `ECPG_INFORMIX_DIVIDE_ZERO`.

`decmul`

Multiply two decimal values.

```
int decmul(decimal *n1, decimal *n2, decimal *result);
```

The function receives pointers to the variables that are the first (`n1`) and the second (`n2`) operands and calculates `n1`*`n2`. `result` is a pointer to the variable that should hold the result of the operation.

On success, 0 is returned and a negative value if the multiplication fails. If overflow or underflow occurred, the function returns `ECPG_INFORMIX_NUM_OVERFLOW` or `ECPG_INFORMIX_NUM_UNDERFLOW` respectively.

`decsub`

Subtract one decimal value from another.

```
int decsub(decimal *n1, decimal *n2, decimal *result);
```

The function receives pointers to the variables that are the first (`n1`) and the second (`n2`) operands and calculates `n1`-`n2`. `result` is a pointer to the variable that should hold the result of the operation.

On success, 0 is returned and a negative value if the subtraction fails. If overflow or underflow occurred, the function returns `ECPG_INFORMIX_NUM_OVERFLOW` or `ECPG_INFORMIX_NUM_UNDERFLOW` respectively.

`dectoasc`

Convert a variable of type decimal to its ASCII representation in a C char* string.

```
int dectoasc(decimal *np, char *cp, int len, int right)
```

The function receives a pointer to a variable of type decimal (`np`) that it converts to its textual representation. `cp` is the buffer that should hold the result of the operation. The parameter `right` specifies, how many digits right of the decimal point should be included in the output. The result will be rounded to this number of decimal digits. Setting `right` to -1 indicates that all available decimal digits should be included in the output. If the length of the output buffer, which is indicated by `len` is not sufficient to hold the textual representation including the trailing zero byte, only a single `*` character is stored in the result and -1 is returned.

The function returns either -1 if the buffer `cp` was too small or `ECPG_INFORMIX_OUT_OF_MEMORY` if memory was exhausted.

`dectodbl`

Convert a variable of type decimal to a double.

```
int dectodbl(decimal *np, double *dblp);
```

The function receives a pointer to the decimal value to convert (`np`) and a pointer to the double variable that should hold the result of the operation (`dblp`).

On success, 0 is returned and a negative value if the conversion failed.

`dectoint`

Convert a variable of type decimal to an integer.

```
int dectoint(decimal *np, int *ip);
```

The function receives a pointer to the decimal value to convert (`np`) and a pointer to the integer variable that should hold the result of the operation (`ip`).

On success, 0 is returned and a negative value if the conversion failed. If an overflow occurred, `ECPG_INFORMIX_NUM_OVERFLOW` is returned.

Note that the ECPG implementation differs from the Informix implementation. Informix limits an integer to the range from -32767 to 32767, while the limits in the ECPG implementation depend on the architecture (`INT_MIN .. INT_MAX`).

`dectolong`

Convert a variable of type decimal to a long integer.

```
int dectolong(decimal *np, long *lngp);
```

The function receives a pointer to the decimal value to convert (`np`) and a pointer to the long variable that should hold the result of the operation (`lngp`).

On success, 0 is returned and a negative value if the conversion failed. If an overflow occurred, `ECPG_INFORMIX_NUM_OVERFLOW` is returned.

Note that the ECPG implementation differs from the Informix implementation. Informix limits a long integer to the range from -2,147,483,647 to 2,147,483,647, while the limits in the ECPG implementation depend on the architecture (`-LONG_MAX .. LONG_MAX`).

`rdatestr`

Converts a date to a C char* string.

```
int rdatestr(date d, char *str);
```

The function receives two arguments, the first one is the date to convert (`d`) and the second one is a pointer to the target string. The output format is always `yyyy-mm-dd`, so you need to allocate at least 11 bytes (including the zero-byte terminator) for the string.

The function returns 0 on success and a negative value in case of error.

Note that ECPG's implementation differs from the Informix implementation. In Informix the format can be influenced by setting environment variables. In ECPG however, you cannot change the output format.

`rstrdate`

Parse the textual representation of a date.

```
int rstrdate(char *str, date *d);
```

The function receives the textual representation of the date to convert (`str`) and a pointer to a variable of type date (`d`). This function does not allow you to specify a format mask. It uses the default format mask of Informix which is `mm/dd/yyyy`. Internally, this function is implemented by means of `rdefmtdate`. Therefore, `rstrdate` is not faster and if you have the choice you should opt for `rdefmtdate` which allows you to specify the format mask explicitly.

The function returns the same values as `rdefmtdate`.

`rtoday`

Get the current date.

```
void rtoday(date *d);
```

The function receives a pointer to a date variable (`d`) that it sets to the current date.

Internally this function uses the `PGTYPESdate_today` function.

`rjulmdy`

Extract the values for the day, the month and the year from a variable of type date.

```
int rjulmdy(date d, short mdy[3]);
```

The function receives the date `d` and a pointer to an array of 3 short integer values `mdy`. The variable name indicates the sequential order: `mdy[0]` will be set to contain the number of the month, `mdy[1]` will be set to the value of the day and `mdy[2]` will contain the year.

The function always returns 0 at the moment.

Internally the function uses the `PGTYPESdate_julmdy` function.

`rdefmtdate`

Use a format mask to convert a character string to a value of type date.

```
int rdefmtdate(date *d, char *fmt, char *str);
```

The function receives a pointer to the date value that should hold the result of the operation (`d`), the format mask to use for parsing the date (`fmt`) and the C char* string containing the textual representation of the date (`str`). The textual representation is expected to match the format mask. However you do not need to have a 1:1 mapping of the string to the format mask. The function only analyzes the sequential order and looks for the literals `yy` or `yyyy` that indicate the position of the year, `mm` to indicate the position of the month and `dd` to indicate the position of the day.

The function returns the following values:

- 0 - The function terminated successfully.
- `ECPG_INFORMIX_ENOSHORTDATE` - The date does not contain delimiters between day, month and year. In this case the input string must be exactly 6 or 8 bytes long but isn't.
- `ECPG_INFORMIX_ENOTDMY` - The format string did not correctly indicate the sequential order of year, month and day.
- `ECPG_INFORMIX_BAD_DAY` - The input string does not contain a valid day.
- `ECPG_INFORMIX_BAD_MONTH` - The input string does not contain a valid month.
- `ECPG_INFORMIX_BAD_YEAR` - The input string does not contain a valid year.

Internally this function is implemented to use the `PGTYPESdate_defmt_asc` function. See the reference there for a table of example input.

`rfmtdate`

Convert a variable of type date to its textual representation using a format mask.

```
int rfmtdate(date d, char *fmt, char *str);
```

The function receives the date to convert (`d`), the format mask (`fmt`) and the string that will hold the textual representation of the date (`str`).

On success, 0 is returned and a negative value if an error occurred.

Internally this function uses the `PGTYPESdate_fmt_asc` function, see the reference there for examples.

`rmdyjul`

Create a date value from an array of 3 short integers that specify the day, the month and the year of the date.

```
int rmdyjul(short mdy[3], date *d);
```

The function receives the array of the 3 short integers (`mdy`) and a pointer to a variable of type date that should hold the result of the operation.

Currently the function returns always 0.

Internally the function is implemented to use the function `PGTYPESdate_mdyjul`.

`rdayofweek`

Return a number representing the day of the week for a date value.

```
int rdayofweek(date d);
```

The function receives the date variable `d` as its only argument and returns an integer that indicates the day of the week for this date.

- 0 - Sunday
- 1 - Monday
- 2 - Tuesday
- 3 - Wednesday
- 4 - Thursday
- 5 - Friday
- 6 - Saturday

Internally the function is implemented to use the function `PGTYPESdate_dayofweek`.

`dtcurrent`

Retrieve the current timestamp.

```
void dtcurrent(timestamp *ts);
```

The function retrieves the current timestamp and saves it into the timestamp variable that `ts` points to.

`dtcvasc`

Parses a timestamp from its textual representation into a timestamp variable.

```
int dtcvasc(char *str, timestamp *ts);
```

The function receives the string to parse (`str`) and a pointer to the timestamp variable that should hold the result of the operation (`ts`).

The function returns 0 on success and a negative value in case of error.

Internally this function uses the `PGTYPEStimestamp_from_asc` function. See the reference there for a table with example inputs.

`dtcvfmtasc`

Parses a timestamp from its textual representation using a format mask into a timestamp variable.

```
dtcvfmtasc(char *inbuf, char *fmtstr, timestamp *dtvalue)
```

The function receives the string to parse (`inbuf`), the format mask to use (`fmtstr`) and a pointer to the timestamp variable that should hold the result of the operation (`dtvalue`).

This function is implemented by means of the `PGTYPEStimestamp_defmt_asc` function. See the documentation there for a list of format specifiers that can be used.

The function returns 0 on success and a negative value in case of error.

`dtsub`

Subtract one timestamp from another and return a variable of type interval.

```
int dtsub(timestamp *ts1, timestamp *ts2, interval *iv);
```

The function will subtract the timestamp variable that `ts2` points to from the timestamp variable that `ts1` points to and will store the result in the interval variable that `iv` points to.

Upon success, the function returns 0 and a negative value if an error occurred.

`dttoasc`

Convert a timestamp variable to a C char* string.

```
int dttoasc(timestamp *ts, char *output);
```

The function receives a pointer to the timestamp variable to convert (`ts`) and the string that should hold the result of the operation (`output`). It converts `ts` to its textual representation according to the SQL standard, which is be `YYYY-MM-DD HH:MM:SS`.

Upon success, the function returns 0 and a negative value if an error occurred.

`dttofmtasc`

Convert a timestamp variable to a C char* using a format mask.

```
int dttofmtasc(timestamp *ts, char *output, int str_len, char *fmtstr);
```

The function receives a pointer to the timestamp to convert as its first argument (`ts`), a pointer to the output buffer (`output`), the maximal length that has been allocated for the output buffer (`str_len`) and the format mask to use for the conversion (`fmtstr`).

Upon success, the function returns 0 and a negative value if an error occurred.

Internally, this function uses the `PGTYPEStimestamp_fmt_asc` function. See the reference there for information on what format mask specifiers can be used.

`intoasc`

Convert an interval variable to a C char* string.

```
int intoasc(interval *i, char *str);
```

The function receives a pointer to the interval variable to convert (`i`) and the string that should hold the result of the operation (`str`). It converts `i` to its textual representation according to the SQL standard, which is be `YYYY-MM-DD HH:MM:SS`.

Upon success, the function returns 0 and a negative value if an error occurred.

`rfmtlong`

Convert a long integer value to its textual representation using a format mask.

```
int rfmtlong(long lng_val, char *fmt, char *outbuf);
```

The function receives the long value `lng_val`, the format mask `fmt` and a pointer to the output buffer `outbuf`. It converts the long value according to the format mask to its textual representation.

The format mask can be composed of the following format specifying characters:

- `*` (asterisk) - if this position would be blank otherwise, fill it with an asterisk.
- `&` (ampersand) - if this position would be blank otherwise, fill it with a zero.
- `#` - turn leading zeroes into blanks.
- `<` - left-justify the number in the string.
- `,` (comma) - group numbers of four or more digits into groups of three digits separated by a comma.
- `.` (period) - this character separates the whole-number part of the number from the fractional part.
- `–` (minus) - the minus sign appears if the number is a negative value.
- `+` (plus) - the plus sign appears if the number is a positive value.
- `(` - this replaces the minus sign in front of the negative number. The minus sign will not appear.
- `)` - this character replaces the minus and is printed behind the negative value.
- `$` - the currency symbol.

`rupshift`

Convert a string to upper case.

```
void rupshift(char *str);
```

The function receives a pointer to the string and transforms every lower case character to upper case.

`byleng`

Return the number of characters in a string without counting trailing blanks.

```
int byleng(char *str, int len);
```

The function expects a fixed-length string as its first argument (`str`) and its length as its second argument (`len`). It returns the number of significant characters, that is the length of the string without trailing blanks.

`ldchar`

Copy a fixed-length string into a null-terminated string.

```
void ldchar(char *src, int len, char *dest);
```

The function receives the fixed-length string to copy (`src`), its length (`len`) and a pointer to the destination memory (`dest`). Note that you need to reserve at least `len+1` bytes for the string that `dest` points to. The function copies at most `len` bytes to the new location (less if the source string has trailing blanks) and adds the null-terminator.

`rgetmsg`

```
int rgetmsg(int msgnum, char *s, int maxsize);
```

This function exists but is not implemented at the moment!

`rtypalign`

```
int rtypalign(int offset, int type);
```

This function exists but is not implemented at the moment!

`rtypmsize`

```
int rtypmsize(int type, int len);
```

This function exists but is not implemented at the moment!

`rtypwidth`

```
int rtypwidth(int sqltype, int sqllen);
```

This function exists but is not implemented at the moment!

`rsetnull`

Set a variable to NULL.

```
int rsetnull(int t, char *ptr);
```

The function receives an integer that indicates the type of the variable and a pointer to the variable itself that is cast to a C char* pointer.

The following types exist:

- `CCHARTYPE` - For a variable of type `char` or `char*`
- `CSHORTTYPE` - For a variable of type `short int`
- `CINTTYPE` - For a variable of type `int`
- `CBOOLTYPE` - For a variable of type `boolean`
- `CFLOATTYPE` - For a variable of type `float`
- `CLONGTYPE` - For a variable of type `long`
- `CDOUBLETYPE` - For a variable of type `double`
- `CDECIMALTYPE` - For a variable of type `decimal`
- `CDATETYPE` - For a variable of type `date`
- `CDTIMETYPE` - For a variable of type `timestamp`

Here is an example of a call to this function:

```
$char c[] = "abc       ";
$short s = 17;
$int i = -74874;

rsetnull(CCHARTYPE, (char *) c);
rsetnull(CSHORTTYPE, (char *) &s);
rsetnull(CINTTYPE, (char *) &i);
```

`risnull`

Test if a variable is NULL.

```
int risnull(int t, char *ptr);
```

The function receives the type of the variable to test (`t`) as well a pointer to this variable (`ptr`). Note that the latter needs to be cast to a char*. See the function `rsetnull` for a list of possible variable types.

Here is an example of how to use this function:

```
$char c[] = "abc       ";
$short s = 17;
$int i = -74874;
```

```
risnull(CCHARTYPE, (char *) c);
risnull(CSHORTTYPE, (char *) &s);
risnull(CINTTYPE, (char *) &i);
```

38.15.5. Additional Constants

Note that all constants here describe errors and all of them are defined to represent negative values. In the descriptions of the different constants you can also find the value that the constants represent in the current implementation. However you should not rely on this number. You can however rely on the fact all of them are defined to represent negative values.

`ECPG_INFORMIX_NUM_OVERFLOW`

Functions return this value if an overflow occurred in a calculation. Internally it is defined as -1200 (the Informix definition).

`ECPG_INFORMIX_NUM_UNDERFLOW`

Functions return this value if an underflow occurred in a calculation. Internally it is defined as -1201 (the Informix definition).

`ECPG_INFORMIX_DIVIDE_ZERO`

Functions return this value if an attempt to divide by zero is observed. Internally it is defined as -1202 (the Informix definition).

`ECPG_INFORMIX_BAD_YEAR`

Functions return this value if a bad value for a year was found while parsing a date. Internally it is defined as -1204 (the Informix definition).

`ECPG_INFORMIX_BAD_MONTH`

Functions return this value if a bad value for a month was found while parsing a date. Internally it is defined as -1205 (the Informix definition).

`ECPG_INFORMIX_BAD_DAY`

Functions return this value if a bad value for a day was found while parsing a date. Internally it is defined as -1206 (the Informix definition).

`ECPG_INFORMIX_ENOSHORTDATE`

Functions return this value if a parsing routine needs a short date representation but did not get the date string in the right length. Internally it is defined as -1209 (the Informix definition).

`ECPG_INFORMIX_DATE_CONVERT`

Functions return this value if an error occurred during date formatting. Internally it is defined as -1210 (the Informix definition).

`ECPG_INFORMIX_OUT_OF_MEMORY`

Functions return this value if memory was exhausted during their operation. Internally it is defined as -1211 (the Informix definition).

`ECPG_INFORMIX_ENOTDMY`

Functions return this value if a parsing routine was supposed to get a format mask (like `mmddyy`) but not all fields were listed correctly. Internally it is defined as -1212 (the Informix definition).

`ECPG_INFORMIX_BAD_NUMERIC`

Functions return this value either if a parsing routine cannot parse the textual representation for a numeric value because it contains errors or if a routine cannot complete a calculation involving

numeric variables because at least one of the numeric variables is invalid. Internally it is defined as -1213 (the Informix definition).

`ECPG_INFORMIX_BAD_EXPONENT`

Functions return this value if a parsing routine cannot parse an exponent. Internally it is defined as -1216 (the Informix definition).

`ECPG_INFORMIX_BAD_DATE`

Functions return this value if a parsing routine cannot parse a date. Internally it is defined as -1218 (the Informix definition).

`ECPG_INFORMIX_EXTRA_CHARS`

Functions return this value if a parsing routine is passed extra characters it cannot parse. Internally it is defined as -1264 (the Informix definition).

38.16. Oracle Compatibility Mode

`ecpg` can be run in a so-called *Oracle compatibility mode*. If this mode is active, it tries to behave as if it were Oracle Pro*C.

Specifically, this mode changes `ecpg` in three ways:

- Pad character arrays receiving character string types with trailing spaces to the specified length
- Zero byte terminate these character arrays, and set the indicator variable if truncation occurs
- Set the null indicator to `-1` when character arrays receive empty character string types

38.17. Internals

This section explains how ECPG works internally. This information can occasionally be useful to help users understand how to use ECPG.

The first four lines written by `ecpg` to the output are fixed lines. Two are comments and two are include lines necessary to interface to the library. Then the preprocessor reads through the file and writes output. Normally it just echoes everything to the output.

When it sees an `EXEC SQL` statement, it intervenes and changes it. The command starts with `EXEC SQL` and ends with `;`. Everything in between is treated as an SQL statement and parsed for variable substitution.

Variable substitution occurs when a symbol starts with a colon (`:`). The variable with that name is looked up among the variables that were previously declared within a `EXEC SQL DECLARE` section.

The most important function in the library is `ECPGdo`, which takes care of executing most commands. It takes a variable number of arguments. This can easily add up to 50 or so arguments, and we hope this will not be a problem on any platform.

The arguments are:

A line number

This is the line number of the original line; used in error messages only.

A string

This is the SQL command that is to be issued. It is modified by the input variables, i.e., the variables that where not known at compile time but are to be entered in the command. Where the variables should go the string contains `?`.

Input variables

Every input variable causes ten arguments to be created. (See below.)

ECPGt_EOIT

An `enum` telling that there are no more input variables.

Output variables

Every output variable causes ten arguments to be created. (See below.) These variables are filled by the function.

ECPGt_EORT

An `enum` telling that there are no more variables.

For every variable that is part of the SQL command, the function gets ten arguments:

1. The type as a special symbol.
2. A pointer to the value or a pointer to the pointer.
3. The size of the variable if it is a `char` or `varchar`.
4. The number of elements in the array (for array fetches).
5. The offset to the next element in the array (for array fetches).
6. The type of the indicator variable as a special symbol.
7. A pointer to the indicator variable.
8. 0
9. The number of elements in the indicator array (for array fetches).
10. The offset to the next element in the indicator array (for array fetches).

Note that not all SQL commands are treated in this way. For instance, an open cursor statement like:

```
EXEC SQL OPEN cursor;
```

is not copied to the output. Instead, the cursor's `DECLARE` command is used at the position of the `OPEN` command because it indeed opens the cursor.

Here is a complete example describing the output of the preprocessor of a file `foo.pgc` (details might change with each particular version of the preprocessor):

```
EXEC SQL BEGIN DECLARE SECTION;
int index;
int result;
EXEC SQL END DECLARE SECTION;
...
EXEC SQL SELECT res INTO :result FROM mytable WHERE index = :index;
```

is translated into:

```
/* Processed by ecpg (2.6.0) */
/* These two include files are added by the preprocessor */
#include <ecpgtype.h>;
#include <ecpglib.h>;

/* exec sql begin declare section */

#line 1 "foo.pgc"

 int index;
 int result;
/* exec sql end declare section */
...
ECPGdo(__LINE__, NULL, "SELECT res FROM mytable WHERE index = ?     ",
```

```
        ECPGt_int,&(index),1L,1L,sizeof(int),
        ECPGt_NO_INDICATOR, NULL , 0L, 0L, 0L, ECPGt_EOIT,
        ECPGt_int,&(result),1L,1L,sizeof(int),
        ECPGt_NO_INDICATOR, NULL , 0L, 0L, 0L, ECPGt_EORT);
#line 147 "foo.pgc"
```

(The indentation here is added for readability and not something the preprocessor does.)

Chapter 39. The Information Schema

The information schema consists of a set of views that contain information about the objects defined in the current database. The information schema is defined in the SQL standard and can therefore be expected to be portable and remain stable — unlike the system catalogs, which are specific to Postgres Pro and are modeled after implementation concerns. The information schema views do not, however, contain information about Postgres Pro-specific features; to inquire about those you need to query the system catalogs or other Postgres Pro-specific views.

> **Note**
>
> When querying the database for constraint information, it is possible for a standard-compliant query that expects to return one row to return several. This is because the SQL standard requires constraint names to be unique within a schema, but Postgres Pro does not enforce this restriction. Postgres Pro automatically-generated constraint names avoid duplicates in the same schema, but users can specify such duplicate names.
>
> This problem can appear when querying information schema views such as `check_constraint_routine_usage`, `check_constraints`, `domain_constraints`, and `referential_constraints`. Some other views have similar issues but contain the table name to help distinguish duplicate rows, e.g., `constraint_column_usage`, `constraint_table_usage`, `table_constraints`.

39.1. The Schema

The information schema itself is a schema named `information_schema`. This schema automatically exists in all databases. The owner of this schema is the initial database user in the cluster, and that user naturally has all the privileges on this schema, including the ability to drop it (but the space savings achieved by that are minuscule).

By default, the information schema is not in the schema search path, so you need to access all objects in it through qualified names. Since the names of some of the objects in the information schema are generic names that might occur in user applications, you should be careful if you want to put the information schema in the path.

39.2. Data Types

The columns of the information schema views use special data types that are defined in the information schema. These are defined as simple domains over ordinary built-in types. You should not use these types for work outside the information schema, but your applications must be prepared for them if they select from the information schema.

These types are:

`cardinal_number`

A nonnegative integer.

`character_data`

A character string (without specific maximum length).

`sql_identifier`

A character string. This type is used for SQL identifiers, the type `character_data` is used for any other kind of text data.

`time_stamp`

A domain over the type `timestamp with time zone`

`yes_or_no`

A character string domain that contains either `YES` or `NO`. This is used to represent Boolean (true/false) data in the information schema. (The information schema was invented before the type `boolean` was added to the SQL standard, so this convention is necessary to keep the information schema backward compatible.)

Every column in the information schema has one of these five types.

39.3. `information_schema_catalog_name`

`information_schema_catalog_name` is a table that always contains one row and one column containing the name of the current database (current catalog, in SQL terminology).

Table 39.1. `information_schema_catalog_name` Columns

Column Type Description
`catalog_name sql_identifier` Name of the database that contains this information schema

39.4. `administrable_role_authorizations`

The view `administrable_role_authorizations` identifies all roles that the current user has the admin option for.

Table 39.2. `administrable_role_authorizations` Columns

Column Type Description
`grantee sql_identifier` Name of the role to which this role membership was granted (can be the current user, or a different role in case of nested role memberships)
`role_name sql_identifier` Name of a role
`is_grantable yes_or_no` Always `YES`

39.5. `applicable_roles`

The view `applicable_roles` identifies all roles whose privileges the current user can use. This means there is some chain of role grants from the current user to the role in question. The current user itself is also an applicable role. The set of applicable roles is generally used for permission checking.

Table 39.3. `applicable_roles` Columns

Column Type Description
`grantee sql_identifier` Name of the role to which this role membership was granted (can be the current user, or a different role in case of nested role memberships)
`role_name sql_identifier` Name of a role
`is_grantable yes_or_no` `YES` if the grantee has the admin option on the role, `NO` if not

39.6. attributes

The view attributes contains information about the attributes of composite data types defined in the database. (Note that the view does not give information about table columns, which are sometimes called attributes in Postgres Pro contexts.) Only those attributes are shown that the current user has access to (by way of being the owner of or having some privilege on the type).

Table 39.4. attributes Columns

Column Type Description
udt_catalog sql_identifier Name of the database containing the data type (always the current database)
udt_schema sql_identifier Name of the schema containing the data type
udt_name sql_identifier Name of the data type
attribute_name sql_identifier Name of the attribute
ordinal_position cardinal_number Ordinal position of the attribute within the data type (count starts at 1)
attribute_default character_data Default expression of the attribute
is_nullable yes_or_no YES if the attribute is possibly nullable, NO if it is known not nullable.
data_type character_data Data type of the attribute, if it is a built-in type, or ARRAY if it is some array (in that case, see the view element_types), else USER-DEFINED (in that case, the type is identified in attribute_udt_name and associated columns).
character_maximum_length cardinal_number If data_type identifies a character or bit string type, the declared maximum length; null for all other data types or if no maximum length was declared.
character_octet_length cardinal_number If data_type identifies a character type, the maximum possible length in octets (bytes) of a datum; null for all other data types. The maximum octet length depends on the declared character maximum length (see above) and the server encoding.
character_set_catalog sql_identifier Applies to a feature not available in Postgres Pro
character_set_schema sql_identifier Applies to a feature not available in Postgres Pro
character_set_name sql_identifier Applies to a feature not available in Postgres Pro
collation_catalog sql_identifier Name of the database containing the collation of the attribute (always the current database), null if default or the data type of the attribute is not collatable
collation_schema sql_identifier Name of the schema containing the collation of the attribute, null if default or the data type of the attribute is not collatable
collation_name sql_identifier Name of the collation of the attribute, null if default or the data type of the attribute is not collatable

Column Type Description
`numeric_precision cardinal_number` If `data_type` identifies a numeric type, this column contains the (declared or implicit) precision of the type for this attribute. The precision indicates the number of significant digits. It can be expressed in decimal (base 10) or binary (base 2) terms, as specified in the column `numeric_precision_radix` . For all other data types, this column is null.
`numeric_precision_radix cardinal_number` If `data_type` identifies a numeric type, this column indicates in which base the values in the columns `numeric_precision` and `numeric_scale` are expressed. The value is either 2 or 10. For all other data types, this column is null.
`numeric_scale cardinal_number` If `data_type` identifies an exact numeric type, this column contains the (declared or implicit) scale of the type for this attribute. The scale indicates the number of significant digits to the right of the decimal point. It can be expressed in decimal (base 10) or binary (base 2) terms, as specified in the column `numeric_precision_radix` . For all other data types, this column is null.
`datetime_precision cardinal_number` If `data_type` identifies a date, time, timestamp, or interval type, this column contains the (declared or implicit) fractional seconds precision of the type for this attribute, that is, the number of decimal digits maintained following the decimal point in the seconds value. For all other data types, this column is null.
`interval_type character_data` If `data_type` identifies an interval type, this column contains the specification which fields the intervals include for this attribute, e.g., `YEAR TO MONTH`, `DAY TO SECOND`, etc. If no field restrictions were specified (that is, the interval accepts all fields), and for all other data types, this field is null.
`interval_precision cardinal_number` Applies to a feature not available in Postgres Pro (see `datetime_precision` for the fractional seconds precision of interval type attributes)
`attribute_udt_catalog sql_identifier` Name of the database that the attribute data type is defined in (always the current database)
`attribute_udt_schema sql_identifier` Name of the schema that the attribute data type is defined in
`attribute_udt_name sql_identifier` Name of the attribute data type
`scope_catalog sql_identifier` Applies to a feature not available in Postgres Pro
`scope_schema sql_identifier` Applies to a feature not available in Postgres Pro
`scope_name sql_identifier` Applies to a feature not available in Postgres Pro
`maximum_cardinality cardinal_number` Always null, because arrays always have unlimited maximum cardinality in Postgres Pro
`dtd_identifier sql_identifier` An identifier of the data type descriptor of the attribute, unique among the data type descriptors pertaining to the composite type. This is mainly useful for joining with other instances of such identifiers. (The specific format of the identifier is not defined and not guaranteed to remain the same in future versions.)
`is_derived_reference_attribute yes_or_no` Applies to a feature not available in Postgres Pro

See also under Section 39.17, a similarly structured view, for further information on some of the columns.

39.7. character_sets

The view character_sets identifies the character sets available in the current database. Since Postgres Pro does not support multiple character sets within one database, this view only shows one, which is the database encoding.

Take note of how the following terms are used in the SQL standard:

character repertoire

An abstract collection of characters, for example UNICODE, UCS, or LATIN1. Not exposed as an SQL object, but visible in this view.

character encoding form

An encoding of some character repertoire. Most older character repertoires only use one encoding form, and so there are no separate names for them (e.g., LATIN2 is an encoding form applicable to the LATIN2 repertoire). But for example Unicode has the encoding forms UTF8, UTF16, etc. (not all supported by Postgres Pro). Encoding forms are not exposed as an SQL object, but are visible in this view.

character set

A named SQL object that identifies a character repertoire, a character encoding, and a default collation. A predefined character set would typically have the same name as an encoding form, but users could define other names. For example, the character set UTF8 would typically identify the character repertoire UCS, encoding form UTF8, and some default collation.

You can think of an "encoding" in Postgres Pro either as a character set or a character encoding form. They will have the same name, and there can only be one in one database.

Table 39.5. character_sets Columns

Column Type Description
character_set_catalog sql_identifier Character sets are currently not implemented as schema objects, so this column is null.
character_set_schema sql_identifier Character sets are currently not implemented as schema objects, so this column is null.
character_set_name sql_identifier Name of the character set, currently implemented as showing the name of the database encoding
character_repertoire sql_identifier Character repertoire, showing UCS if the encoding is UTF8, else just the encoding name
form_of_use sql_identifier Character encoding form, same as the database encoding
default_collate_catalog sql_identifier Name of the database containing the default collation (always the current database, if any collation is identified)
default_collate_schema sql_identifier Name of the schema containing the default collation
default_collate_name sql_identifier Name of the default collation. The default collation is identified as the collation that matches the COLLATE and CTYPE settings of the current database. If there is no such collation, then this column and the associated schema and catalog columns are null.

39.8. check_constraint_routine_usage

The view check_constraint_routine_usage identifies routines (functions and procedures) that are used by a check constraint. Only those routines are shown that are owned by a currently enabled role.

Table 39.6. check_constraint_routine_usage Columns

Column Type Description
constraint_catalog sql_identifier Name of the database containing the constraint (always the current database)
constraint_schema sql_identifier Name of the schema containing the constraint
constraint_name sql_identifier Name of the constraint
specific_catalog sql_identifier Name of the database containing the function (always the current database)
specific_schema sql_identifier Name of the schema containing the function
specific_name sql_identifier The “specific name” of the function. See Section 39.45 for more information.

39.9. check_constraints

The view check_constraints contains all check constraints, either defined on a table or on a domain, that are owned by a currently enabled role. (The owner of the table or domain is the owner of the constraint.)

Table 39.7. check_constraints Columns

Column Type Description
constraint_catalog sql_identifier Name of the database containing the constraint (always the current database)
constraint_schema sql_identifier Name of the schema containing the constraint
constraint_name sql_identifier Name of the constraint
check_clause character_data The check expression of the check constraint

39.10. collations

The view collations contains the collations available in the current database.

Table 39.8. collations Columns

Column Type Description
collation_catalog sql_identifier Name of the database containing the collation (always the current database)
collation_schema sql_identifier Name of the schema containing the collation
collation_name sql_identifier

Column Type Description
Name of the default collation
`pad_attribute character_data` Always `NO PAD` (The alternative `PAD SPACE` is not supported by Postgres Pro.)

39.11. collation_character_set_applicability

The view `collation_character_set_applicability` identifies which character set the available collations are applicable to. In Postgres Pro, there is only one character set per database (see explanation in Section 39.7), so this view does not provide much useful information.

Table 39.9. `collation_character_set_applicability` Columns

Column Type Description
`collation_catalog sql_identifier` Name of the database containing the collation (always the current database)
`collation_schema sql_identifier` Name of the schema containing the collation
`collation_name sql_identifier` Name of the default collation
`character_set_catalog sql_identifier` Character sets are currently not implemented as schema objects, so this column is null
`character_set_schema sql_identifier` Character sets are currently not implemented as schema objects, so this column is null
`character_set_name sql_identifier` Name of the character set

39.12. column_column_usage

The view `column_column_usage` identifies all generated columns that depend on another base column in the same table. Only tables owned by a currently enabled role are included.

Table 39.10. `column_column_usage` Columns

Column Type Description
`table_catalog sql_identifier` Name of the database containing the table (always the current database)
`table_schema sql_identifier` Name of the schema containing the table
`table_name sql_identifier` Name of the table
`column_name sql_identifier` Name of the base column that a generated column depends on
`dependent_column sql_identifier` Name of the generated column

39.13. column_domain_usage

The view `column_domain_usage` identifies all columns (of a table or a view) that make use of some domain defined in the current database and owned by a currently enabled role.

Table 39.11. `column_domain_usage` Columns

Column Type Description
`domain_catalog sql_identifier` Name of the database containing the domain (always the current database)
`domain_schema sql_identifier` Name of the schema containing the domain
`domain_name sql_identifier` Name of the domain
`table_catalog sql_identifier` Name of the database containing the table (always the current database)
`table_schema sql_identifier` Name of the schema containing the table
`table_name sql_identifier` Name of the table
`column_name sql_identifier` Name of the column

39.14. column_options

The view `column_options` contains all the options defined for foreign table columns in the current database. Only those foreign table columns are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.12. `column_options` Columns

Column Type Description
`table_catalog sql_identifier` Name of the database that contains the foreign table (always the current database)
`table_schema sql_identifier` Name of the schema that contains the foreign table
`table_name sql_identifier` Name of the foreign table
`column_name sql_identifier` Name of the column
`option_name sql_identifier` Name of an option
`option_value character_data` Value of the option

39.15. column_privileges

The view `column_privileges` identifies all privileges granted on columns to a currently enabled role or by a currently enabled role. There is one row for each combination of column, grantor, and grantee.

If a privilege has been granted on an entire table, it will show up in this view as a grant for each column, but only for the privilege types where column granularity is possible: `SELECT`, `INSERT`, `UPDATE`, `REFERENCES`.

Table 39.13. `column_privileges` Columns

Column Type Description
`grantor` `sql_identifier` Name of the role that granted the privilege
`grantee` `sql_identifier` Name of the role that the privilege was granted to
`table_catalog` `sql_identifier` Name of the database that contains the table that contains the column (always the current database)
`table_schema` `sql_identifier` Name of the schema that contains the table that contains the column
`table_name` `sql_identifier` Name of the table that contains the column
`column_name` `sql_identifier` Name of the column
`privilege_type` `character_data` Type of the privilege: `SELECT`, `INSERT`, `UPDATE`, or `REFERENCES`
`is_grantable` `yes_or_no` `YES` if the privilege is grantable, `NO` if not

39.16. `column_udt_usage`

The view `column_udt_usage` identifies all columns that use data types owned by a currently enabled role. Note that in Postgres Pro, built-in data types behave like user-defined types, so they are included here as well. See also Section 39.17 for details.

Table 39.14. `column_udt_usage` Columns

Column Type Description
`udt_catalog` `sql_identifier` Name of the database that the column data type (the underlying type of the domain, if applicable) is defined in (always the current database)
`udt_schema` `sql_identifier` Name of the schema that the column data type (the underlying type of the domain, if applicable) is defined in
`udt_name` `sql_identifier` Name of the column data type (the underlying type of the domain, if applicable)
`table_catalog` `sql_identifier` Name of the database containing the table (always the current database)
`table_schema` `sql_identifier` Name of the schema containing the table
`table_name` `sql_identifier` Name of the table
`column_name` `sql_identifier` Name of the column

39.17. columns

The view columns contains information about all table columns (or view columns) in the database. System columns (ctid, etc.) are not included. Only those columns are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.15. columns Columns

Column Type Description
table_catalog sql_identifier Name of the database containing the table (always the current database)
table_schema sql_identifier Name of the schema containing the table
table_name sql_identifier Name of the table
column_name sql_identifier Name of the column
ordinal_position cardinal_number Ordinal position of the column within the table (count starts at 1)
column_default character_data Default expression of the column
is_nullable yes_or_no YES if the column is possibly nullable, NO if it is known not nullable. A not-null constraint is one way a column can be known not nullable, but there can be others.
data_type character_data Data type of the column, if it is a built-in type, or ARRAY if it is some array (in that case, see the view element_types), else USER-DEFINED (in that case, the type is identified in udt_name and associated columns). If the column is based on a domain, this column refers to the type underlying the domain (and the domain is identified in domain_name and associated columns).
character_maximum_length cardinal_number If data_type identifies a character or bit string type, the declared maximum length; null for all other data types or if no maximum length was declared.
character_octet_length cardinal_number If data_type identifies a character type, the maximum possible length in octets (bytes) of a datum; null for all other data types. The maximum octet length depends on the declared character maximum length (see above) and the server encoding.
numeric_precision cardinal_number If data_type identifies a numeric type, this column contains the (declared or implicit) precision of the type for this column. The precision indicates the number of significant digits. It can be expressed in decimal (base 10) or binary (base 2) terms, as specified in the column numeric_precision_radix . For all other data types, this column is null.
numeric_precision_radix cardinal_number If data_type identifies a numeric type, this column indicates in which base the values in the columns numeric_precision and numeric_scale are expressed. The value is either 2 or 10. For all other data types, this column is null.
numeric_scale cardinal_number If data_type identifies an exact numeric type, this column contains the (declared or implicit) scale of the type for this column. The scale indicates the number of significant digits to the right of the decimal point. It can be expressed in decimal (base 10) or binary (base 2) terms,

Column Type Description
as specified in the column `numeric_precision_radix`. For all other data types, this column is null.
`datetime_precision cardinal_number` If `data_type` identifies a date, time, timestamp, or interval type, this column contains the (declared or implicit) fractional seconds precision of the type for this column, that is, the number of decimal digits maintained following the decimal point in the seconds value. For all other data types, this column is null.
`interval_type character_data` If `data_type` identifies an interval type, this column contains the specification which fields the intervals include for this column, e.g., `YEAR TO MONTH`, `DAY TO SECOND`, etc. If no field restrictions were specified (that is, the interval accepts all fields), and for all other data types, this field is null.
`interval_precision cardinal_number` Applies to a feature not available in Postgres Pro (see `datetime_precision` for the fractional seconds precision of interval type columns)
`character_set_catalog sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_schema sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_name sql_identifier` Applies to a feature not available in Postgres Pro
`collation_catalog sql_identifier` Name of the database containing the collation of the column (always the current database), null if default or the data type of the column is not collatable
`collation_schema sql_identifier` Name of the schema containing the collation of the column, null if default or the data type of the column is not collatable
`collation_name sql_identifier` Name of the collation of the column, null if default or the data type of the column is not collatable
`domain_catalog sql_identifier` If the column has a domain type, the name of the database that the domain is defined in (always the current database), else null.
`domain_schema sql_identifier` If the column has a domain type, the name of the schema that the domain is defined in, else null.
`domain_name sql_identifier` If the column has a domain type, the name of the domain, else null.
`udt_catalog sql_identifier` Name of the database that the column data type (the underlying type of the domain, if applicable) is defined in (always the current database)
`udt_schema sql_identifier` Name of the schema that the column data type (the underlying type of the domain, if applicable) is defined in
`udt_name sql_identifier` Name of the column data type (the underlying type of the domain, if applicable)
`scope_catalog sql_identifier` Applies to a feature not available in Postgres Pro

Column Type Description
`scope_schema sql_identifier` Applies to a feature not available in Postgres Pro
`scope_name sql_identifier` Applies to a feature not available in Postgres Pro
`maximum_cardinality cardinal_number` Always null, because arrays always have unlimited maximum cardinality in Postgres Pro
`dtd_identifier sql_identifier` An identifier of the data type descriptor of the column, unique among the data type descriptors pertaining to the table. This is mainly useful for joining with other instances of such identifiers. (The specific format of the identifier is not defined and not guaranteed to remain the same in future versions.)
`is_self_referencing yes_or_no` Applies to a feature not available in Postgres Pro
`is_identity yes_or_no` If the column is an identity column, then `YES`, else `NO`.
`identity_generation character_data` If the column is an identity column, then `ALWAYS` or `BY DEFAULT`, reflecting the definition of the column.
`identity_start character_data` If the column is an identity column, then the start value of the internal sequence, else null.
`identity_increment character_data` If the column is an identity column, then the increment of the internal sequence, else null.
`identity_maximum character_data` If the column is an identity column, then the maximum value of the internal sequence, else null.
`identity_minimum character_data` If the column is an identity column, then the minimum value of the internal sequence, else null.
`identity_cycle yes_or_no` If the column is an identity column, then `YES` if the internal sequence cycles or `NO` if it does not; otherwise null.
`is_generated character_data` If the column is a generated column, then `ALWAYS`, else `NEVER`.
`generation_expression character_data` If the column is a generated column, then the generation expression, else null.
`is_updatable yes_or_no` `YES` if the column is updatable, `NO` if not (Columns in base tables are always updatable, columns in views not necessarily)

Since data types can be defined in a variety of ways in SQL, and Postgres Pro contains additional ways to define data types, their representation in the information schema can be somewhat difficult. The column `data_type` is supposed to identify the underlying built-in type of the column. In Postgres Pro, this means that the type is defined in the system catalog schema `pg_catalog`. This column might be useful if the application can handle the well-known built-in types specially (for example, format the numeric types differently or use the data in the precision columns). The columns `udt_name`, `udt_schema`, and `udt_catalog` always identify the underlying data type of the column, even if the column is based on a domain. (Since Postgres Pro treats built-in types like user-defined types, built-in types appear here as well. This is an extension of the SQL standard.) These columns should be used if an application wants to process data differently according to the type, because in that case it wouldn't matter if the column is

really based on a domain. If the column is based on a domain, the identity of the domain is stored in the columns `domain_name`, `domain_schema`, and `domain_catalog`. If you want to pair up columns with their associated data types and treat domains as separate types, you could write `coalesce(domain_name, udt_name)`, etc.

39.18. constraint_column_usage

The view `constraint_column_usage` identifies all columns in the current database that are used by some constraint. Only those columns are shown that are contained in a table owned by a currently enabled role. For a check constraint, this view identifies the columns that are used in the check expression. For a foreign key constraint, this view identifies the columns that the foreign key references. For a unique or primary key constraint, this view identifies the constrained columns.

Table 39.16. `constraint_column_usage` Columns

Column Type Description
`table_catalog sql_identifier` Name of the database that contains the table that contains the column that is used by some constraint (always the current database)
`table_schema sql_identifier` Name of the schema that contains the table that contains the column that is used by some constraint
`table_name sql_identifier` Name of the table that contains the column that is used by some constraint
`column_name sql_identifier` Name of the column that is used by some constraint
`constraint_catalog sql_identifier` Name of the database that contains the constraint (always the current database)
`constraint_schema sql_identifier` Name of the schema that contains the constraint
`constraint_name sql_identifier` Name of the constraint

39.19. constraint_table_usage

The view `constraint_table_usage` identifies all tables in the current database that are used by some constraint and are owned by a currently enabled role. (This is different from the view `table_constraints`, which identifies all table constraints along with the table they are defined on.) For a foreign key constraint, this view identifies the table that the foreign key references. For a unique or primary key constraint, this view simply identifies the table the constraint belongs to. Check constraints and not-null constraints are not included in this view.

Table 39.17. `constraint_table_usage` Columns

Column Type Description
`table_catalog sql_identifier` Name of the database that contains the table that is used by some constraint (always the current database)
`table_schema sql_identifier` Name of the schema that contains the table that is used by some constraint
`table_name sql_identifier` Name of the table that is used by some constraint

Column Type Description
`constraint_catalog sql_identifier` Name of the database that contains the constraint (always the current database)
`constraint_schema sql_identifier` Name of the schema that contains the constraint
`constraint_name sql_identifier` Name of the constraint

39.20. data_type_privileges

The view `data_type_privileges` identifies all data type descriptors that the current user has access to, by way of being the owner of the described object or having some privilege for it. A data type descriptor is generated whenever a data type is used in the definition of a table column, a domain, or a function (as parameter or return type) and stores some information about how the data type is used in that instance (for example, the declared maximum length, if applicable). Each data type descriptor is assigned an arbitrary identifier that is unique among the data type descriptor identifiers assigned for one object (table, domain, function). This view is probably not useful for applications, but it is used to define some other views in the information schema.

Table 39.18. `data_type_privileges` Columns

Column Type Description
`object_catalog sql_identifier` Name of the database that contains the described object (always the current database)
`object_schema sql_identifier` Name of the schema that contains the described object
`object_name sql_identifier` Name of the described object
`object_type character_data` The type of the described object: one of `TABLE` (the data type descriptor pertains to a column of that table), `DOMAIN` (the data type descriptors pertains to that domain), `ROUTINE` (the data type descriptor pertains to a parameter or the return data type of that function).
`dtd_identifier sql_identifier` The identifier of the data type descriptor, which is unique among the data type descriptors for that same object.

39.21. domain_constraints

The view `domain_constraints` contains all constraints belonging to domains defined in the current database. Only those domains are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.19. `domain_constraints` Columns

Column Type Description
`constraint_catalog sql_identifier` Name of the database that contains the constraint (always the current database)
`constraint_schema sql_identifier` Name of the schema that contains the constraint
`constraint_name sql_identifier` Name of the constraint

Column Type Description
`domain_catalog sql_identifier` Name of the database that contains the domain (always the current database)
`domain_schema sql_identifier` Name of the schema that contains the domain
`domain_name sql_identifier` Name of the domain
`is_deferrable yes_or_no` `YES` if the constraint is deferrable, `NO` if not
`initially_deferred yes_or_no` `YES` if the constraint is deferrable and initially deferred, `NO` if not

39.22. domain_udt_usage

The view `domain_udt_usage` identifies all domains that are based on data types owned by a currently enabled role. Note that in Postgres Pro, built-in data types behave like user-defined types, so they are included here as well.

Table 39.20. `domain_udt_usage` Columns

Column Type Description
`udt_catalog sql_identifier` Name of the database that the domain data type is defined in (always the current database)
`udt_schema sql_identifier` Name of the schema that the domain data type is defined in
`udt_name sql_identifier` Name of the domain data type
`domain_catalog sql_identifier` Name of the database that contains the domain (always the current database)
`domain_schema sql_identifier` Name of the schema that contains the domain
`domain_name sql_identifier` Name of the domain

39.23. domains

The view `domains` contains all domains defined in the current database. Only those domains are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.21. `domains` Columns

Column Type Description
`domain_catalog sql_identifier` Name of the database that contains the domain (always the current database)
`domain_schema sql_identifier` Name of the schema that contains the domain
`domain_name sql_identifier` Name of the domain
`data_type character_data`

Column Type **Description**
Data type of the domain, if it is a built-in type, or ARRAY if it is some array (in that case, see the view element_types), else USER-DEFINED (in that case, the type is identified in udt_name and associated columns).
character_maximum_length cardinal_number If the domain has a character or bit string type, the declared maximum length; null for all other data types or if no maximum length was declared.
character_octet_length cardinal_number If the domain has a character type, the maximum possible length in octets (bytes) of a datum; null for all other data types. The maximum octet length depends on the declared character maximum length (see above) and the server encoding.
character_set_catalog sql_identifier Applies to a feature not available in Postgres Pro
character_set_schema sql_identifier Applies to a feature not available in Postgres Pro
character_set_name sql_identifier Applies to a feature not available in Postgres Pro
collation_catalog sql_identifier Name of the database containing the collation of the domain (always the current database), null if default or the data type of the domain is not collatable
collation_schema sql_identifier Name of the schema containing the collation of the domain, null if default or the data type of the domain is not collatable
collation_name sql_identifier Name of the collation of the domain, null if default or the data type of the domain is not collatable
numeric_precision cardinal_number If the domain has a numeric type, this column contains the (declared or implicit) precision of the type for this domain. The precision indicates the number of significant digits. It can be expressed in decimal (base 10) or binary (base 2) terms, as specified in the column numeric_precision_radix . For all other data types, this column is null.
numeric_precision_radix cardinal_number If the domain has a numeric type, this column indicates in which base the values in the columns numeric_precision and numeric_scale are expressed. The value is either 2 or 10. For all other data types, this column is null.
numeric_scale cardinal_number If the domain has an exact numeric type, this column contains the (declared or implicit) scale of the type for this domain. The scale indicates the number of significant digits to the right of the decimal point. It can be expressed in decimal (base 10) or binary (base 2) terms, as specified in the column numeric_precision_radix . For all other data types, this column is null.
datetime_precision cardinal_number If data_type identifies a date, time, timestamp, or interval type, this column contains the (declared or implicit) fractional seconds precision of the type for this domain, that is, the number of decimal digits maintained following the decimal point in the seconds value. For all other data types, this column is null.
interval_type character_data If data_type identifies an interval type, this column contains the specification which fields the intervals include for this domain, e.g., YEAR TO MONTH, DAY TO SECOND, etc. If no field restrictions were specified (that is, the interval accepts all fields), and for all other data types, this field is null.

Column Type Description
`interval_precision cardinal_number` Applies to a feature not available in Postgres Pro (see `datetime_precision` for the fractional seconds precision of interval type domains)
`domain_default character_data` Default expression of the domain
`udt_catalog sql_identifier` Name of the database that the domain data type is defined in (always the current database)
`udt_schema sql_identifier` Name of the schema that the domain data type is defined in
`udt_name sql_identifier` Name of the domain data type
`scope_catalog sql_identifier` Applies to a feature not available in Postgres Pro
`scope_schema sql_identifier` Applies to a feature not available in Postgres Pro
`scope_name sql_identifier` Applies to a feature not available in Postgres Pro
`maximum_cardinality cardinal_number` Always null, because arrays always have unlimited maximum cardinality in Postgres Pro
`dtd_identifier sql_identifier` An identifier of the data type descriptor of the domain, unique among the data type descriptors pertaining to the domain (which is trivial, because a domain only contains one data type descriptor). This is mainly useful for joining with other instances of such identifiers. (The specific format of the identifier is not defined and not guaranteed to remain the same in future versions.)

39.24. `element_types`

The view `element_types` contains the data type descriptors of the elements of arrays. When a table column, composite-type attribute, domain, function parameter, or function return value is defined to be of an array type, the respective information schema view only contains `ARRAY` in the column `data_type`. To obtain information on the element type of the array, you can join the respective view with this view. For example, to show the columns of a table with data types and array element types, if applicable, you could do:

```
SELECT c.column_name, c.data_type, e.data_type AS element_type
FROM information_schema.columns c LEFT JOIN information_schema.element_types e
     ON ((c.table_catalog, c.table_schema, c.table_name, 'TABLE', c.dtd_identifier)
       = (e.object_catalog, e.object_schema, e.object_name, e.object_type,
 e.collection_type_identifier))
WHERE c.table_schema = '...' AND c.table_name = '...'
ORDER BY c.ordinal_position;
```

This view only includes objects that the current user has access to, by way of being the owner or having some privilege.

Table 39.22. `element_types` Columns

Column Type Description
`object_catalog sql_identifier` Name of the database that contains the object that uses the array being described (always the current database)

Column Type Description
`object_schema sql_identifier` Name of the schema that contains the object that uses the array being described
`object_name sql_identifier` Name of the object that uses the array being described
`object_type character_data` The type of the object that uses the array being described: one of `TABLE` (the array is used by a column of that table), `USER-DEFINED TYPE` (the array is used by an attribute of that composite type), `DOMAIN` (the array is used by that domain), `ROUTINE` (the array is used by a parameter or the return data type of that function).
`collection_type_identifier sql_identifier` The identifier of the data type descriptor of the array being described. Use this to join with the `dtd_identifier` columns of other information schema views.
`data_type character_data` Data type of the array elements, if it is a built-in type, else `USER-DEFINED` (in that case, the type is identified in `udt_name` and associated columns).
`character_maximum_length cardinal_number` Always null, since this information is not applied to array element data types in Postgres Pro
`character_octet_length cardinal_number` Always null, since this information is not applied to array element data types in Postgres Pro
`character_set_catalog sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_schema sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_name sql_identifier` Applies to a feature not available in Postgres Pro
`collation_catalog sql_identifier` Name of the database containing the collation of the element type (always the current database), null if default or the data type of the element is not collatable
`collation_schema sql_identifier` Name of the schema containing the collation of the element type, null if default or the data type of the element is not collatable
`collation_name sql_identifier` Name of the collation of the element type, null if default or the data type of the element is not collatable
`numeric_precision cardinal_number` Always null, since this information is not applied to array element data types in Postgres Pro
`numeric_precision_radix cardinal_number` Always null, since this information is not applied to array element data types in Postgres Pro
`numeric_scale cardinal_number` Always null, since this information is not applied to array element data types in Postgres Pro
`datetime_precision cardinal_number` Always null, since this information is not applied to array element data types in Postgres Pro
`interval_type character_data` Always null, since this information is not applied to array element data types in Postgres Pro
`interval_precision cardinal_number` Always null, since this information is not applied to array element data types in Postgres Pro
`domain_default character_data`

Column Type Description
Not yet implemented
`udt_catalog` `sql_identifier` Name of the database that the data type of the elements is defined in (always the current database)
`udt_schema` `sql_identifier` Name of the schema that the data type of the elements is defined in
`udt_name` `sql_identifier` Name of the data type of the elements
`scope_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`scope_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`scope_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`maximum_cardinality` `cardinal_number` Always null, because arrays always have unlimited maximum cardinality in Postgres Pro
`dtd_identifier` `sql_identifier` An identifier of the data type descriptor of the element. This is currently not useful.

39.25. `enabled_roles`

The view `enabled_roles` identifies the currently "enabled roles". The enabled roles are recursively defined as the current user together with all roles that have been granted to the enabled roles with automatic inheritance. In other words, these are all roles that the current user has direct or indirect, automatically inheriting membership in.

For permission checking, the set of "applicable roles" is applied, which can be broader than the set of enabled roles. So generally, it is better to use the view `applicable_roles` instead of this one; See Section 39.5 for details on `applicable_roles` view.

Table 39.23. `enabled_roles` Columns

Column Type Description
`role_name` `sql_identifier` Name of a role

39.26. `foreign_data_wrapper_options`

The view `foreign_data_wrapper_options` contains all the options defined for foreign-data wrappers in the current database. Only those foreign-data wrappers are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.24. `foreign_data_wrapper_options` Columns

Column Type Description
`foreign_data_wrapper_catalog` `sql_identifier` Name of the database that the foreign-data wrapper is defined in (always the current database)
`foreign_data_wrapper_name` `sql_identifier`

Column Type Description
Name of the foreign-data wrapper
`option_name sql_identifier` Name of an option
`option_value character_data` Value of the option

39.27. foreign_data_wrappers

The view `foreign_data_wrappers` contains all foreign-data wrappers defined in the current database. Only those foreign-data wrappers are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.25. `foreign_data_wrappers` Columns

Column Type Description
`foreign_data_wrapper_catalog sql_identifier` Name of the database that contains the foreign-data wrapper (always the current database)
`foreign_data_wrapper_name sql_identifier` Name of the foreign-data wrapper
`authorization_identifier sql_identifier` Name of the owner of the foreign server
`library_name character_data` File name of the library that implementing this foreign-data wrapper
`foreign_data_wrapper_language character_data` Language used to implement this foreign-data wrapper

39.28. foreign_server_options

The view `foreign_server_options` contains all the options defined for foreign servers in the current database. Only those foreign servers are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.26. `foreign_server_options` Columns

Column Type Description
`foreign_server_catalog sql_identifier` Name of the database that the foreign server is defined in (always the current database)
`foreign_server_name sql_identifier` Name of the foreign server
`option_name sql_identifier` Name of an option
`option_value character_data` Value of the option

39.29. foreign_servers

The view `foreign_servers` contains all foreign servers defined in the current database. Only those foreign servers are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.27. `foreign_servers` Columns

Column Type Description
`foreign_server_catalog sql_identifier` Name of the database that the foreign server is defined in (always the current database)
`foreign_server_name sql_identifier` Name of the foreign server
`foreign_data_wrapper_catalog sql_identifier` Name of the database that contains the foreign-data wrapper used by the foreign server (always the current database)
`foreign_data_wrapper_name sql_identifier` Name of the foreign-data wrapper used by the foreign server
`foreign_server_type character_data` Foreign server type information, if specified upon creation
`foreign_server_version character_data` Foreign server version information, if specified upon creation
`authorization_identifier sql_identifier` Name of the owner of the foreign server

39.30. `foreign_table_options`

The view `foreign_table_options` contains all the options defined for foreign tables in the current database. Only those foreign tables are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.28. `foreign_table_options` Columns

Column Type Description
`foreign_table_catalog sql_identifier` Name of the database that contains the foreign table (always the current database)
`foreign_table_schema sql_identifier` Name of the schema that contains the foreign table
`foreign_table_name sql_identifier` Name of the foreign table
`option_name sql_identifier` Name of an option
`option_value character_data` Value of the option

39.31. `foreign_tables`

The view `foreign_tables` contains all foreign tables defined in the current database. Only those foreign tables are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.29. `foreign_tables` Columns

Column Type Description
`foreign_table_catalog sql_identifier` Name of the database that the foreign table is defined in (always the current database)
`foreign_table_schema sql_identifier` Name of the schema that contains the foreign table

Column Type Description
`foreign_table_name` `sql_identifier` Name of the foreign table
`foreign_server_catalog` `sql_identifier` Name of the database that the foreign server is defined in (always the current database)
`foreign_server_name` `sql_identifier` Name of the foreign server

39.32. key_column_usage

The view `key_column_usage` identifies all columns in the current database that are restricted by some unique, primary key, or foreign key constraint. Check constraints are not included in this view. Only those columns are shown that the current user has access to, by way of being the owner or having some privilege.

Table 39.30. `key_column_usage` Columns

Column Type Description
`constraint_catalog` `sql_identifier` Name of the database that contains the constraint (always the current database)
`constraint_schema` `sql_identifier` Name of the schema that contains the constraint
`constraint_name` `sql_identifier` Name of the constraint
`table_catalog` `sql_identifier` Name of the database that contains the table that contains the column that is restricted by this constraint (always the current database)
`table_schema` `sql_identifier` Name of the schema that contains the table that contains the column that is restricted by this constraint
`table_name` `sql_identifier` Name of the table that contains the column that is restricted by this constraint
`column_name` `sql_identifier` Name of the column that is restricted by this constraint
`ordinal_position` `cardinal_number` Ordinal position of the column within the constraint key (count starts at 1)
`position_in_unique_constraint` `cardinal_number` For a foreign-key constraint, ordinal position of the referenced column within its unique constraint (count starts at 1); otherwise null

39.33. parameters

The view `parameters` contains information about the parameters (arguments) of all functions in the current database. Only those functions are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.31. `parameters` Columns

Column Type Description
`specific_catalog` `sql_identifier` Name of the database containing the function (always the current database)

Column Type Description
`specific_schema` `sql_identifier` Name of the schema containing the function
`specific_name` `sql_identifier` The “specific name” of the function. See Section 39.45 for more information.
`ordinal_position` `cardinal_number` Ordinal position of the parameter in the argument list of the function (count starts at 1)
`parameter_mode` `character_data` `IN` for input parameter, `OUT` for output parameter, and `INOUT` for input/output parameter.
`is_result` `yes_or_no` Applies to a feature not available in Postgres Pro
`as_locator` `yes_or_no` Applies to a feature not available in Postgres Pro
`parameter_name` `sql_identifier` Name of the parameter, or null if the parameter has no name
`data_type` `character_data` Data type of the parameter, if it is a built-in type, or `ARRAY` if it is some array (in that case, see the view `element_types`), else `USER-DEFINED` (in that case, the type is identified in `udt_name` and associated columns).
`character_maximum_length` `cardinal_number` Always null, since this information is not applied to parameter data types in Postgres Pro
`character_octet_length` `cardinal_number` Always null, since this information is not applied to parameter data types in Postgres Pro
`character_set_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`collation_catalog` `sql_identifier` Always null, since this information is not applied to parameter data types in Postgres Pro
`collation_schema` `sql_identifier` Always null, since this information is not applied to parameter data types in Postgres Pro
`collation_name` `sql_identifier` Always null, since this information is not applied to parameter data types in Postgres Pro
`numeric_precision` `cardinal_number` Always null, since this information is not applied to parameter data types in Postgres Pro
`numeric_precision_radix` `cardinal_number` Always null, since this information is not applied to parameter data types in Postgres Pro
`numeric_scale` `cardinal_number` Always null, since this information is not applied to parameter data types in Postgres Pro
`datetime_precision` `cardinal_number` Always null, since this information is not applied to parameter data types in Postgres Pro
`interval_type` `character_data` Always null, since this information is not applied to parameter data types in Postgres Pro
`interval_precision` `cardinal_number` Always null, since this information is not applied to parameter data types in Postgres Pro

Column Type Description
udt_catalog sql_identifier Name of the database that the data type of the parameter is defined in (always the current database)
udt_schema sql_identifier Name of the schema that the data type of the parameter is defined in
udt_name sql_identifier Name of the data type of the parameter
scope_catalog sql_identifier Applies to a feature not available in Postgres Pro
scope_schema sql_identifier Applies to a feature not available in Postgres Pro
scope_name sql_identifier Applies to a feature not available in Postgres Pro
maximum_cardinality cardinal_number Always null, because arrays always have unlimited maximum cardinality in Postgres Pro
dtd_identifier sql_identifier An identifier of the data type descriptor of the parameter, unique among the data type descriptors pertaining to the function. This is mainly useful for joining with other instances of such identifiers. (The specific format of the identifier is not defined and not guaranteed to remain the same in future versions.)
parameter_default character_data The default expression of the parameter, or null if none or if the function is not owned by a currently enabled role.

39.34. referential_constraints

The view referential_constraints contains all referential (foreign key) constraints in the current database. Only those constraints are shown for which the current user has write access to the referencing table (by way of being the owner or having some privilege other than SELECT).

Table 39.32. referential_constraints Columns

Column Type Description
constraint_catalog sql_identifier Name of the database containing the constraint (always the current database)
constraint_schema sql_identifier Name of the schema containing the constraint
constraint_name sql_identifier Name of the constraint
unique_constraint_catalog sql_identifier Name of the database that contains the unique or primary key constraint that the foreign key constraint references (always the current database)
unique_constraint_schema sql_identifier Name of the schema that contains the unique or primary key constraint that the foreign key constraint references
unique_constraint_name sql_identifier Name of the unique or primary key constraint that the foreign key constraint references
match_option character_data Match option of the foreign key constraint: FULL, PARTIAL, or NONE.

Column Type Description
update_rule character_data Update rule of the foreign key constraint: CASCADE, SET NULL, SET DEFAULT, RESTRICT, or NO ACTION.
delete_rule character_data Delete rule of the foreign key constraint: CASCADE, SET NULL, SET DEFAULT, RESTRICT, or NO ACTION.

39.35. role_column_grants

The view role_column_grants identifies all privileges granted on columns where the grantor or grantee is a currently enabled role. Further information can be found under column_privileges. The only effective difference between this view and column_privileges is that this view omits columns that have been made accessible to the current user by way of a grant to PUBLIC.

Table 39.33. role_column_grants Columns

Column Type Description
grantor sql_identifier Name of the role that granted the privilege
grantee sql_identifier Name of the role that the privilege was granted to
table_catalog sql_identifier Name of the database that contains the table that contains the column (always the current database)
table_schema sql_identifier Name of the schema that contains the table that contains the column
table_name sql_identifier Name of the table that contains the column
column_name sql_identifier Name of the column
privilege_type character_data Type of the privilege: SELECT, INSERT, UPDATE, or REFERENCES
is_grantable yes_or_no YES if the privilege is grantable, NO if not

39.36. role_routine_grants

The view role_routine_grants identifies all privileges granted on functions where the grantor or grantee is a currently enabled role. Further information can be found under routine_privileges. The only effective difference between this view and routine_privileges is that this view omits functions that have been made accessible to the current user by way of a grant to PUBLIC.

Table 39.34. role_routine_grants Columns

Column Type Description
grantor sql_identifier Name of the role that granted the privilege
grantee sql_identifier Name of the role that the privilege was granted to
specific_catalog sql_identifier

Column Type Description
Name of the database containing the function (always the current database)
`specific_schema` `sql_identifier` Name of the schema containing the function
`specific_name` `sql_identifier` The “specific name” of the function. See Section 39.45 for more information.
`routine_catalog` `sql_identifier` Name of the database containing the function (always the current database)
`routine_schema` `sql_identifier` Name of the schema containing the function
`routine_name` `sql_identifier` Name of the function (might be duplicated in case of overloading)
`privilege_type` `character_data` Always `EXECUTE` (the only privilege type for functions)
`is_grantable` `yes_or_no` `YES` if the privilege is grantable, `NO` if not

39.37. `role_table_grants`

The view `role_table_grants` identifies all privileges granted on tables or views where the grantor or grantee is a currently enabled role. Further information can be found under `table_privileges`. The only effective difference between this view and `table_privileges` is that this view omits tables that have been made accessible to the current user by way of a grant to `PUBLIC`.

Table 39.35. `role_table_grants` Columns

Column Type Description
`grantor` `sql_identifier` Name of the role that granted the privilege
`grantee` `sql_identifier` Name of the role that the privilege was granted to
`table_catalog` `sql_identifier` Name of the database that contains the table (always the current database)
`table_schema` `sql_identifier` Name of the schema that contains the table
`table_name` `sql_identifier` Name of the table
`privilege_type` `character_data` Type of the privilege: `SELECT`, `INSERT`, `UPDATE`, `DELETE`, `TRUNCATE`, `REFERENCES`, or `TRIGGER`
`is_grantable` `yes_or_no` `YES` if the privilege is grantable, `NO` if not
`with_hierarchy` `yes_or_no` In the SQL standard, `WITH HIERARCHY OPTION` is a separate (sub-)privilege allowing certain operations on table inheritance hierarchies. In Postgres Pro, this is included in the `SELECT` privilege, so this column shows `YES` if the privilege is `SELECT`, else `NO`.

39.38. `role_udt_grants`

The view `role_udt_grants` is intended to identify `USAGE` privileges granted on user-defined types where the grantor or grantee is a currently enabled role. Further information can be found under `udt_priv-`

ileges. The only effective difference between this view and udt_privileges is that this view omits objects that have been made accessible to the current user by way of a grant to PUBLIC. Since data types do not have real privileges in Postgres Pro, but only an implicit grant to PUBLIC, this view is empty.

Table 39.36. role_udt_grants Columns

Column Type Description
grantor sql_identifier The name of the role that granted the privilege
grantee sql_identifier The name of the role that the privilege was granted to
udt_catalog sql_identifier Name of the database containing the type (always the current database)
udt_schema sql_identifier Name of the schema containing the type
udt_name sql_identifier Name of the type
privilege_type character_data Always TYPE USAGE
is_grantable yes_or_no YES if the privilege is grantable, NO if not

39.39. role_usage_grants

The view role_usage_grants identifies USAGE privileges granted on various kinds of objects where the grantor or grantee is a currently enabled role. Further information can be found under usage_privileges. The only effective difference between this view and usage_privileges is that this view omits objects that have been made accessible to the current user by way of a grant to PUBLIC.

Table 39.37. role_usage_grants Columns

Column Type Description
grantor sql_identifier The name of the role that granted the privilege
grantee sql_identifier The name of the role that the privilege was granted to
object_catalog sql_identifier Name of the database containing the object (always the current database)
object_schema sql_identifier Name of the schema containing the object, if applicable, else an empty string
object_name sql_identifier Name of the object
object_type character_data COLLATION or DOMAIN or FOREIGN DATA WRAPPER or FOREIGN SERVER or SEQUENCE
privilege_type character_data Always USAGE
is_grantable yes_or_no YES if the privilege is grantable, NO if not

39.40. routine_column_usage

The view routine_column_usage identifies all columns that are used by a function or procedure, either in the SQL body or in parameter default expressions. (This only works for unquoted SQL bodies, not quoted bodies or functions in other languages.) A column is only included if its table is owned by a currently enabled role.

Table 39.38. routine_column_usage **Columns**

Column Type Description
specific_catalog sql_identifier Name of the database containing the function (always the current database)
specific_schema sql_identifier Name of the schema containing the function
specific_name sql_identifier The “specific name” of the function. See Section 39.45 for more information.
routine_catalog sql_identifier Name of the database containing the function (always the current database)
routine_schema sql_identifier Name of the schema containing the function
routine_name sql_identifier Name of the function (might be duplicated in case of overloading)
table_catalog sql_identifier Name of the database that contains the table that is used by the function (always the current database)
table_schema sql_identifier Name of the schema that contains the table that is used by the function
table_name sql_identifier Name of the table that is used by the function
column_name sql_identifier Name of the column that is used by the function

39.41. routine_privileges

The view routine_privileges identifies all privileges granted on functions to a currently enabled role or by a currently enabled role. There is one row for each combination of function, grantor, and grantee.

Table 39.39. routine_privileges **Columns**

Column Type Description
grantor sql_identifier Name of the role that granted the privilege
grantee sql_identifier Name of the role that the privilege was granted to
specific_catalog sql_identifier Name of the database containing the function (always the current database)
specific_schema sql_identifier Name of the schema containing the function
specific_name sql_identifier The “specific name” of the function. See Section 39.45 for more information.
routine_catalog sql_identifier

Column Type Description
Name of the database containing the function (always the current database)
`routine_schema` `sql_identifier` Name of the schema containing the function
`routine_name` `sql_identifier` Name of the function (might be duplicated in case of overloading)
`privilege_type` `character_data` Always `EXECUTE` (the only privilege type for functions)
`is_grantable` `yes_or_no` `YES` if the privilege is grantable, `NO` if not

39.42. `routine_routine_usage`

The view `routine_routine_usage` identifies all functions or procedures that are used by another (or the same) function or procedure, either in the SQL body or in parameter default expressions. (This only works for unquoted SQL bodies, not quoted bodies or functions in other languages.) An entry is included here only if the used function is owned by a currently enabled role. (There is no such restriction on the using function.)

Note that the entries for both functions in the view refer to the "specific" name of the routine, even though the column names are used in a way that is inconsistent with other information schema views about routines. This is per SQL standard, although it is arguably a misdesign. See Section 39.45 for more information about specific names.

Table 39.40. `routine_routine_usage` **Columns**

Column Type Description
`specific_catalog` `sql_identifier` Name of the database containing the using function (always the current database)
`specific_schema` `sql_identifier` Name of the schema containing the using function
`specific_name` `sql_identifier` The "specific name" of the using function.
`routine_catalog` `sql_identifier` Name of the database that contains the function that is used by the first function (always the current database)
`routine_schema` `sql_identifier` Name of the schema that contains the function that is used by the first function
`routine_name` `sql_identifier` The "specific name" of the function that is used by the first function.

39.43. `routine_sequence_usage`

The view `routine_sequence_usage` identifies all sequences that are used by a function or procedure, either in the SQL body or in parameter default expressions. (This only works for unquoted SQL bodies, not quoted bodies or functions in other languages.) A sequence is only included if that sequence is owned by a currently enabled role.

Table 39.41. `routine_sequence_usage` **Columns**

Column Type Description
`specific_catalog` `sql_identifier`

Column Type Description
Name of the database containing the function (always the current database)
`specific_schema` `sql_identifier` Name of the schema containing the function
`specific_name` `sql_identifier` The “specific name” of the function. See Section 39.45 for more information.
`routine_catalog` `sql_identifier` Name of the database containing the function (always the current database)
`routine_schema` `sql_identifier` Name of the schema containing the function
`routine_name` `sql_identifier` Name of the function (might be duplicated in case of overloading)
`schema_catalog` `sql_identifier` Name of the database that contains the sequence that is used by the function (always the current database)
`sequence_schema` `sql_identifier` Name of the schema that contains the sequence that is used by the function
`sequence_name` `sql_identifier` Name of the sequence that is used by the function

39.44. `routine_table_usage`

The view `routine_table_usage` is meant to identify all tables that are used by a function or procedure. This information is currently not tracked by PostgreSQL.

Table 39.42. `routine_table_usage` **Columns**

Column Type Description
`specific_catalog` `sql_identifier` Name of the database containing the function (always the current database)
`specific_schema` `sql_identifier` Name of the schema containing the function
`specific_name` `sql_identifier` The “specific name” of the function. See Section 39.45 for more information.
`routine_catalog` `sql_identifier` Name of the database containing the function (always the current database)
`routine_schema` `sql_identifier` Name of the schema containing the function
`routine_name` `sql_identifier` Name of the function (might be duplicated in case of overloading)
`table_catalog` `sql_identifier` Name of the database that contains the table that is used by the function (always the current database)
`table_schema` `sql_identifier` Name of the schema that contains the table that is used by the function
`table_name` `sql_identifier` Name of the table that is used by the function

39.45. routines

The view routines contains all functions and procedures in the current database. Only those functions and procedures are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.43. routines Columns

Column Type Description
specific_catalog sql_identifier Name of the database containing the function (always the current database)
specific_schema sql_identifier Name of the schema containing the function
specific_name sql_identifier The “specific name” of the function. This is a name that uniquely identifies the function in the schema, even if the real name of the function is overloaded. The format of the specific name is not defined, it should only be used to compare it to other instances of specific routine names.
routine_catalog sql_identifier Name of the database containing the function (always the current database)
routine_schema sql_identifier Name of the schema containing the function
routine_name sql_identifier Name of the function (might be duplicated in case of overloading)
routine_type character_data FUNCTION for a function, PROCEDURE for a procedure
module_catalog sql_identifier Applies to a feature not available in Postgres Pro
module_schema sql_identifier Applies to a feature not available in Postgres Pro
module_name sql_identifier Applies to a feature not available in Postgres Pro
udt_catalog sql_identifier Applies to a feature not available in Postgres Pro
udt_schema sql_identifier Applies to a feature not available in Postgres Pro
udt_name sql_identifier Applies to a feature not available in Postgres Pro
data_type character_data Return data type of the function, if it is a built-in type, or ARRAY if it is some array (in that case, see the view element_types), else USER-DEFINED (in that case, the type is identified in type_udt_name and associated columns). Null for a procedure.
character_maximum_length cardinal_number Always null, since this information is not applied to return data types in Postgres Pro
character_octet_length cardinal_number Always null, since this information is not applied to return data types in Postgres Pro
character_set_catalog sql_identifier Applies to a feature not available in Postgres Pro
character_set_schema sql_identifier Applies to a feature not available in Postgres Pro

Column Type Description
`character_set_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`collation_catalog` `sql_identifier` Always null, since this information is not applied to return data types in Postgres Pro
`collation_schema` `sql_identifier` Always null, since this information is not applied to return data types in Postgres Pro
`collation_name` `sql_identifier` Always null, since this information is not applied to return data types in Postgres Pro
`numeric_precision` `cardinal_number` Always null, since this information is not applied to return data types in Postgres Pro
`numeric_precision_radix` `cardinal_number` Always null, since this information is not applied to return data types in Postgres Pro
`numeric_scale` `cardinal_number` Always null, since this information is not applied to return data types in Postgres Pro
`datetime_precision` `cardinal_number` Always null, since this information is not applied to return data types in Postgres Pro
`interval_type` `character_data` Always null, since this information is not applied to return data types in Postgres Pro
`interval_precision` `cardinal_number` Always null, since this information is not applied to return data types in Postgres Pro
`type_udt_catalog` `sql_identifier` Name of the database that the return data type of the function is defined in (always the current database). Null for a procedure.
`type_udt_schema` `sql_identifier` Name of the schema that the return data type of the function is defined in. Null for a procedure.
`type_udt_name` `sql_identifier` Name of the return data type of the function. Null for a procedure.
`scope_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`scope_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`scope_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`maximum_cardinality` `cardinal_number` Always null, because arrays always have unlimited maximum cardinality in Postgres Pro
`dtd_identifier` `sql_identifier` An identifier of the data type descriptor of the return data type of this function, unique among the data type descriptors pertaining to the function. This is mainly useful for joining with other instances of such identifiers. (The specific format of the identifier is not defined and not guaranteed to remain the same in future versions.)
`routine_body` `character_data` If the function is an SQL function, then `SQL`, else `EXTERNAL`.
`routine_definition` `character_data` The source text of the function (null if the function is not owned by a currently enabled role). (According to the SQL standard, this column is only applicable if `routine_body` is `SQL`, but in

Column Type **Description**
Postgres Pro it will contain whatever source text was specified when the function was created.)
`external_name character_data` If this function is a C function, then the external name (link symbol) of the function; else null. (This works out to be the same value that is shown in `routine_definition` .)
`external_language character_data` The language the function is written in
`parameter_style character_data` Always `GENERAL` (The SQL standard defines other parameter styles, which are not available in Postgres Pro.)
`is_deterministic yes_or_no` If the function is declared immutable (called deterministic in the SQL standard), then `YES`, else `NO`. (You cannot query the other volatility levels available in Postgres Pro through the information schema.)
`sql_data_access character_data` Always `MODIFIES`, meaning that the function possibly modifies SQL data. This information is not useful for Postgres Pro.
`is_null_call yes_or_no` If the function automatically returns null if any of its arguments are null, then `YES`, else `NO`. Null for a procedure.
`sql_path character_data` Applies to a feature not available in Postgres Pro
`schema_level_routine yes_or_no` Always `YES` (The opposite would be a method of a user-defined type, which is a feature not available in Postgres Pro.)
`max_dynamic_result_sets cardinal_number` Applies to a feature not available in Postgres Pro
`is_user_defined_cast yes_or_no` Applies to a feature not available in Postgres Pro
`is_implicitly_invocable yes_or_no` Applies to a feature not available in Postgres Pro
`security_type character_data` If the function runs with the privileges of the current user, then `INVOKER`, if the function runs with the privileges of the user who defined it, then `DEFINER`.
`to_sql_specific_catalog sql_identifier` Applies to a feature not available in Postgres Pro
`to_sql_specific_schema sql_identifier` Applies to a feature not available in Postgres Pro
`to_sql_specific_name sql_identifier` Applies to a feature not available in Postgres Pro
`as_locator yes_or_no` Applies to a feature not available in Postgres Pro
`created time_stamp` Applies to a feature not available in Postgres Pro
`last_altered time_stamp` Applies to a feature not available in Postgres Pro
`new_savepoint_level yes_or_no`

Column Type **Description**
Applies to a feature not available in Postgres Pro
`is_udt_dependent` `yes_or_no` Currently always `NO`. The alternative `YES` applies to a feature not available in Postgres Pro.
`result_cast_from_data_type` `character_data` Applies to a feature not available in Postgres Pro
`result_cast_as_locator` `yes_or_no` Applies to a feature not available in Postgres Pro
`result_cast_char_max_length` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_char_octet_length` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_char_set_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_char_set_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_char_set_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_collation_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_collation_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_collation_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_numeric_precision` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_numeric_precision_radix` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_numeric_scale` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_datetime_precision` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_interval_type` `character_data` Applies to a feature not available in Postgres Pro
`result_cast_interval_precision` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_type_udt_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_type_udt_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_type_udt_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_scope_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_scope_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`result_cast_scope_name` `sql_identifier`

Column Type Description
Applies to a feature not available in Postgres Pro
`result_cast_maximum_cardinality` `cardinal_number` Applies to a feature not available in Postgres Pro
`result_cast_dtd_identifier` `sql_identifier` Applies to a feature not available in Postgres Pro

39.46. schemata

The view `schemata` contains all schemas in the current database that the current user has access to (by way of being the owner or having some privilege).

Table 39.44. `schemata` Columns

Column Type Description
`catalog_name` `sql_identifier` Name of the database that the schema is contained in (always the current database)
`schema_name` `sql_identifier` Name of the schema
`schema_owner` `sql_identifier` Name of the owner of the schema
`default_character_set_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`default_character_set_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`default_character_set_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`sql_path` `character_data` Applies to a feature not available in Postgres Pro

39.47. sequences

The view `sequences` contains all sequences defined in the current database. Only those sequences are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.45. `sequences` Columns

Column Type Description
`sequence_catalog` `sql_identifier` Name of the database that contains the sequence (always the current database)
`sequence_schema` `sql_identifier` Name of the schema that contains the sequence
`sequence_name` `sql_identifier` Name of the sequence
`data_type` `character_data` The data type of the sequence.
`numeric_precision` `cardinal_number` This column contains the (declared or implicit) precision of the sequence data type (see above). The precision indicates the number of significant digits. It can be expressed in dec-

Column Type Description
imal (base 10) or binary (base 2) terms, as specified in the column numeric_precision_radix.
numeric_precision_radix cardinal_number This column indicates in which base the values in the columns numeric_precision and numeric_scale are expressed. The value is either 2 or 10.
numeric_scale cardinal_number This column contains the (declared or implicit) scale of the sequence data type (see above). The scale indicates the number of significant digits to the right of the decimal point. It can be expressed in decimal (base 10) or binary (base 2) terms, as specified in the column numeric_precision_radix .
start_value character_data The start value of the sequence
minimum_value character_data The minimum value of the sequence
maximum_value character_data The maximum value of the sequence
increment character_data The increment of the sequence
cycle_option yes_or_no YES if the sequence cycles, else NO

Note that in accordance with the SQL standard, the start, minimum, maximum, and increment values are returned as character strings.

39.48. sql_features

The table sql_features contains information about which formal features defined in the SQL standard are supported by Postgres Pro. This is the same information that is presented in Appendix D. There you can also find some additional background information.

Table 39.46. sql_features Columns

Column Type Description
feature_id character_data Identifier string of the feature
feature_name character_data Descriptive name of the feature
sub_feature_id character_data Identifier string of the subfeature, or a zero-length string if not a subfeature
sub_feature_name character_data Descriptive name of the subfeature, or a zero-length string if not a subfeature
is_supported yes_or_no YES if the feature is fully supported by the current version of Postgres Pro, NO if not
is_verified_by character_data Always null, since the Postgres Pro development group does not perform formal testing of feature conformance
comments character_data Possibly a comment about the supported status of the feature

39.49. sql_implementation_info

The table sql_implementation_info contains information about various aspects that are left implementation-defined by the SQL standard. This information is primarily intended for use in the context of the ODBC interface; users of other interfaces will probably find this information to be of little use. For this reason, the individual implementation information items are not described here; you will find them in the description of the ODBC interface.

Table 39.47. sql_implementation_info Columns

Column Type Description
implementation_info_id character_data Identifier string of the implementation information item
implementation_info_name character_data Descriptive name of the implementation information item
integer_value cardinal_number Value of the implementation information item, or null if the value is contained in the column character_value
character_value character_data Value of the implementation information item, or null if the value is contained in the column integer_value
comments character_data Possibly a comment pertaining to the implementation information item

39.50. sql_parts

The table sql_parts contains information about which of the several parts of the SQL standard are supported by Postgres Pro.

Table 39.48. sql_parts Columns

Column Type Description
feature_id character_data An identifier string containing the number of the part
feature_name character_data Descriptive name of the part
is_supported yes_or_no YES if the part is fully supported by the current version of Postgres Pro, NO if not
is_verified_by character_data Always null, since the Postgres Pro development group does not perform formal testing of feature conformance
comments character_data Possibly a comment about the supported status of the part

39.51. sql_sizing

The table sql_sizing contains information about various size limits and maximum values in Postgres Pro. This information is primarily intended for use in the context of the ODBC interface; users of other interfaces will probably find this information to be of little use. For this reason, the individual sizing items are not described here; you will find them in the description of the ODBC interface.

Table 39.49. `sql_sizing` Columns

Column Type Description
`sizing_id cardinal_number` Identifier of the sizing item
`sizing_name character_data` Descriptive name of the sizing item
`supported_value cardinal_number` Value of the sizing item, or 0 if the size is unlimited or cannot be determined, or null if the features for which the sizing item is applicable are not supported
`comments character_data` Possibly a comment pertaining to the sizing item

39.52. table_constraints

The view `table_constraints` contains all constraints belonging to tables that the current user owns or has some privilege other than `SELECT` on.

Table 39.50. `table_constraints` Columns

Column Type Description
`constraint_catalog sql_identifier` Name of the database that contains the constraint (always the current database)
`constraint_schema sql_identifier` Name of the schema that contains the constraint
`constraint_name sql_identifier` Name of the constraint
`table_catalog sql_identifier` Name of the database that contains the table (always the current database)
`table_schema sql_identifier` Name of the schema that contains the table
`table_name sql_identifier` Name of the table
`constraint_type character_data` Type of the constraint: `CHECK`, `FOREIGN KEY`, `PRIMARY KEY`, or `UNIQUE`
`is_deferrable yes_or_no` `YES` if the constraint is deferrable, `NO` if not
`initially_deferred yes_or_no` `YES` if the constraint is deferrable and initially deferred, `NO` if not
`enforced yes_or_no` Applies to a feature not available in Postgres Pro (currently always `YES`)

39.53. table_privileges

The view `table_privileges` identifies all privileges granted on tables or views to a currently enabled role or by a currently enabled role. There is one row for each combination of table, grantor, and grantee.

Table 39.51. `table_privileges` Columns

Column Type Description
`grantor sql_identifier`

Column Type Description
Name of the role that granted the privilege
grantee sql_identifier Name of the role that the privilege was granted to
table_catalog sql_identifier Name of the database that contains the table (always the current database)
table_schema sql_identifier Name of the schema that contains the table
table_name sql_identifier Name of the table
privilege_type character_data Type of the privilege: SELECT, INSERT, UPDATE, DELETE, TRUNCATE, REFERENCES, or TRIGGER
is_grantable yes_or_no YES if the privilege is grantable, NO if not
with_hierarchy yes_or_no In the SQL standard, WITH HIERARCHY OPTION is a separate (sub-)privilege allowing certain operations on table inheritance hierarchies. In Postgres Pro, this is included in the SELECT privilege, so this column shows YES if the privilege is SELECT, else NO.

39.54. tables

The view tables contains all tables and views defined in the current database. Only those tables and views are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.52. tables Columns

Column Type Description
table_catalog sql_identifier Name of the database that contains the table (always the current database)
table_schema sql_identifier Name of the schema that contains the table
table_name sql_identifier Name of the table
table_type character_data Type of the table: BASE TABLE for a persistent base table (the normal table type), VIEW for a view, FOREIGN for a foreign table, or LOCAL TEMPORARY for a temporary table
self_referencing_column_name sql_identifier Applies to a feature not available in Postgres Pro
reference_generation character_data Applies to a feature not available in Postgres Pro
user_defined_type_catalog sql_identifier If the table is a typed table, the name of the database that contains the underlying data type (always the current database), else null.
user_defined_type_schema sql_identifier If the table is a typed table, the name of the schema that contains the underlying data type, else null.
user_defined_type_name sql_identifier If the table is a typed table, the name of the underlying data type, else null.
is_insertable_into yes_or_no

Column Type Description
YES if the table is insertable into, NO if not (Base tables are always insertable into, views not necessarily.)
is_typed yes_or_no YES if the table is a typed table, NO if not
commit_action character_data Not yet implemented

39.55. transforms

The view transforms contains information about the transforms defined in the current database. More precisely, it contains a row for each function contained in a transform (the "from SQL" or "to SQL" function).

Table 39.53. transforms Columns

Column Type Description
udt_catalog sql_identifier Name of the database that contains the type the transform is for (always the current database)
udt_schema sql_identifier Name of the schema that contains the type the transform is for
udt_name sql_identifier Name of the type the transform is for
specific_catalog sql_identifier Name of the database containing the function (always the current database)
specific_schema sql_identifier Name of the schema containing the function
specific_name sql_identifier The "specific name" of the function. See Section 39.45 for more information.
group_name sql_identifier The SQL standard allows defining transforms in "groups", and selecting a group at run time. Postgres Pro does not support this. Instead, transforms are specific to a language. As a compromise, this field contains the language the transform is for.
transform_type character_data FROM SQL or TO SQL

39.56. triggered_update_columns

For triggers in the current database that specify a column list (like UPDATE OF column1, column2), the view triggered_update_columns identifies these columns. Triggers that do not specify a column list are not included in this view. Only those columns are shown that the current user owns or has some privilege other than SELECT on.

Table 39.54. triggered_update_columns Columns

Column Type Description
trigger_catalog sql_identifier Name of the database that contains the trigger (always the current database)
trigger_schema sql_identifier Name of the schema that contains the trigger

Column Type Description
`trigger_name sql_identifier` Name of the trigger
`event_object_catalog sql_identifier` Name of the database that contains the table that the trigger is defined on (always the current database)
`event_object_schema sql_identifier` Name of the schema that contains the table that the trigger is defined on
`event_object_table sql_identifier` Name of the table that the trigger is defined on
`event_object_column sql_identifier` Name of the column that the trigger is defined on

39.57. `triggers`

The view `triggers` contains all triggers defined in the current database on tables and views that the current user owns or has some privilege other than `SELECT` on.

Table 39.55. `triggers` Columns

Column Type Description
`trigger_catalog sql_identifier` Name of the database that contains the trigger (always the current database)
`trigger_schema sql_identifier` Name of the schema that contains the trigger
`trigger_name sql_identifier` Name of the trigger
`event_manipulation character_data` Event that fires the trigger (`INSERT`, `UPDATE`, or `DELETE`)
`event_object_catalog sql_identifier` Name of the database that contains the table that the trigger is defined on (always the current database)
`event_object_schema sql_identifier` Name of the schema that contains the table that the trigger is defined on
`event_object_table sql_identifier` Name of the table that the trigger is defined on
`action_order cardinal_number` Firing order among triggers on the same table having the same `event_manipulation` , `action_timing` , and `action_orientation` . In Postgres Pro, triggers are fired in name order, so this column reflects that.
`action_condition character_data` `WHEN` condition of the trigger, null if none (also null if the table is not owned by a currently enabled role)
`action_statement character_data` Statement that is executed by the trigger (currently always `EXECUTE FUNCTION` *function*`(...)`)
`action_orientation character_data` Identifies whether the trigger fires once for each processed row or once for each statement (`ROW` or `STATEMENT`)

Column Type Description
action_timing character_data Time at which the trigger fires (BEFORE, AFTER, or INSTEAD OF)
action_reference_old_table sql_identifier Name of the “old” transition table, or null if none
action_reference_new_table sql_identifier Name of the “new” transition table, or null if none
action_reference_old_row sql_identifier Applies to a feature not available in Postgres Pro
action_reference_new_row sql_identifier Applies to a feature not available in Postgres Pro
created time_stamp Applies to a feature not available in Postgres Pro

Triggers in Postgres Pro have two incompatibilities with the SQL standard that affect the representation in the information schema. First, trigger names are local to each table in Postgres Pro, rather than being independent schema objects. Therefore there can be duplicate trigger names defined in one schema, so long as they belong to different tables. (trigger_catalog and trigger_schema are really the values pertaining to the table that the trigger is defined on.) Second, triggers can be defined to fire on multiple events in Postgres Pro (e.g., ON INSERT OR UPDATE), whereas the SQL standard only allows one. If a trigger is defined to fire on multiple events, it is represented as multiple rows in the information schema, one for each type of event. As a consequence of these two issues, the primary key of the view triggers is really (trigger_catalog, trigger_schema, event_object_table, trigger_name, event_manipulation) instead of (trigger_catalog, trigger_schema, trigger_name), which is what the SQL standard specifies. Nonetheless, if you define your triggers in a manner that conforms with the SQL standard (trigger names unique in the schema and only one event type per trigger), this will not affect you.

> **Note**
>
> Prior to PostgreSQL 9.1, this view's columns action_timing, action_reference_old_table, action_reference_new_table, action_reference_old_row, and action_reference_new_row were named condition_timing, condition_reference_old_table, condition_reference_new_table, condition_reference_old_row, and condition_reference_new_row respectively. That was how they were named in the SQL:1999 standard. The new naming conforms to SQL:2003 and later.

39.58. udt_privileges

The view udt_privileges identifies USAGE privileges granted on user-defined types to a currently enabled role or by a currently enabled role. There is one row for each combination of type, grantor, and grantee. This view shows only composite types (see under Section 39.60 for why); see Section 39.59 for domain privileges.

Table 39.56. udt_privileges Columns

Column Type Description
grantor sql_identifier Name of the role that granted the privilege
grantee sql_identifier Name of the role that the privilege was granted to
udt_catalog sql_identifier

Column Type Description
Name of the database containing the type (always the current database)
udt_schema sql_identifier Name of the schema containing the type
udt_name sql_identifier Name of the type
privilege_type character_data Always TYPE USAGE
is_grantable yes_or_no YES if the privilege is grantable, NO if not

39.59. usage_privileges

The view usage_privileges identifies USAGE privileges granted on various kinds of objects to a currently enabled role or by a currently enabled role. In Postgres Pro, this currently applies to collations, domains, foreign-data wrappers, foreign servers, and sequences. There is one row for each combination of object, grantor, and grantee.

Since collations do not have real privileges in Postgres Pro, this view shows implicit non-grantable USAGE privileges granted by the owner to PUBLIC for all collations. The other object types, however, show real privileges.

In Postgres Pro, sequences also support SELECT and UPDATE privileges in addition to the USAGE privilege. These are nonstandard and therefore not visible in the information schema.

Table 39.57. usage_privileges Columns

Column Type Description
grantor sql_identifier Name of the role that granted the privilege
grantee sql_identifier Name of the role that the privilege was granted to
object_catalog sql_identifier Name of the database containing the object (always the current database)
object_schema sql_identifier Name of the schema containing the object, if applicable, else an empty string
object_name sql_identifier Name of the object
object_type character_data COLLATION or DOMAIN or FOREIGN DATA WRAPPER or FOREIGN SERVER or SEQUENCE
privilege_type character_data Always USAGE
is_grantable yes_or_no YES if the privilege is grantable, NO if not

39.60. user_defined_types

The view user_defined_types currently contains all composite types defined in the current database. Only those types are shown that the current user has access to (by way of being the owner or having some privilege).

SQL knows about two kinds of user-defined types: structured types (also known as composite types in Postgres Pro) and distinct types (not implemented in Postgres Pro). To be future-proof, use the column `user_defined_type_category` to differentiate between these. Other user-defined types such as base types and enums, which are Postgres Pro extensions, are not shown here. For domains, see Section 39.23 instead.

Table 39.58. `user_defined_types` Columns

Column Type Description
`user_defined_type_catalog` `sql_identifier` Name of the database that contains the type (always the current database)
`user_defined_type_schema` `sql_identifier` Name of the schema that contains the type
`user_defined_type_name` `sql_identifier` Name of the type
`user_defined_type_category` `character_data` Currently always `STRUCTURED`
`is_instantiable` `yes_or_no` Applies to a feature not available in Postgres Pro
`is_final` `yes_or_no` Applies to a feature not available in Postgres Pro
`ordering_form` `character_data` Applies to a feature not available in Postgres Pro
`ordering_category` `character_data` Applies to a feature not available in Postgres Pro
`ordering_routine_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`ordering_routine_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`ordering_routine_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`reference_type` `character_data` Applies to a feature not available in Postgres Pro
`data_type` `character_data` Applies to a feature not available in Postgres Pro
`character_maximum_length` `cardinal_number` Applies to a feature not available in Postgres Pro
`character_octet_length` `cardinal_number` Applies to a feature not available in Postgres Pro
`character_set_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_schema` `sql_identifier` Applies to a feature not available in Postgres Pro
`character_set_name` `sql_identifier` Applies to a feature not available in Postgres Pro
`collation_catalog` `sql_identifier` Applies to a feature not available in Postgres Pro
`collation_schema` `sql_identifier` Applies to a feature not available in Postgres Pro

Column Type Description
`collation_name sql_identifier` Applies to a feature not available in Postgres Pro
`numeric_precision cardinal_number` Applies to a feature not available in Postgres Pro
`numeric_precision_radix cardinal_number` Applies to a feature not available in Postgres Pro
`numeric_scale cardinal_number` Applies to a feature not available in Postgres Pro
`datetime_precision cardinal_number` Applies to a feature not available in Postgres Pro
`interval_type character_data` Applies to a feature not available in Postgres Pro
`interval_precision cardinal_number` Applies to a feature not available in Postgres Pro
`source_dtd_identifier sql_identifier` Applies to a feature not available in Postgres Pro
`ref_dtd_identifier sql_identifier` Applies to a feature not available in Postgres Pro

39.61. user_mapping_options

The view `user_mapping_options` contains all the options defined for user mappings in the current database. Only those user mappings are shown where the current user has access to the corresponding foreign server (by way of being the owner or having some privilege).

Table 39.59. `user_mapping_options` Columns

Column Type Description
`authorization_identifier sql_identifier` Name of the user being mapped, or `PUBLIC` if the mapping is public
`foreign_server_catalog sql_identifier` Name of the database that the foreign server used by this mapping is defined in (always the current database)
`foreign_server_name sql_identifier` Name of the foreign server used by this mapping
`option_name sql_identifier` Name of an option
`option_value character_data` Value of the option. This column will show as null unless the current user is the user being mapped, or the mapping is for `PUBLIC` and the current user is the server owner, or the current user is a superuser. The intent is to protect password information stored as user mapping option.

39.62. user_mappings

The view `user_mappings` contains all user mappings defined in the current database. Only those user mappings are shown where the current user has access to the corresponding foreign server (by way of being the owner or having some privilege).

Table 39.60. `user_mappings` Columns

Column Type Description
`authorization_identifier sql_identifier` Name of the user being mapped, or `PUBLIC` if the mapping is public
`foreign_server_catalog sql_identifier` Name of the database that the foreign server used by this mapping is defined in (always the current database)
`foreign_server_name sql_identifier` Name of the foreign server used by this mapping

39.63. view_column_usage

The view `view_column_usage` identifies all columns that are used in the query expression of a view (the `SELECT` statement that defines the view). A column is only included if the table that contains the column is owned by a currently enabled role.

> **Note**
>
> Columns of system tables are not included. This should be fixed sometime.

Table 39.61. `view_column_usage` Columns

Column Type Description
`view_catalog sql_identifier` Name of the database that contains the view (always the current database)
`view_schema sql_identifier` Name of the schema that contains the view
`view_name sql_identifier` Name of the view
`table_catalog sql_identifier` Name of the database that contains the table that contains the column that is used by the view (always the current database)
`table_schema sql_identifier` Name of the schema that contains the table that contains the column that is used by the view
`table_name sql_identifier` Name of the table that contains the column that is used by the view
`column_name sql_identifier` Name of the column that is used by the view

39.64. view_routine_usage

The view `view_routine_usage` identifies all routines (functions and procedures) that are used in the query expression of a view (the `SELECT` statement that defines the view). A routine is only included if that routine is owned by a currently enabled role.

Table 39.62. `view_routine_usage` Columns

Column Type Description
`table_catalog sql_identifier`

Column Type Description
Name of the database containing the view (always the current database)
`table_schema sql_identifier` Name of the schema containing the view
`table_name sql_identifier` Name of the view
`specific_catalog sql_identifier` Name of the database containing the function (always the current database)
`specific_schema sql_identifier` Name of the schema containing the function
`specific_name sql_identifier` The “specific name” of the function. See Section 39.45 for more information.

39.65. `view_table_usage`

The view `view_table_usage` identifies all tables that are used in the query expression of a view (the `SELECT` statement that defines the view). A table is only included if that table is owned by a currently enabled role.

> **Note**
>
> System tables are not included. This should be fixed sometime.

Table 39.63. `view_table_usage` Columns

Column Type Description
`view_catalog sql_identifier` Name of the database that contains the view (always the current database)
`view_schema sql_identifier` Name of the schema that contains the view
`view_name sql_identifier` Name of the view
`table_catalog sql_identifier` Name of the database that contains the table that is used by the view (always the current database)
`table_schema sql_identifier` Name of the schema that contains the table that is used by the view
`table_name sql_identifier` Name of the table that is used by the view

39.66. `views`

The view `views` contains all views defined in the current database. Only those views are shown that the current user has access to (by way of being the owner or having some privilege).

Table 39.64. `views` Columns

Column Type Description
`table_catalog sql_identifier`

Column Type **Description**
Name of the database that contains the view (always the current database)
`table_schema sql_identifier` Name of the schema that contains the view
`table_name sql_identifier` Name of the view
`view_definition character_data` Query expression defining the view (null if the view is not owned by a currently enabled role)
`check_option character_data` `CASCADED` or `LOCAL` if the view has a `CHECK OPTION` defined on it, `NONE` if not
`is_updatable yes_or_no` `YES` if the view is updatable (allows `UPDATE` and `DELETE`), `NO` if not
`is_insertable_into yes_or_no` `YES` if the view is insertable into (allows `INSERT`), `NO` if not
`is_trigger_updatable yes_or_no` `YES` if the view has an `INSTEAD OF UPDATE` trigger defined on it, `NO` if not
`is_trigger_deletable yes_or_no` `YES` if the view has an `INSTEAD OF DELETE` trigger defined on it, `NO` if not
`is_trigger_insertable_into yes_or_no` `YES` if the view has an `INSTEAD OF INSERT` trigger defined on it, `NO` if not

Part V. Server Programming

This part is about extending the server functionality with user-defined functions, data types, triggers, etc. These are advanced topics which should probably be approached only after all the other user documentation about Postgres Pro has been understood. Later chapters in this part describe the server-side programming languages available in the Postgres Pro distribution as well as general issues concerning server-side programming languages. It is essential to read at least the earlier sections of Chapter 40 (covering functions) before diving into the material about server-side programming languages.

Chapter 40. Extending SQL

In the sections that follow, we will discuss how you can extend the Postgres Pro SQL query language by adding:

- functions (starting in Section 40.3)
- aggregates (starting in Section 40.12)
- data types (starting in Section 40.13)
- operators (starting in Section 40.14)
- operator classes for indexes (starting in Section 40.16)
- packages of related objects (starting in Section 40.17)

40.1. How Extensibility Works

Postgres Pro is extensible because its operation is catalog-driven. If you are familiar with standard relational database systems, you know that they store information about databases, tables, columns, etc., in what are commonly known as system catalogs. (Some systems call this the data dictionary.) The catalogs appear to the user as tables like any other, but the DBMS stores its internal bookkeeping in them. One key difference between Postgres Pro and standard relational database systems is that Postgres Pro stores much more information in its catalogs: not only information about tables and columns, but also information about data types, functions, access methods, and so on. These tables can be modified by the user, and since Postgres Pro bases its operation on these tables, this means that Postgres Pro can be extended by users. By comparison, conventional database systems can only be extended by changing hardcoded procedures in the source code or by loading modules specially written by the DBMS vendor.

The Postgres Pro server can moreover incorporate user-written code into itself through dynamic loading. That is, the user can specify an object code file (e.g., a shared library) that implements a new type or function, and Postgres Pro will load it as required. Code written in SQL is even more trivial to add to the server. This ability to modify its operation “on the fly” makes Postgres Pro uniquely suited for rapid prototyping of new applications and storage structures.

40.2. The Postgres Pro Type System

Postgres Pro data types can be divided into base types, container types, domains, and pseudo-types.

40.2.1. Base Types

Base types are those, like `integer`, that are implemented below the level of the SQL language (typically in a low-level language such as C). They generally correspond to what are often known as abstract data types. Postgres Pro can only operate on such types through functions provided by the user and only understands the behavior of such types to the extent that the user describes them. The built-in base types are described in Chapter 8.

Enumerated (enum) types can be considered as a subcategory of base types. The main difference is that they can be created using just SQL commands, without any low-level programming. Refer to Section 8.7 for more information.

40.2.2. Container Types

Postgres Pro has three kinds of “container” types, which are types that contain multiple values of other types. These are arrays, composites, and ranges.

Arrays can hold multiple values that are all of the same type. An array type is automatically created for each base type, composite type, range type, and domain type. But there are no arrays of arrays. So far as the type system is concerned, multi-dimensional arrays are the same as one-dimensional arrays. Refer to Section 8.15 for more information.

Composite types, or row types, are created whenever the user creates a table. It is also possible to use CREATE TYPE to define a “stand-alone” composite type with no associated table. A composite type is

simply a list of types with associated field names. A value of a composite type is a row or record of field values. Refer to Section 8.16 for more information.

A range type can hold two values of the same type, which are the lower and upper bounds of the range. Range types are user-created, although a few built-in ones exist. Refer to Section 8.17 for more information.

40.2.3. Domains

A domain is based on a particular underlying type and for many purposes is interchangeable with its underlying type. However, a domain can have constraints that restrict its valid values to a subset of what the underlying type would allow. Domains are created using the SQL command CREATE DOMAIN. Refer to Section 8.18 for more information.

40.2.4. Pseudo-Types

There are a few "pseudo-types" for special purposes. Pseudo-types cannot appear as columns of tables or components of container types, but they can be used to declare the argument and result types of functions. This provides a mechanism within the type system to identify special classes of functions. Table 8.27 lists the existing pseudo-types.

40.2.5. Polymorphic Types

Some pseudo-types of special interest are the *polymorphic types*, which are used to declare *polymorphic functions*. This powerful feature allows a single function definition to operate on many different data types, with the specific data type(s) being determined by the data types actually passed to it in a particular call. The polymorphic types are shown in Table 40.1. Some examples of their use appear in Section 40.5.11.

Table 40.1. Polymorphic Types

Name	Family	Description
`anyelement`	Simple	Indicates that a function accepts any data type
`anyarray`	Simple	Indicates that a function accepts any array data type
`anynonarray`	Simple	Indicates that a function accepts any non-array data type
`anyenum`	Simple	Indicates that a function accepts any enum data type (see Section 8.7)
`anyrange`	Simple	Indicates that a function accepts any range data type (see Section 8.17)
`anymultirange`	Simple	Indicates that a function accepts any multirange data type (see Section 8.17)
`anycompatible`	Common	Indicates that a function accepts any data type, with automatic promotion of multiple arguments to a common data type
`anycompatiblearray`	Common	Indicates that a function accepts any array data type, with automatic promotion of multiple arguments to a common data type
`anycompatiblenonarray`	Common	Indicates that a function accepts any non-array data type, with automatic promotion of multiple arguments to a common data type

Name	Family	Description
anycompatiblerange	Common	Indicates that a function accepts any range data type, with automatic promotion of multiple arguments to a common data type
anycompatiblemultirange	Common	Indicates that a function accepts any multirange data type, with automatic promotion of multiple arguments to a common data type

Polymorphic arguments and results are tied to each other and are resolved to specific data types when a query calling a polymorphic function is parsed. When there is more than one polymorphic argument, the actual data types of the input values must match up as described below. If the function's result type is polymorphic, or it has output parameters of polymorphic types, the types of those results are deduced from the actual types of the polymorphic inputs as described below.

For the “simple” family of polymorphic types, the matching and deduction rules work like this:

Each position (either argument or return value) declared as anyelement is allowed to have any specific actual data type, but in any given call they must all be the *same* actual type. Each position declared as anyarray can have any array data type, but similarly they must all be the same type. And similarly, positions declared as anyrange must all be the same range type. Likewise for anymultirange.

Furthermore, if there are positions declared anyarray and others declared anyelement, the actual array type in the anyarray positions must be an array whose elements are the same type appearing in the anyelement positions. anynonarray is treated exactly the same as anyelement, but adds the additional constraint that the actual type must not be an array type. anyenum is treated exactly the same as anyelement, but adds the additional constraint that the actual type must be an enum type.

Similarly, if there are positions declared anyrange and others declared anyelement or anyarray, the actual range type in the anyrange positions must be a range whose subtype is the same type appearing in the anyelement positions and the same as the element type of the anyarray positions. If there are positions declared anymultirange, their actual multirange type must contain ranges matching parameters declared anyrange and base elements matching parameters declared anyelement and anyarray.

Thus, when more than one argument position is declared with a polymorphic type, the net effect is that only certain combinations of actual argument types are allowed. For example, a function declared as equal(anyelement, anyelement) will take any two input values, so long as they are of the same data type.

When the return value of a function is declared as a polymorphic type, there must be at least one argument position that is also polymorphic, and the actual data type(s) supplied for the polymorphic arguments determine the actual result type for that call. For example, if there were not already an array subscripting mechanism, one could define a function that implements subscripting as subscript(anyarray, integer) returns anyelement. This declaration constrains the actual first argument to be an array type, and allows the parser to infer the correct result type from the actual first argument's type. Another example is that a function declared as f(anyarray) returns anyenum will only accept arrays of enum types.

In most cases, the parser can infer the actual data type for a polymorphic result type from arguments that are of a different polymorphic type in the same family; for example anyarray can be deduced from anyelement or vice versa. An exception is that a polymorphic result of type anyrange requires an argument of type anyrange; it cannot be deduced from anyarray or anyelement arguments. This is because there could be multiple range types with the same subtype.

Note that anynonarray and anyenum do not represent separate type variables; they are the same type as anyelement, just with an additional constraint. For example, declaring a function as f(anyelement, anyenum) is equivalent to declaring it as f(anyenum, anyenum): both actual arguments have to be the same enum type.

For the “common” family of polymorphic types, the matching and deduction rules work approximately the same as for the “simple” family, with one major difference: the actual types of the arguments need not be identical, so long as they can be implicitly cast to a single common type. The common type is selected following the same rules as for UNION and related constructs (see Section 10.5). Selection of the common type considers the actual types of anycompatible and anycompatiblenonarray inputs, the array element types of anycompatiblearray inputs, the range subtypes of anycompatiblerange inputs, and the multirange subtypes of anycompatiblemultirange inputs. If anycompatiblenonarray is present then the common type is required to be a non-array type. Once a common type is identified, arguments in anycompatible and anycompatiblenonarray positions are automatically cast to that type, and arguments in anycompatiblearray positions are automatically cast to the array type for that type.

Since there is no way to select a range type knowing only its subtype, use of anycompatiblerange and/or anycompatiblemultirange requires that all arguments declared with that type have the same actual range and/or multirange type, and that that type's subtype agree with the selected common type, so that no casting of the range values is required. As with anyrange and anymultirange, use of anycompatiblerange and anymultirange as a function result type requires that there be an anycompatiblerange or anycompatiblemultirange argument.

Notice that there is no anycompatibleenum type. Such a type would not be very useful, since there normally are not any implicit casts to enum types, meaning that there would be no way to resolve a common type for dissimilar enum inputs.

The “simple” and “common” polymorphic families represent two independent sets of type variables. Consider for example

```
CREATE FUNCTION myfunc(a anyelement, b anyelement,
                       c anycompatible, d anycompatible)
RETURNS anycompatible AS ...
```

In an actual call of this function, the first two inputs must have exactly the same type. The last two inputs must be promotable to a common type, but this type need not have anything to do with the type of the first two inputs. The result will have the common type of the last two inputs.

A variadic function (one taking a variable number of arguments, as in Section 40.5.6) can be polymorphic: this is accomplished by declaring its last parameter as VARIADIC anyarray or VARIADIC anycompatiblearray. For purposes of argument matching and determining the actual result type, such a function behaves the same as if you had written the appropriate number of anynonarray or anycompatiblenonarray parameters.

40.3. User-Defined Functions

Postgres Pro provides four kinds of functions:

- query language functions (functions written in SQL) (Section 40.5)
- procedural language functions (functions written in, for example, PL/pgSQL or PL/Tcl) (Section 40.8)
- internal functions (Section 40.9)
- C-language functions (Section 40.10)

Every kind of function can take base types, composite types, or combinations of these as arguments (parameters). In addition, every kind of function can return a base type or a composite type. Functions can also be defined to return sets of base or composite values.

Many kinds of functions can take or return certain pseudo-types (such as polymorphic types), but the available facilities vary. Consult the description of each kind of function for more details.

It's easiest to define SQL functions, so we'll start by discussing those. Most of the concepts presented for SQL functions will carry over to the other types of functions.

Throughout this chapter, it can be useful to look at the reference page of the CREATE FUNCTION command to understand the examples better.

40.4. User-Defined Procedures

A procedure is a database object similar to a function. The key differences are:

- Procedures are defined with the `CREATE PROCEDURE` command, not `CREATE FUNCTION`.
- Procedures do not return a function value; hence `CREATE PROCEDURE` lacks a `RETURNS` clause. However, procedures can instead return data to their callers via output parameters.
- While a function is called as part of a query or DML command, a procedure is called in isolation using the `CALL` command.
- A procedure can commit or roll back transactions during its execution (then automatically beginning a new transaction), so long as the invoking `CALL` command is not part of an explicit transaction block. A function cannot do that.
- Certain function attributes, such as strictness, don't apply to procedures. Those attributes control how the function is used in a query, which isn't relevant to procedures.

The explanations in the following sections about how to define user-defined functions apply to procedures as well, except for the points made above.

Collectively, functions and procedures are also known as *routines*. There are commands such as `ALTER ROUTINE` and `DROP ROUTINE` that can operate on functions and procedures without having to know which kind it is. Note, however, that there is no `CREATE ROUTINE` command.

40.5. Query Language (SQL) Functions

SQL functions execute an arbitrary list of SQL statements, returning the result of the last query in the list. In the simple (non-set) case, the first row of the last query's result will be returned. (Bear in mind that “the first row” of a multirow result is not well-defined unless you use `ORDER BY`.) If the last query happens to return no rows at all, the null value will be returned.

Alternatively, an SQL function can be declared to return a set (that is, multiple rows) by specifying the function's return type as `SETOF` *`sometype`*, or equivalently by declaring it as `RETURNS TABLE(`*`columns`*`)`. In this case all rows of the last query's result are returned. Further details appear below.

The body of an SQL function must be a list of SQL statements separated by semicolons. A semicolon after the last statement is optional. Unless the function is declared to return `void`, the last statement must be a `SELECT`, or an `INSERT`, `UPDATE`, or `DELETE` that has a `RETURNING` clause.

Any collection of commands in the SQL language can be packaged together and defined as a function. Besides `SELECT` queries, the commands can include data modification queries (`INSERT`, `UPDATE`, and `DELETE`), as well as other SQL commands. (You cannot use transaction control commands, e.g., `COMMIT`, `SAVEPOINT`, and some utility commands, e.g., `VACUUM`, in SQL functions.) However, the final command must be a `SELECT` or have a `RETURNING` clause that returns whatever is specified as the function's return type. Alternatively, if you want to define an SQL function that performs actions but has no useful value to return, you can define it as returning `void`. For example, this function removes rows with negative salaries from the `emp` table:

```
CREATE FUNCTION clean_emp() RETURNS void AS '
    DELETE FROM emp
        WHERE salary < 0;
' LANGUAGE SQL;

SELECT clean_emp();

 clean_emp
-----------

(1 row)
```

You can also write this as a procedure, thus avoiding the issue of the return type. For example:

```
CREATE PROCEDURE clean_emp() AS '
    DELETE FROM emp
        WHERE salary < 0;
' LANGUAGE SQL;

CALL clean_emp();
```

In simple cases like this, the difference between a function returning `void` and a procedure is mostly stylistic. However, procedures offer additional functionality such as transaction control that is not available in functions. Also, procedures are SQL standard whereas returning `void` is a PostgreSQL extension.

> **Note**
>
> The entire body of an SQL function is parsed before any of it is executed. While an SQL function can contain commands that alter the system catalogs (e.g., `CREATE TABLE`), the effects of such commands will not be visible during parse analysis of later commands in the function. Thus, for example, `CREATE TABLE foo (...); INSERT INTO foo VALUES(...);` will not work as desired if packaged up into a single SQL function, since `foo` won't exist yet when the `INSERT` command is parsed. It's recommended to use PL/pgSQL instead of an SQL function in this type of situation.

The syntax of the `CREATE FUNCTION` command requires the function body to be written as a string constant. It is usually most convenient to use dollar quoting (see Section 4.1.2.4) for the string constant. If you choose to use regular single-quoted string constant syntax, you must double single quote marks (`'`) and backslashes (`\`) (assuming escape string syntax) in the body of the function (see Section 4.1.2.1).

40.5.1. Arguments for SQL Functions

Arguments of an SQL function can be referenced in the function body using either names or numbers. Examples of both methods appear below.

To use a name, declare the function argument as having a name, and then just write that name in the function body. If the argument name is the same as any column name in the current SQL command within the function, the column name will take precedence. To override this, qualify the argument name with the name of the function itself, that is *`function_name.argument_name`*. (If this would conflict with a qualified column name, again the column name wins. You can avoid the ambiguity by choosing a different alias for the table within the SQL command.)

In the older numeric approach, arguments are referenced using the syntax `$`*`n`*: `$1` refers to the first input argument, `$2` to the second, and so on. This will work whether or not the particular argument was declared with a name.

If an argument is of a composite type, then the dot notation, e.g., *`argname.fieldname`* or `$1.`*`fieldname`*, can be used to access attributes of the argument. Again, you might need to qualify the argument's name with the function name to make the form with an argument name unambiguous.

SQL function arguments can only be used as data values, not as identifiers. Thus for example this is reasonable:

```
INSERT INTO mytable VALUES ($1);
```

but this will not work:

```
INSERT INTO $1 VALUES (42);
```

> **Note**
>
> The ability to use names to reference SQL function arguments was added in PostgreSQL 9.2. Functions to be used in older servers must use the `$`*`n`* notation.

40.5.2. SQL Functions on Base Types

The simplest possible SQL function has no arguments and simply returns a base type, such as `integer`:

```
CREATE FUNCTION one() RETURNS integer AS $$
    SELECT 1 AS result;
$$ LANGUAGE SQL;

-- Alternative syntax for string literal:
CREATE FUNCTION one() RETURNS integer AS '
    SELECT 1 AS result;
' LANGUAGE SQL;

SELECT one();

 one
-----
   1
```

Notice that we defined a column alias within the function body for the result of the function (with the name `result`), but this column alias is not visible outside the function. Hence, the result is labeled `one` instead of `result`.

It is almost as easy to define SQL functions that take base types as arguments:

```
CREATE FUNCTION add_em(x integer, y integer) RETURNS integer AS $$
    SELECT x + y;
$$ LANGUAGE SQL;

SELECT add_em(1, 2) AS answer;

 answer
--------
      3
```

Alternatively, we could dispense with names for the arguments and use numbers:

```
CREATE FUNCTION add_em(integer, integer) RETURNS integer AS $$
    SELECT $1 + $2;
$$ LANGUAGE SQL;

SELECT add_em(1, 2) AS answer;

 answer
--------
      3
```

Here is a more useful function, which might be used to debit a bank account:

```
CREATE FUNCTION tf1 (accountno integer, debit numeric) RETURNS numeric AS $$
    UPDATE bank
        SET balance = balance - debit
        WHERE accountno = tf1.accountno;
    SELECT 1;
$$ LANGUAGE SQL;
```

A user could execute this function to debit account 17 by $100.00 as follows:

```
SELECT tf1(17, 100.0);
```

In this example, we chose the name `accountno` for the first argument, but this is the same as the name of a column in the `bank` table. Within the `UPDATE` command, `accountno` refers to the column `bank.accountno`,

so `tf1.accountno` must be used to refer to the argument. We could of course avoid this by using a different name for the argument.

In practice one would probably like a more useful result from the function than a constant 1, so a more likely definition is:

```
CREATE FUNCTION tf1 (accountno integer, debit numeric) RETURNS numeric AS $$
    UPDATE bank
        SET balance = balance - debit
        WHERE accountno = tf1.accountno;
    SELECT balance FROM bank WHERE accountno = tf1.accountno;
$$ LANGUAGE SQL;
```

which adjusts the balance and returns the new balance. The same thing could be done in one command using `RETURNING`:

```
CREATE FUNCTION tf1 (accountno integer, debit numeric) RETURNS numeric AS $$
    UPDATE bank
        SET balance = balance - debit
        WHERE accountno = tf1.accountno
    RETURNING balance;
$$ LANGUAGE SQL;
```

If the final `SELECT` or `RETURNING` clause in a SQL function does not return exactly the function's declared result type, PostgreSQL will automatically cast the value to the required type, if that is possible with an implicit or assignment cast. Otherwise, you must write an explicit cast. For example, suppose we wanted the previous `add_em` function to return type `float8` instead. It's sufficient to write

```
CREATE FUNCTION add_em(integer, integer) RETURNS float8 AS $$
    SELECT $1 + $2;
$$ LANGUAGE SQL;
```

since the `integer` sum can be implicitly cast to `float8`. (See Chapter 10 or CREATE CAST for more about casts.)

40.5.3. SQL Functions on Composite Types

When writing functions with arguments of composite types, we must not only specify which argument we want but also the desired attribute (field) of that argument. For example, suppose that `emp` is a table containing employee data, and therefore also the name of the composite type of each row of the table. Here is a function `double_salary` that computes what someone's salary would be if it were doubled:

```
CREATE TABLE emp (
    name        text,
    salary      numeric,
    age         integer,
    cubicle     point
);

INSERT INTO emp VALUES ('Bill', 4200, 45, '(2,1)');

CREATE FUNCTION double_salary(emp) RETURNS numeric AS $$
    SELECT $1.salary * 2 AS salary;
$$ LANGUAGE SQL;

SELECT name, double_salary(emp.*) AS dream
    FROM emp
    WHERE emp.cubicle ~= point '(2,1)';

 name | dream
------+-------
 Bill |  8400
```

Notice the use of the syntax `$1.salary` to select one field of the argument row value. Also notice how the calling `SELECT` command uses *`table_name`*`.*` to select the entire current row of a table as a composite value. The table row can alternatively be referenced using just the table name, like this:

```
SELECT name, double_salary(emp) AS dream
    FROM emp
    WHERE emp.cubicle ~= point '(2,1)';
```

but this usage is deprecated since it's easy to get confused. (See Section 8.16.5 for details about these two notations for the composite value of a table row.)

Sometimes it is handy to construct a composite argument value on-the-fly. This can be done with the `ROW` construct. For example, we could adjust the data being passed to the function:

```
SELECT name, double_salary(ROW(name, salary*1.1, age, cubicle)) AS dream
    FROM emp;
```

It is also possible to build a function that returns a composite type. This is an example of a function that returns a single `emp` row:

```
CREATE FUNCTION new_emp() RETURNS emp AS $$
    SELECT text 'None' AS name,
        1000.0 AS salary,
        25 AS age,
        point '(2,2)' AS cubicle;
$$ LANGUAGE SQL;
```

In this example we have specified each of the attributes with a constant value, but any computation could have been substituted for these constants.

Note two important things about defining the function:

- The select list order in the query must be exactly the same as that in which the columns appear in the composite type. (Naming the columns, as we did above, is irrelevant to the system.)
- We must ensure each expression's type can be cast to that of the corresponding column of the composite type. Otherwise we'll get errors like this:

  ```
  ERROR:  return type mismatch in function declared to return emp
  DETAIL:  Final statement returns text instead of point at column 4.
  ```

  As with the base-type case, the system will not insert explicit casts automatically, only implicit or assignment casts.

A different way to define the same function is:

```
CREATE FUNCTION new_emp() RETURNS emp AS $$
    SELECT ROW('None', 1000.0, 25, '(2,2)')::emp;
$$ LANGUAGE SQL;
```

Here we wrote a `SELECT` that returns just a single column of the correct composite type. This isn't really better in this situation, but it is a handy alternative in some cases — for example, if we need to compute the result by calling another function that returns the desired composite value. Another example is that if we are trying to write a function that returns a domain over composite, rather than a plain composite type, it is always necessary to write it as returning a single column, since there is no way to cause a coercion of the whole row result.

We could call this function directly either by using it in a value expression:

```
SELECT new_emp();

          new_emp
--------------------------
 (None,1000.0,25,"(2,2)")
```

or by calling it as a table function:

```
SELECT * FROM new_emp();

 name | salary | age | cubicle
------+--------+-----+---------
 None | 1000.0 |  25 | (2,2)
```

The second way is described more fully in Section 40.5.8.

When you use a function that returns a composite type, you might want only one field (attribute) from its result. You can do that with syntax like this:

```
SELECT (new_emp()).name;

 name
------
 None
```

The extra parentheses are needed to keep the parser from getting confused. If you try to do it without them, you get something like this:

```
SELECT new_emp().name;
ERROR:  syntax error at or near "."
LINE 1: SELECT new_emp().name;
                        ^
```

Another option is to use functional notation for extracting an attribute:

```
SELECT name(new_emp());

 name
------
 None
```

As explained in Section 8.16.5, the field notation and functional notation are equivalent.

Another way to use a function returning a composite type is to pass the result to another function that accepts the correct row type as input:

```
CREATE FUNCTION getname(emp) RETURNS text AS $$
    SELECT $1.name;
$$ LANGUAGE SQL;

SELECT getname(new_emp());
 getname
---------
 None
(1 row)
```

40.5.4. SQL Functions with Output Parameters

An alternative way of describing a function's results is to define it with *output parameters*, as in this example:

```
CREATE FUNCTION add_em (IN x int, IN y int, OUT sum int)
AS 'SELECT x + y'
LANGUAGE SQL;

SELECT add_em(3,7);
 add_em
--------
     10
(1 row)
```

This is not essentially different from the version of `add_em` shown in Section 40.5.2. The real value of output parameters is that they provide a convenient way of defining functions that return several columns. For example,

```
CREATE FUNCTION sum_n_product (x int, y int, OUT sum int, OUT product int)
AS 'SELECT x + y, x * y'
LANGUAGE SQL;

 SELECT * FROM sum_n_product(11,42);
 sum | product
-----+---------
  53 |     462
(1 row)
```

What has essentially happened here is that we have created an anonymous composite type for the result of the function. The above example has the same end result as

```
CREATE TYPE sum_prod AS (sum int, product int);

CREATE FUNCTION sum_n_product (int, int) RETURNS sum_prod
AS 'SELECT $1 + $2, $1 * $2'
LANGUAGE SQL;
```

but not having to bother with the separate composite type definition is often handy. Notice that the names attached to the output parameters are not just decoration, but determine the column names of the anonymous composite type. (If you omit a name for an output parameter, the system will choose a name on its own.)

Notice that output parameters are not included in the calling argument list when invoking such a function from SQL. This is because Postgres Pro considers only the input parameters to define the function's calling signature. That means also that only the input parameters matter when referencing the function for purposes such as dropping it. We could drop the above function with either of

```
DROP FUNCTION sum_n_product (x int, y int, OUT sum int, OUT product int);
DROP FUNCTION sum_n_product (int, int);
```

Parameters can be marked as `IN` (the default), `OUT`, `INOUT`, or `VARIADIC`. An `INOUT` parameter serves as both an input parameter (part of the calling argument list) and an output parameter (part of the result record type). `VARIADIC` parameters are input parameters, but are treated specially as described below.

40.5.5. SQL Procedures with Output Parameters

Output parameters are also supported in procedures, but they work a bit differently from functions. In `CALL` commands, output parameters must be included in the argument list. For example, the bank account debiting routine from earlier could be written like this:

```
CREATE PROCEDURE tp1 (accountno integer, debit numeric, OUT new_balance numeric) AS $$
    UPDATE bank
        SET balance = balance - debit
        WHERE accountno = tp1.accountno
    RETURNING balance;
$$ LANGUAGE SQL;
```

To call this procedure, an argument matching the `OUT` parameter must be included. It's customary to write `NULL`:

```
CALL tp1(17, 100.0, NULL);
```

If you write something else, it must be an expression that is implicitly coercible to the declared type of the parameter, just as for input parameters. Note however that such an expression will not be evaluated.

When calling a procedure from PL/pgSQL, instead of writing `NULL` you must write a variable that will receive the procedure's output. See Section 45.6.3 for details.

40.5.6. SQL Functions with Variable Numbers of Arguments

SQL functions can be declared to accept variable numbers of arguments, so long as all the "optional" arguments are of the same data type. The optional arguments will be passed to the function as an array. The function is declared by marking the last parameter as `VARIADIC`; this parameter must be declared as being of an array type. For example:

```
CREATE FUNCTION mleast(VARIADIC arr numeric[]) RETURNS numeric AS $$
    SELECT min($1[i]) FROM generate_subscripts($1, 1) g(i);
$$ LANGUAGE SQL;

SELECT mleast(10, -1, 5, 4.4);
 mleast
--------
     -1
(1 row)
```

Effectively, all the actual arguments at or beyond the `VARIADIC` position are gathered up into a one-dimensional array, as if you had written

```
SELECT mleast(ARRAY[10, -1, 5, 4.4]);    -- doesn't work
```

You can't actually write that, though — or at least, it will not match this function definition. A parameter marked `VARIADIC` matches one or more occurrences of its element type, not of its own type.

Sometimes it is useful to be able to pass an already-constructed array to a variadic function; this is particularly handy when one variadic function wants to pass on its array parameter to another one. Also, this is the only secure way to call a variadic function found in a schema that permits untrusted users to create objects; see Section 10.3. You can do this by specifying `VARIADIC` in the call:

```
SELECT mleast(VARIADIC ARRAY[10, -1, 5, 4.4]);
```

This prevents expansion of the function's variadic parameter into its element type, thereby allowing the array argument value to match normally. `VARIADIC` can only be attached to the last actual argument of a function call.

Specifying `VARIADIC` in the call is also the only way to pass an empty array to a variadic function, for example:

```
SELECT mleast(VARIADIC ARRAY[]::numeric[]);
```

Simply writing `SELECT mleast()` does not work because a variadic parameter must match at least one actual argument. (You could define a second function also named `mleast`, with no parameters, if you wanted to allow such calls.)

The array element parameters generated from a variadic parameter are treated as not having any names of their own. This means it is not possible to call a variadic function using named arguments (Section 4.3), except when you specify `VARIADIC`. For example, this will work:

```
SELECT mleast(VARIADIC arr => ARRAY[10, -1, 5, 4.4]);
```

but not these:

```
SELECT mleast(arr => 10);
SELECT mleast(arr => ARRAY[10, -1, 5, 4.4]);
```

40.5.7. SQL Functions with Default Values for Arguments

Functions can be declared with default values for some or all input arguments. The default values are inserted whenever the function is called with insufficiently many actual arguments. Since arguments can only be omitted from the end of the actual argument list, all parameters after a parameter with a default value have to have default values as well. (Although the use of named argument notation could allow this restriction to be relaxed, it's still enforced so that positional argument notation works sensibly.) Whether or not you use it, this capability creates a need for precautions when calling functions in databases where some users mistrust other users; see Section 10.3.

For example:

```
CREATE FUNCTION foo(a int, b int DEFAULT 2, c int DEFAULT 3)
RETURNS int
LANGUAGE SQL
AS $$
    SELECT $1 + $2 + $3;
$$;

SELECT foo(10, 20, 30);
 foo
-----
  60
(1 row)

SELECT foo(10, 20);
 foo
-----
  33
(1 row)

SELECT foo(10);
 foo
-----
  15
(1 row)

SELECT foo();  -- fails since there is no default for the first argument
ERROR:  function foo() does not exist
```

The = sign can also be used in place of the key word `DEFAULT`.

40.5.8. SQL Functions as Table Sources

All SQL functions can be used in the `FROM` clause of a query, but it is particularly useful for functions returning composite types. If the function is defined to return a base type, the table function produces a one-column table. If the function is defined to return a composite type, the table function produces a column for each attribute of the composite type.

Here is an example:

```
CREATE TABLE foo (fooid int, foosubid int, fooname text);
INSERT INTO foo VALUES (1, 1, 'Joe');
INSERT INTO foo VALUES (1, 2, 'Ed');
INSERT INTO foo VALUES (2, 1, 'Mary');

CREATE FUNCTION getfoo(int) RETURNS foo AS $$
    SELECT * FROM foo WHERE fooid = $1;
$$ LANGUAGE SQL;

SELECT *, upper(fooname) FROM getfoo(1) AS t1;

 fooid | foosubid | fooname | upper
-------+----------+---------+-------
     1 |        1 | Joe     | JOE
(1 row)
```

As the example shows, we can work with the columns of the function's result just the same as if they were columns of a regular table.

Note that we only got one row out of the function. This is because we did not use `SETOF`. That is described in the next section.

40.5.9. SQL Functions Returning Sets

When an SQL function is declared as returning `SETOF` *sometype*, the function's final query is executed to completion, and each row it outputs is returned as an element of the result set.

This feature is normally used when calling the function in the `FROM` clause. In this case each row returned by the function becomes a row of the table seen by the query. For example, assume that table `foo` has the same contents as above, and we say:

```
CREATE FUNCTION getfoo(int) RETURNS SETOF foo AS $$
    SELECT * FROM foo WHERE fooid = $1;
$$ LANGUAGE SQL;

SELECT * FROM getfoo(1) AS t1;
```

Then we would get:

```
 fooid | foosubid | fooname
-------+----------+---------
     1 |        1 | Joe
     1 |        2 | Ed
(2 rows)
```

It is also possible to return multiple rows with the columns defined by output parameters, like this:

```
CREATE TABLE tab (y int, z int);
INSERT INTO tab VALUES (1, 2), (3, 4), (5, 6), (7, 8);

CREATE FUNCTION sum_n_product_with_tab (x int, OUT sum int, OUT product int)
RETURNS SETOF record
AS $$
    SELECT $1 + tab.y, $1 * tab.y FROM tab;
$$ LANGUAGE SQL;

SELECT * FROM sum_n_product_with_tab(10);
 sum | product
-----+---------
  11 |      10
  13 |      30
  15 |      50
  17 |      70
(4 rows)
```

The key point here is that you must write `RETURNS SETOF record` to indicate that the function returns multiple rows instead of just one. If there is only one output parameter, write that parameter's type instead of `record`.

It is frequently useful to construct a query's result by invoking a set-returning function multiple times, with the parameters for each invocation coming from successive rows of a table or subquery. The preferred way to do this is to use the `LATERAL` key word, which is described in Section 7.2.1.5. Here is an example using a set-returning function to enumerate elements of a tree structure:

```
SELECT * FROM nodes;
   name    | parent
-----------+--------
 Top       |
 Child1    | Top
 Child2    | Top
 Child3    | Top
 SubChild1 | Child1
 SubChild2 | Child1
(6 rows)
```

```
CREATE FUNCTION listchildren(text) RETURNS SETOF text AS $$
    SELECT name FROM nodes WHERE parent = $1
$$ LANGUAGE SQL STABLE;

SELECT * FROM listchildren('Top');
 listchildren
--------------
 Child1
 Child2
 Child3
(3 rows)

SELECT name, child FROM nodes, LATERAL listchildren(name) AS child;
  name  |   child
--------+-----------
 Top    | Child1
 Top    | Child2
 Top    | Child3
 Child1 | SubChild1
 Child1 | SubChild2
(5 rows)
```

This example does not do anything that we couldn't have done with a simple join, but in more complex calculations the option to put some of the work into a function can be quite convenient.

Functions returning sets can also be called in the select list of a query. For each row that the query generates by itself, the set-returning function is invoked, and an output row is generated for each element of the function's result set. The previous example could also be done with queries like these:

```
SELECT listchildren('Top');
 listchildren
--------------
 Child1
 Child2
 Child3
(3 rows)

SELECT name, listchildren(name) FROM nodes;
  name  | listchildren
--------+--------------
 Top    | Child1
 Top    | Child2
 Top    | Child3
 Child1 | SubChild1
 Child1 | SubChild2
(5 rows)
```

In the last `SELECT`, notice that no output row appears for `Child2`, `Child3`, etc. This happens because `listchildren` returns an empty set for those arguments, so no result rows are generated. This is the same behavior as we got from an inner join to the function result when using the `LATERAL` syntax.

Postgres Pro's behavior for a set-returning function in a query's select list is almost exactly the same as if the set-returning function had been written in a `LATERAL FROM`-clause item instead. For example,

```
SELECT x, generate_series(1,5) AS g FROM tab;
```

is almost equivalent to

```
SELECT x, g FROM tab, LATERAL generate_series(1,5) AS g;
```

It would be exactly the same, except that in this specific example, the planner could choose to put `g` on the outside of the nested-loop join, since `g` has no actual lateral dependency on `tab`. That would result

in a different output row order. Set-returning functions in the select list are always evaluated as though they are on the inside of a nested-loop join with the rest of the FROM clause, so that the function(s) are run to completion before the next row from the FROM clause is considered.

If there is more than one set-returning function in the query's select list, the behavior is similar to what you get from putting the functions into a single LATERAL ROWS FROM(...) FROM-clause item. For each row from the underlying query, there is an output row using the first result from each function, then an output row using the second result, and so on. If some of the set-returning functions produce fewer outputs than others, null values are substituted for the missing data, so that the total number of rows emitted for one underlying row is the same as for the set-returning function that produced the most outputs. Thus the set-returning functions run "in lockstep" until they are all exhausted, and then execution continues with the next underlying row.

Set-returning functions can be nested in a select list, although that is not allowed in FROM-clause items. In such cases, each level of nesting is treated separately, as though it were a separate LATERAL ROWS FROM(...) item. For example, in

```
SELECT srf1(srf2(x), srf3(y)), srf4(srf5(z)) FROM tab;
```

the set-returning functions srf2, srf3, and srf5 would be run in lockstep for each row of tab, and then srf1 and srf4 would be applied in lockstep to each row produced by the lower functions.

Set-returning functions cannot be used within conditional-evaluation constructs, such as CASE or COALESCE. For example, consider

```
SELECT x, CASE WHEN x > 0 THEN generate_series(1, 5) ELSE 0 END FROM tab;
```

It might seem that this should produce five repetitions of input rows that have x > 0, and a single repetition of those that do not; but actually, because generate_series(1, 5) would be run in an implicit LATERAL FROM item before the CASE expression is ever evaluated, it would produce five repetitions of every input row. To reduce confusion, such cases produce a parse-time error instead.

Note

If a function's last command is INSERT, UPDATE, or DELETE with RETURNING, that command will always be executed to completion, even if the function is not declared with SETOF or the calling query does not fetch all the result rows. Any extra rows produced by the RETURNING clause are silently dropped, but the commanded table modifications still happen (and are all completed before returning from the function).

Note

Before Postgres Pro 10, putting more than one set-returning function in the same select list did not behave very sensibly unless they always produced equal numbers of rows. Otherwise, what you got was a number of output rows equal to the least common multiple of the numbers of rows produced by the set-returning functions. Also, nested set-returning functions did not work as described above; instead, a set-returning function could have at most one set-returning argument, and each nest of set-returning functions was run independently. Also, conditional execution (set-returning functions inside CASE etc) was previously allowed, complicating things even more. Use of the LATERAL syntax is recommended when writing queries that need to work in older Postgres Pro versions, because that will give consistent results across different versions. If you have a query that is relying on conditional execution of a set-returning function, you may be able to fix it by moving the conditional test into a custom set-returning function. For example,

```
SELECT x, CASE WHEN y > 0 THEN generate_series(1, z) ELSE 5 END FROM tab;
```

could become

```
CREATE FUNCTION case_generate_series(cond bool, start int, fin int, els int)
  RETURNS SETOF int AS $$
BEGIN
```

```
  IF cond THEN
    RETURN QUERY SELECT generate_series(start, fin);
  ELSE
    RETURN QUERY SELECT els;
  END IF;
END$$ LANGUAGE plpgsql;

SELECT x, case_generate_series(y > 0, 1, z, 5) FROM tab;
```

This formulation will work the same in all versions of Postgres Pro.

40.5.10. SQL Functions Returning TABLE

There is another way to declare a function as returning a set, which is to use the syntax `RETURNS TABLE(columns)`. This is equivalent to using one or more `OUT` parameters plus marking the function as returning `SETOF record` (or `SETOF` a single output parameter's type, as appropriate). This notation is specified in recent versions of the SQL standard, and thus may be more portable than using `SETOF`.

For example, the preceding sum-and-product example could also be done this way:

```
CREATE FUNCTION sum_n_product_with_tab (x int)
RETURNS TABLE(sum int, product int) AS $$
    SELECT $1 + tab.y, $1 * tab.y FROM tab;
$$ LANGUAGE SQL;
```

It is not allowed to use explicit `OUT` or `INOUT` parameters with the `RETURNS TABLE` notation — you must put all the output columns in the `TABLE` list.

40.5.11. Polymorphic SQL Functions

SQL functions can be declared to accept and return the polymorphic types described in Section 40.2.5. Here is a polymorphic function `make_array` that builds up an array from two arbitrary data type elements:

```
CREATE FUNCTION make_array(anyelement, anyelement) RETURNS anyarray AS $$
    SELECT ARRAY[$1, $2];
$$ LANGUAGE SQL;

SELECT make_array(1, 2) AS intarray, make_array('a'::text, 'b') AS textarray;
 intarray | textarray
----------+-----------
 {1,2}    | {a,b}
(1 row)
```

Notice the use of the typecast `'a'::text` to specify that the argument is of type `text`. This is required if the argument is just a string literal, since otherwise it would be treated as type `unknown`, and array of `unknown` is not a valid type. Without the typecast, you will get errors like this:

```
ERROR:  could not determine polymorphic type because input has type unknown
```

With `make_array` declared as above, you must provide two arguments that are of exactly the same data type; the system will not attempt to resolve any type differences. Thus for example this does not work:

```
SELECT make_array(1, 2.5) AS numericarray;
ERROR:  function make_array(integer, numeric) does not exist
```

An alternative approach is to use the “common” family of polymorphic types, which allows the system to try to identify a suitable common type:

```
CREATE FUNCTION make_array2(anycompatible, anycompatible)
RETURNS anycompatiblearray AS $$
    SELECT ARRAY[$1, $2];
$$ LANGUAGE SQL;
```

```
SELECT make_array2(1, 2.5) AS numericarray;
 numericarray
--------------
 {1,2.5}
(1 row)
```

Because the rules for common type resolution default to choosing type `text` when all inputs are of unknown types, this also works:

```
SELECT make_array2('a', 'b') AS textarray;
 textarray
-----------
 {a,b}
(1 row)
```

It is permitted to have polymorphic arguments with a fixed return type, but the converse is not. For example:

```
CREATE FUNCTION is_greater(anyelement, anyelement) RETURNS boolean AS $$
    SELECT $1 > $2;
$$ LANGUAGE SQL;

SELECT is_greater(1, 2);
 is_greater
------------
 f
(1 row)

CREATE FUNCTION invalid_func() RETURNS anyelement AS $$
    SELECT 1;
$$ LANGUAGE SQL;
ERROR:  cannot determine result data type
DETAIL:  A result of type anyelement requires at least one input of type anyelement,
 anyarray, anynonarray, anyenum, or anyrange.
```

Polymorphism can be used with functions that have output arguments. For example:

```
CREATE FUNCTION dup (f1 anyelement, OUT f2 anyelement, OUT f3 anyarray)
AS 'select $1, array[$1,$1]' LANGUAGE SQL;

SELECT * FROM dup(22);
 f2 |   f3
----+---------
 22 | {22,22}
(1 row)
```

Polymorphism can also be used with variadic functions. For example:

```
CREATE FUNCTION anyleast (VARIADIC anyarray) RETURNS anyelement AS $$
    SELECT min($1[i]) FROM generate_subscripts($1, 1) g(i);
$$ LANGUAGE SQL;

SELECT anyleast(10, -1, 5, 4);
 anyleast
----------
       -1
(1 row)

SELECT anyleast('abc'::text, 'def');
 anyleast
----------
 abc
```

```
(1 row)

CREATE FUNCTION concat_values(text, VARIADIC anyarray) RETURNS text AS $$
    SELECT array_to_string($2, $1);
$$ LANGUAGE SQL;

SELECT concat_values('|', 1, 4, 2);
 concat_values
---------------
 1|4|2
(1 row)
```

40.5.12. SQL Functions with Collations

When an SQL function has one or more parameters of collatable data types, a collation is identified for each function call depending on the collations assigned to the actual arguments, as described in Section 23.2. If a collation is successfully identified (i.e., there are no conflicts of implicit collations among the arguments) then all the collatable parameters are treated as having that collation implicitly. This will affect the behavior of collation-sensitive operations within the function. For example, using the `anyleast` function described above, the result of

```
SELECT anyleast('abc'::text, 'ABC');
```

will depend on the database's default collation. In `C` locale the result will be `ABC`, but in many other locales it will be `abc`. The collation to use can be forced by adding a `COLLATE` clause to any of the arguments, for example

```
SELECT anyleast('abc'::text, 'ABC' COLLATE "C");
```

Alternatively, if you wish a function to operate with a particular collation regardless of what it is called with, insert `COLLATE` clauses as needed in the function definition. This version of `anyleast` would always use `en_US` locale to compare strings:

```
CREATE FUNCTION anyleast (VARIADIC anyarray) RETURNS anyelement AS $$
    SELECT min($1[i] COLLATE "en_US") FROM generate_subscripts($1, 1) g(i);
$$ LANGUAGE SQL;
```

But note that this will throw an error if applied to a non-collatable data type.

If no common collation can be identified among the actual arguments, then an SQL function treats its parameters as having their data types' default collation (which is usually the database's default collation, but could be different for parameters of domain types).

The behavior of collatable parameters can be thought of as a limited form of polymorphism, applicable only to textual data types.

40.6. Function Overloading

More than one function can be defined with the same SQL name, so long as the arguments they take are different. In other words, function names can be *overloaded*. Whether or not you use it, this capability entails security precautions when calling functions in databases where some users mistrust other users; see Section 10.3. When a query is executed, the server will determine which function to call from the data types and the number of the provided arguments. Overloading can also be used to simulate functions with a variable number of arguments, up to a finite maximum number.

When creating a family of overloaded functions, one should be careful not to create ambiguities. For instance, given the functions:

```
CREATE FUNCTION test(int, real) RETURNS ...
CREATE FUNCTION test(smallint, double precision) RETURNS ...
```

it is not immediately clear which function would be called with some trivial input like `test(1, 1.5)`. The currently implemented resolution rules are described in Chapter 10, but it is unwise to design a system that subtly relies on this behavior.

A function that takes a single argument of a composite type should generally not have the same name as any attribute (field) of that type. Recall that *attribute*(*table*) is considered equivalent to *table*.*attribute*. In the case that there is an ambiguity between a function on a composite type and an attribute of the composite type, the attribute will always be used. It is possible to override that choice by schema-qualifying the function name (that is, *schema*.*func*(*table*)) but it's better to avoid the problem by not choosing conflicting names.

Another possible conflict is between variadic and non-variadic functions. For instance, it is possible to create both foo(numeric) and foo(VARIADIC numeric[]). In this case it is unclear which one should be matched to a call providing a single numeric argument, such as foo(10.1). The rule is that the function appearing earlier in the search path is used, or if the two functions are in the same schema, the non-variadic one is preferred.

When overloading C-language functions, there is an additional constraint: The C name of each function in the family of overloaded functions must be different from the C names of all other functions, either internal or dynamically loaded. If this rule is violated, the behavior is not portable. You might get a run-time linker error, or one of the functions will get called (usually the internal one). The alternative form of the AS clause for the SQL CREATE FUNCTION command decouples the SQL function name from the function name in the C source code. For instance:

```
CREATE FUNCTION test(int) RETURNS int
    AS 'filename', 'test_1arg'
    LANGUAGE C;
CREATE FUNCTION test(int, int) RETURNS int
    AS 'filename', 'test_2arg'
    LANGUAGE C;
```

The names of the C functions here reflect one of many possible conventions.

40.7. Function Volatility Categories

Every function has a *volatility* classification, with the possibilities being VOLATILE, STABLE, or IMMUTABLE. VOLATILE is the default if the CREATE FUNCTION command does not specify a category. The volatility category is a promise to the optimizer about the behavior of the function:

- A VOLATILE function can do anything, including modifying the database. It can return different results on successive calls with the same arguments. The optimizer makes no assumptions about the behavior of such functions. A query using a volatile function will re-evaluate the function at every row where its value is needed.
- A STABLE function cannot modify the database and is guaranteed to return the same results given the same arguments for all rows within a single statement. This category allows the optimizer to optimize multiple calls of the function to a single call. In particular, it is safe to use an expression containing such a function in an index scan condition. (Since an index scan will evaluate the comparison value only once, not once at each row, it is not valid to use a VOLATILE function in an index scan condition.)
- An IMMUTABLE function cannot modify the database and is guaranteed to return the same results given the same arguments forever. This category allows the optimizer to pre-evaluate the function when a query calls it with constant arguments. For example, a query like SELECT ... WHERE x = 2 + 2 can be simplified on sight to SELECT ... WHERE x = 4, because the function underlying the integer addition operator is marked IMMUTABLE.

For best optimization results, you should label your functions with the strictest volatility category that is valid for them.

Any function with side-effects *must* be labeled VOLATILE, so that calls to it cannot be optimized away. Even a function with no side-effects needs to be labeled VOLATILE if its value can change within a single query; some examples are random(), currval(), timeofday().

Another important example is that the current_timestamp family of functions qualify as STABLE, since their values do not change within a transaction.

There is relatively little difference between STABLE and IMMUTABLE categories when considering simple interactive queries that are planned and immediately executed: it doesn't matter a lot whether a function is executed once during planning or once during query execution startup. But there is a big difference if the plan is saved and reused later. Labeling a function IMMUTABLE when it really isn't might allow it to be prematurely folded to a constant during planning, resulting in a stale value being re-used during subsequent uses of the plan. This is a hazard when using prepared statements or when using function languages that cache plans (such as PL/pgSQL).

For functions written in SQL or in any of the standard procedural languages, there is a second important property determined by the volatility category, namely the visibility of any data changes that have been made by the SQL command that is calling the function. A VOLATILE function will see such changes, a STABLE or IMMUTABLE function will not. This behavior is implemented using the snapshotting behavior of MVCC (see Chapter 13): STABLE and IMMUTABLE functions use a snapshot established as of the start of the calling query, whereas VOLATILE functions obtain a fresh snapshot at the start of each query they execute.

> **Note**
>
> Functions written in C can manage snapshots however they want, but it's usually a good idea to make C functions work this way too.

Because of this snapshotting behavior, a function containing only SELECT commands can safely be marked STABLE, even if it selects from tables that might be undergoing modifications by concurrent queries. Postgres Pro will execute all commands of a STABLE function using the snapshot established for the calling query, and so it will see a fixed view of the database throughout that query.

The same snapshotting behavior is used for SELECT commands within IMMUTABLE functions. It is generally unwise to select from database tables within an IMMUTABLE function at all, since the immutability will be broken if the table contents ever change. However, Postgres Pro does not enforce that you do not do that.

A common error is to label a function IMMUTABLE when its results depend on a configuration parameter. For example, a function that manipulates timestamps might well have results that depend on the TimeZone setting. For safety, such functions should be labeled STABLE instead.

> **Note**
>
> Postgres Pro requires that STABLE and IMMUTABLE functions contain no SQL commands other than SELECT to prevent data modification. (This is not a completely bulletproof test, since such functions could still call VOLATILE functions that modify the database. If you do that, you will find that the STABLE or IMMUTABLE function does not notice the database changes applied by the called function, since they are hidden from its snapshot.)

40.8. Procedural Language Functions

Postgres Pro allows user-defined functions to be written in other languages besides SQL and C. These other languages are generically called *procedural languages* (PLs). Procedural languages aren't built into the Postgres Pro server; they are offered by loadable modules. See Chapter 44 and following chapters for more information.

40.9. Internal Functions

Internal functions are functions written in C that have been statically linked into the Postgres Pro server. The “body” of the function definition specifies the C-language name of the function, which need not be the same as the name being declared for SQL use. (For reasons of backward compatibility, an empty body is accepted as meaning that the C-language function name is the same as the SQL name.)

Normally, all internal functions present in the server are declared during the initialization of the database cluster (see Section 18.2), but a user could use `CREATE FUNCTION` to create additional alias names for an internal function. Internal functions are declared in `CREATE FUNCTION` with language name `internal`. For instance, to create an alias for the `sqrt` function:

```
CREATE FUNCTION square_root(double precision) RETURNS double precision
    AS 'dsqrt'
    LANGUAGE internal
    STRICT;
```

(Most internal functions expect to be declared “strict”.)

> **Note**
>
> Not all “predefined” functions are “internal” in the above sense. Some predefined functions are written in SQL.

40.10. C-Language Functions

User-defined functions can be written in C (or a language that can be made compatible with C, such as C++). Such functions are compiled into dynamically loadable objects (also called shared libraries) and are loaded by the server on demand. The dynamic loading feature is what distinguishes “C language” functions from “internal” functions — the actual coding conventions are essentially the same for both. (Hence, the standard internal function library is a rich source of coding examples for user-defined C functions.)

Currently only one calling convention is used for C functions (“version 1”). Support for that calling convention is indicated by writing a `PG_FUNCTION_INFO_V1()` macro call for the function, as illustrated below.

40.10.1. Dynamic Loading

The first time a user-defined function in a particular loadable object file is called in a session, the dynamic loader loads that object file into memory so that the function can be called. The `CREATE FUNCTION` for a user-defined C function must therefore specify two pieces of information for the function: the name of the loadable object file, and the C name (link symbol) of the specific function to call within that object file. If the C name is not explicitly specified then it is assumed to be the same as the SQL function name.

The following algorithm is used to locate the shared object file based on the name given in the `CREATE FUNCTION` command:

1. If the name is an absolute path, the given file is loaded.
2. If the name starts with the string `$libdir`, that part is replaced by the Postgres Pro package library directory name, which is determined at build time.
3. If the name does not contain a directory part, the file is searched for in the path specified by the configuration variable dynamic_library_path.
4. Otherwise (the file was not found in the path, or it contains a non-absolute directory part), the dynamic loader will try to take the name as given, which will most likely fail. (It is unreliable to depend on the current working directory.)

If this sequence does not work, the platform-specific shared library file name extension (often `.so`) is appended to the given name and this sequence is tried again. If that fails as well, the load will fail.

It is recommended to locate shared libraries either relative to `$libdir` or through the dynamic library path. This simplifies version upgrades if the new installation is at a different location. The actual directory that `$libdir` stands for can be found out with the command `pg_config --pkglibdir`.

The user ID the Postgres Pro server runs as must be able to traverse the path to the file you intend to load. Making the file or a higher-level directory not readable and/or not executable by the postgres user is a common mistake.

In any case, the file name that is given in the `CREATE FUNCTION` command is recorded literally in the system catalogs, so if the file needs to be loaded again the same procedure is applied.

> **Note**
>
> Postgres Pro will not compile a C function automatically. The object file must be compiled before it is referenced in a `CREATE FUNCTION` command. See Section 40.10.5 for additional information.

To ensure that a dynamically loaded object file is not loaded into an incompatible server, Postgres Pro checks that the file contains a "magic block" with the appropriate contents. This allows the server to detect obvious incompatibilities, such as code compiled for a different major version of Postgres Pro. To include a magic block, write this in one (and only one) of the module source files, after having included the header `fmgr.h`:

```
PG_MODULE_MAGIC;
```

After it is used for the first time, a dynamically loaded object file is retained in memory. Future calls in the same session to the function(s) in that file will only incur the small overhead of a symbol table lookup. If you need to force a reload of an object file, for example after recompiling it, begin a fresh session.

Optionally, a dynamically loaded file can contain initialization and finalization functions. If the file includes a function named `_PG_init`, that function will be called immediately after loading the file. The function receives no parameters and should return void. If the file includes a function named `_PG_fini`, that function will be called immediately before unloading the file. Likewise, the function receives no parameters and should return void. Note that `_PG_fini` will only be called during an unload of the file, not during process termination. (Presently, unloads are disabled and will never occur, but this may change in the future.)

40.10.2. Base Types in C-Language Functions

To know how to write C-language functions, you need to know how Postgres Pro internally represents base data types and how they can be passed to and from functions. Internally, Postgres Pro regards a base type as a "blob of memory". The user-defined functions that you define over a type in turn define the way that Postgres Pro can operate on it. That is, Postgres Pro will only store and retrieve the data from disk and use your user-defined functions to input, process, and output the data.

Base types can have one of three internal formats:

- pass by value, fixed-length
- pass by reference, fixed-length
- pass by reference, variable-length

By-value types can only be 1, 2, or 4 bytes in length (also 8 bytes, if `sizeof(Datum)` is 8 on your machine). You should be careful to define your types such that they will be the same size (in bytes) on all architectures. For example, the `long` type is dangerous because it is 4 bytes on some machines and 8 bytes on others, whereas `int` type is 4 bytes on most Unix machines. A reasonable implementation of the `int4` type on Unix machines might be:

```
/* 4-byte integer, passed by value */
typedef int int4;
```

(The actual Postgres Pro C code calls this type `int32`, because it is a convention in C that `int`*XX* means *XX bits*. Note therefore also that the C type `int8` is 1 byte in size. The SQL type `int8` is called `int64` in C. See also Table 40.2.)

On the other hand, fixed-length types of any size can be passed by-reference. For example, here is a sample implementation of a Postgres Pro type:

```
/* 16-byte structure, passed by reference */
typedef struct
{
    double  x, y;
} Point;
```

Only pointers to such types can be used when passing them in and out of Postgres Pro functions. To return a value of such a type, allocate the right amount of memory with `palloc`, fill in the allocated memory, and return a pointer to it. (Also, if you just want to return the same value as one of your input arguments that's of the same data type, you can skip the extra `palloc` and just return the pointer to the input value.)

Finally, all variable-length types must also be passed by reference. All variable-length types must begin with an opaque length field of exactly 4 bytes, which will be set by `SET_VARSIZE`; never set this field directly! All data to be stored within that type must be located in the memory immediately following that length field. The length field contains the total length of the structure, that is, it includes the size of the length field itself.

Another important point is to avoid leaving any uninitialized bits within data type values; for example, take care to zero out any alignment padding bytes that might be present in structs. Without this, logically-equivalent constants of your data type might be seen as unequal by the planner, leading to inefficient (though not incorrect) plans.

> **Warning**
>
> *Never* modify the contents of a pass-by-reference input value. If you do so you are likely to corrupt on-disk data, since the pointer you are given might point directly into a disk buffer. The sole exception to this rule is explained in Section 40.12.

As an example, we can define the type `text` as follows:

```
typedef struct {
    int32 length;
    char data[FLEXIBLE_ARRAY_MEMBER];
} text;
```

The `[FLEXIBLE_ARRAY_MEMBER]` notation means that the actual length of the data part is not specified by this declaration.

When manipulating variable-length types, we must be careful to allocate the correct amount of memory and set the length field correctly. For example, if we wanted to store 40 bytes in a `text` structure, we might use a code fragment like this:

```
#include "postgres.h"
...
char buffer[40]; /* our source data */
...
text *destination = (text *) palloc(VARHDRSZ + 40);
SET_VARSIZE(destination, VARHDRSZ + 40);
memcpy(destination->data, buffer, 40);
...
```

`VARHDRSZ` is the same as `sizeof(int32)`, but it's considered good style to use the macro `VARHDRSZ` to refer to the size of the overhead for a variable-length type. Also, the length field *must* be set using the `SET_VARSIZE` macro, not by simple assignment.

Table 40.2 shows the C types corresponding to many of the built-in SQL data types of Postgres Pro. The “Defined In” column gives the header file that needs to be included to get the type definition. (The actual

definition might be in a different file that is included by the listed file. It is recommended that users stick to the defined interface.) Note that you should always include `postgres.h` first in any source file of server code, because it declares a number of things that you will need anyway, and because including other headers first can cause portability issues.

Table 40.2. Equivalent C Types for Built-in SQL Types

SQL Type	C Type	Defined In
boolean	bool	postgres.h (maybe compiler built-in)
box	BOX*	utils/geo_decls.h
bytea	bytea*	postgres.h
"char"	char	(compiler built-in)
character	BpChar*	postgres.h
cid	CommandId	postgres.h
date	DateADT	utils/date.h
float4 (real)	float4	postgres.h
float8 (double precision)	float8	postgres.h
int2 (smallint)	int16	postgres.h
int4 (integer)	int32	postgres.h
int8 (bigint)	int64	postgres.h
interval	Interval*	datatype/timestamp.h
lseg	LSEG*	utils/geo_decls.h
name	Name	postgres.h
numeric	Numeric	utils/numeric.h
oid	Oid	postgres.h
oidvector	oidvector*	postgres.h
path	PATH*	utils/geo_decls.h
point	POINT*	utils/geo_decls.h
regproc	RegProcedure	postgres.h
text	text*	postgres.h
tid	ItemPointer	storage/itemptr.h
time	TimeADT	utils/date.h
time with time zone	TimeTzADT	utils/date.h
timestamp	Timestamp	datatype/timestamp.h
timestamp with time zone	TimestampTz	datatype/timestamp.h
varchar	VarChar*	postgres.h
xid	TransactionId	postgres.h

Now that we've gone over all of the possible structures for base types, we can show some examples of real functions.

40.10.3. Version 1 Calling Conventions

The version-1 calling convention relies on macros to suppress most of the complexity of passing arguments and results. The C declaration of a version-1 function is always:

```
Datum funcname(PG_FUNCTION_ARGS)
```

In addition, the macro call:

```
PG_FUNCTION_INFO_V1(funcname);
```

must appear in the same source file. (Conventionally, it's written just before the function itself.) This macro call is not needed for `internal`-language functions, since Postgres Pro assumes that all internal functions use the version-1 convention. It is, however, required for dynamically-loaded functions.

In a version-1 function, each actual argument is fetched using a `PG_GETARG_`*xxx*`()` macro that corresponds to the argument's data type. (In non-strict functions there needs to be a previous check about argument null-ness using `PG_ARGISNULL()`; see below.) The result is returned using a `PG_RETURN_`*xxx*`()` macro for the return type. `PG_GETARG_`*xxx*`()` takes as its argument the number of the function argument to fetch, where the count starts at 0. `PG_RETURN_`*xxx*`()` takes as its argument the actual value to return.

Here are some examples using the version-1 calling convention:

```
#include "postgres.h"
#include <string.h>
#include "fmgr.h"
#include "utils/geo_decls.h"

PG_MODULE_MAGIC;

/* by value */

PG_FUNCTION_INFO_V1(add_one);

Datum
add_one(PG_FUNCTION_ARGS)
{
    int32   arg = PG_GETARG_INT32(0);

    PG_RETURN_INT32(arg + 1);
}

/* by reference, fixed length */

PG_FUNCTION_INFO_V1(add_one_float8);

Datum
add_one_float8(PG_FUNCTION_ARGS)
{
    /* The macros for FLOAT8 hide its pass-by-reference nature. */
    float8   arg = PG_GETARG_FLOAT8(0);

    PG_RETURN_FLOAT8(arg + 1.0);
}

PG_FUNCTION_INFO_V1(makepoint);

Datum
makepoint(PG_FUNCTION_ARGS)
{
    /* Here, the pass-by-reference nature of Point is not hidden. */
    Point     *pointx = PG_GETARG_POINT_P(0);
    Point     *pointy = PG_GETARG_POINT_P(1);
    Point     *new_point = (Point *) palloc(sizeof(Point));
```

```
    new_point->x = pointx->x;
    new_point->y = pointy->y;

    PG_RETURN_POINT_P(new_point);
}

/* by reference, variable length */

PG_FUNCTION_INFO_V1(copytext);

Datum
copytext(PG_FUNCTION_ARGS)
{
    text     *t = PG_GETARG_TEXT_PP(0);

    /*
     * VARSIZE_ANY_EXHDR is the size of the struct in bytes, minus the
     * VARHDRSZ or VARHDRSZ_SHORT of its header.  Construct the copy with a
     * full-length header.
     */
    text     *new_t = (text *) palloc(VARSIZE_ANY_EXHDR(t) + VARHDRSZ);
    SET_VARSIZE(new_t, VARSIZE_ANY_EXHDR(t) + VARHDRSZ);

    /*
     * VARDATA is a pointer to the data region of the new struct.  The source
     * could be a short datum, so retrieve its data through VARDATA_ANY.
     */
    memcpy((void *) VARDATA(new_t), /* destination */
           (void *) VARDATA_ANY(t), /* source */
           VARSIZE_ANY_EXHDR(t));   /* how many bytes */
    PG_RETURN_TEXT_P(new_t);
}

PG_FUNCTION_INFO_V1(concat_text);

Datum
concat_text(PG_FUNCTION_ARGS)
{
    text  *arg1 = PG_GETARG_TEXT_PP(0);
    text  *arg2 = PG_GETARG_TEXT_PP(1);
    int32 arg1_size = VARSIZE_ANY_EXHDR(arg1);
    int32 arg2_size = VARSIZE_ANY_EXHDR(arg2);
    int32 new_text_size = arg1_size + arg2_size + VARHDRSZ;
    text *new_text = (text *) palloc(new_text_size);

    SET_VARSIZE(new_text, new_text_size);
    memcpy(VARDATA(new_text), VARDATA_ANY(arg1), arg1_size);
    memcpy(VARDATA(new_text) + arg1_size, VARDATA_ANY(arg2), arg2_size);
    PG_RETURN_TEXT_P(new_text);
}
```

Supposing that the above code has been prepared in file `funcs.c` and compiled into a shared object, we could define the functions to Postgres Pro with commands like this:

```
CREATE FUNCTION add_one(integer) RETURNS integer
     AS 'DIRECTORY/funcs', 'add_one'
     LANGUAGE C STRICT;
```

```
-- note overloading of SQL function name "add_one"
CREATE FUNCTION add_one(double precision) RETURNS double precision
     AS 'DIRECTORY/funcs', 'add_one_float8'
     LANGUAGE C STRICT;

CREATE FUNCTION makepoint(point, point) RETURNS point
     AS 'DIRECTORY/funcs', 'makepoint'
     LANGUAGE C STRICT;

CREATE FUNCTION copytext(text) RETURNS text
     AS 'DIRECTORY/funcs', 'copytext'
     LANGUAGE C STRICT;

CREATE FUNCTION concat_text(text, text) RETURNS text
     AS 'DIRECTORY/funcs', 'concat_text'
     LANGUAGE C STRICT;
```

Here, *DIRECTORY* stands for the directory of the shared library file (for instance the Postgres Pro tutorial directory, which contains the code for the examples used in this section). (Better style would be to use just 'funcs' in the AS clause, after having added *DIRECTORY* to the search path. In any case, we can omit the system-specific extension for a shared library, commonly .so.)

Notice that we have specified the functions as "strict", meaning that the system should automatically assume a null result if any input value is null. By doing this, we avoid having to check for null inputs in the function code. Without this, we'd have to check for null values explicitly, using PG_ARGISNULL().

The macro PG_ARGISNULL(*n*) allows a function to test whether each input is null. (Of course, doing this is only necessary in functions not declared "strict".) As with the PG_GETARG_*xxx*() macros, the input arguments are counted beginning at zero. Note that one should refrain from executing PG_GETARG_*xxx*() until one has verified that the argument isn't null. To return a null result, execute PG_RETURN_NULL(); this works in both strict and nonstrict functions.

At first glance, the version-1 coding conventions might appear to be just pointless obscurantism, compared to using plain C calling conventions. They do however allow us to deal with NULLable arguments/return values, and "toasted" (compressed or out-of-line) values.

Other options provided by the version-1 interface are two variants of the PG_GETARG_*xxx*() macros. The first of these, PG_GETARG_*xxx*_COPY(), guarantees to return a copy of the specified argument that is safe for writing into. (The normal macros will sometimes return a pointer to a value that is physically stored in a table, which must not be written to. Using the PG_GETARG_*xxx*_COPY() macros guarantees a writable result.) The second variant consists of the PG_GETARG_*xxx*_SLICE() macros which take three arguments. The first is the number of the function argument (as above). The second and third are the offset and length of the segment to be returned. Offsets are counted from zero, and a negative length requests that the remainder of the value be returned. These macros provide more efficient access to parts of large values in the case where they have storage type "external". (The storage type of a column can be specified using ALTER TABLE *tablename* ALTER COLUMN *colname* SET STORAGE *storagetype*. *storagetype* is one of plain, external, extended, or main.)

Finally, the version-1 function call conventions make it possible to return set results (Section 40.10.8) and implement trigger functions (Chapter 41) and procedural-language call handlers (Chapter 56).

40.10.4. Writing Code

Before we turn to the more advanced topics, we should discuss some coding rules for Postgres Pro C-language functions. While it might be possible to load functions written in languages other than C into Postgres Pro, this is usually difficult (when it is possible at all) because other languages, such as C++, FORTRAN, or Pascal often do not follow the same calling convention as C. That is, other languages do not pass argument and return values between functions in the same way. For this reason, we will assume that your C-language functions are actually written in C.

The basic rules for writing and building C functions are as follows:

- Use `pg_config --includedir-server`to find out where the Postgres Pro server header files are installed on your system (or the system that your users will be running on).
- Compiling and linking your code so that it can be dynamically loaded into Postgres Pro always requires special flags. See Section 40.10.5 for a detailed explanation of how to do it for your particular operating system.
- Remember to define a “magic block” for your shared library, as described in Section 40.10.1.
- When allocating memory, use the Postgres Pro functions `palloc`and `pfree`instead of the corresponding C library functions `malloc` and `free`. The memory allocated by `palloc` will be freed automatically at the end of each transaction, preventing memory leaks.
- Always zero the bytes of your structures using `memset` (or allocate them with `palloc0` in the first place). Even if you assign to each field of your structure, there might be alignment padding (holes in the structure) that contain garbage values. Without this, it's difficult to support hash indexes or hash joins, as you must pick out only the significant bits of your data structure to compute a hash. The planner also sometimes relies on comparing constants via bitwise equality, so you can get undesirable planning results if logically-equivalent values aren't bitwise equal.
- Most of the internal Postgres Pro types are declared in `postgres.h`, while the function manager interfaces (`PG_FUNCTION_ARGS`, etc.) are in `fmgr.h`, so you will need to include at least these two files. For portability reasons it's best to include `postgres.h` *first*, before any other system or user header files. Including `postgres.h` will also include `elog.h` and `palloc.h` for you.
- Symbol names defined within object files must not conflict with each other or with symbols defined in the Postgres Pro server executable. You will have to rename your functions or variables if you get error messages to this effect.

40.10.5. Compiling and Linking Dynamically-Loaded Functions

Before you are able to use your Postgres Pro extension functions written in C, they must be compiled and linked in a special way to produce a file that can be dynamically loaded by the server. To be precise, a *shared library* needs to be created.

For information beyond what is contained in this section you should read the documentation of your operating system, in particular the manual pages for the C compiler, `cc`, and the link editor, `ld`.

Creating shared libraries is generally analogous to linking executables: first the source files are compiled into object files, then the object files are linked together. The object files need to be created as *position-independent code* (PIC), which conceptually means that they can be placed at an arbitrary location in memory when they are loaded by the executable. (Object files intended for executables are usually not compiled that way.) The command to link a shared library contains special flags to distinguish it from linking an executable (at least in theory — on some systems the practice is much uglier).

In the following examples we assume that your source code is in a file `foo.c` and we will create a shared library `foo.so`. The intermediate object file will be called `foo.o` unless otherwise noted. A shared library can contain more than one object file, but we only use one here.

FreeBSD

The compiler flag to create PIC is `-fPIC`. To create shared libraries the compiler flag is `-shared`.

```
gcc -fPIC -c foo.c
gcc -shared -o foo.so foo.o
```

This is applicable as of version 3.0 of FreeBSD.

HP-UX

The compiler flag of the system compiler to create PIC is `+z`. When using GCC it's `-fPIC`. The linker flag for shared libraries is `-b`. So:

```
cc +z -c foo.c
```

or:

```
gcc -fPIC -c foo.c
```

and then:

```
ld -b -o foo.sl foo.o
```

HP-UX uses the extension `.sl` for shared libraries, unlike most other systems.

Linux

The compiler flag to create PIC is `-fPIC`. The compiler flag to create a shared library is `-shared`. A complete example looks like this:

```
cc -fPIC -c foo.c
cc -shared -o foo.so foo.o
```

macOS

Here is an example. It assumes the developer tools are installed.

```
cc -c foo.c
cc -bundle -flat_namespace -undefined suppress -o foo.so foo.o
```

NetBSD

The compiler flag to create PIC is `-fPIC`. For ELF systems, the compiler with the flag `-shared` is used to link shared libraries. On the older non-ELF systems, `ld -Bshareable` is used.

```
gcc -fPIC -c foo.c
gcc -shared -o foo.so foo.o
```

OpenBSD

The compiler flag to create PIC is `-fPIC`. `ld -Bshareable` is used to link shared libraries.

```
gcc -fPIC -c foo.c
ld -Bshareable -o foo.so foo.o
```

Solaris

The compiler flag to create PIC is `-KPIC` with the Sun compiler and `-fPIC` with GCC. To link shared libraries, the compiler option is `-G` with either compiler or alternatively `-shared` with GCC.

```
cc -KPIC -c foo.c
cc -G -o foo.so foo.o
```

or

```
gcc -fPIC -c foo.c
gcc -G -o foo.so foo.o
```

> **Tip**
>
> If this is too complicated for you, you should consider using *GNU Libtool*, which hides the platform differences behind a uniform interface.

The resulting shared library file can then be loaded into Postgres Pro. When specifying the file name to the `CREATE FUNCTION` command, one must give it the name of the shared library file, not the intermediate object file. Note that the system's standard shared-library extension (usually `.so` or `.sl`) can be omitted from the `CREATE FUNCTION` command, and normally should be omitted for best portability.

Refer back to Section 40.10.1 about where the server expects to find the shared library files.

40.10.6. Composite-Type Arguments

Composite types do not have a fixed layout like C structures. Instances of a composite type can contain null fields. In addition, composite types that are part of an inheritance hierarchy can have different fields than other members of the same inheritance hierarchy. Therefore, Postgres Pro provides a function interface for accessing fields of composite types from C.

Suppose we want to write a function to answer the query:

```
SELECT name, c_overpaid(emp, 1500) AS overpaid
    FROM emp
    WHERE name = 'Bill' OR name = 'Sam';
```

Using the version-1 calling conventions, we can define `c_overpaid` as:

```
#include "postgres.h"
#include "executor/executor.h"  /* for GetAttributeByName() */

PG_MODULE_MAGIC;

PG_FUNCTION_INFO_V1(c_overpaid);

Datum
c_overpaid(PG_FUNCTION_ARGS)
{
    HeapTupleHeader  t = PG_GETARG_HEAPTUPLEHEADER(0);
    int32            limit = PG_GETARG_INT32(1);
    bool isnull;
    Datum salary;

    salary = GetAttributeByName(t, "salary", &isnull);
    if (isnull)
        PG_RETURN_BOOL(false);
    /* Alternatively, we might prefer to do PG_RETURN_NULL() for null salary. */

    PG_RETURN_BOOL(DatumGetInt32(salary) > limit);
}
```

`GetAttributeByName` is the Postgres Pro system function that returns attributes out of the specified row. It has three arguments: the argument of type `HeapTupleHeader` passed into the function, the name of the desired attribute, and a return parameter that tells whether the attribute is null. `GetAttributeByName` returns a `Datum` value that you can convert to the proper data type by using the appropriate `DatumGet`*`XXX`*`()` macro. Note that the return value is meaningless if the null flag is set; always check the null flag before trying to do anything with the result.

There is also `GetAttributeByNum`, which selects the target attribute by column number instead of name.

The following command declares the function `c_overpaid` in SQL:

```
CREATE FUNCTION c_overpaid(emp, integer) RETURNS boolean
    AS 'DIRECTORY/funcs', 'c_overpaid'
    LANGUAGE C STRICT;
```

Notice we have used `STRICT` so that we did not have to check whether the input arguments were NULL.

40.10.7. Returning Rows (Composite Types)

To return a row or composite-type value from a C-language function, you can use a special API that provides macros and functions to hide most of the complexity of building composite data types. To use this API, the source file must include:

```
#include "funcapi.h"
```

There are two ways you can build a composite data value (henceforth a “tuple”): you can build it from an array of Datum values, or from an array of C strings that can be passed to the input conversion functions of the tuple's column data types. In either case, you first need to obtain or construct a `TupleDesc` descriptor for the tuple structure. When working with Datums, you pass the `TupleDesc` to `BlessTupleDesc`, and then call `heap_form_tuple` for each row. When working with C strings, you pass the `TupleDesc` to `TupleDescGetAttInMetadata`, and then call `BuildTupleFromCStrings` for each row. In the case of a function returning a set of tuples, the setup steps can all be done once during the first call of the function.

Several helper functions are available for setting up the needed `TupleDesc`. The recommended way to do this in most functions returning composite values is to call:

```
TypeFuncClass get_call_result_type(FunctionCallInfo fcinfo,
                                   Oid *resultTypeId,
                                   TupleDesc *resultTupleDesc)
```

passing the same `fcinfo` struct passed to the calling function itself. (This of course requires that you use the version-1 calling conventions.) `resultTypeId` can be specified as `NULL` or as the address of a local variable to receive the function's result type OID. `resultTupleDesc` should be the address of a local `TupleDesc` variable. Check that the result is `TYPEFUNC_COMPOSITE`; if so, `resultTupleDesc` has been filled with the needed `TupleDesc`. (If it is not, you can report an error along the lines of “function returning record called in context that cannot accept type record”.)

> **Tip**
>
> `get_call_result_type` can resolve the actual type of a polymorphic function result; so it is useful in functions that return scalar polymorphic results, not only functions that return composites. The `resultTypeId` output is primarily useful for functions returning polymorphic scalars.

> **Note**
>
> `get_call_result_type` has a sibling `get_expr_result_type`, which can be used to resolve the expected output type for a function call represented by an expression tree. This can be used when trying to determine the result type from outside the function itself. There is also `get_func_result_type`, which can be used when only the function's OID is available. However these functions are not able to deal with functions declared to return `record`, and `get_func_result_type` cannot resolve polymorphic types, so you should preferentially use `get_call_result_type`.

Older, now-deprecated functions for obtaining `TupleDesc`s are:

```
TupleDesc RelationNameGetTupleDesc(const char *relname)
```

to get a `TupleDesc` for the row type of a named relation, and:

```
TupleDesc TypeGetTupleDesc(Oid typeoid, List *colaliases)
```

to get a `TupleDesc` based on a type OID. This can be used to get a `TupleDesc` for a base or composite type. It will not work for a function that returns `record`, however, and it cannot resolve polymorphic types.

Once you have a `TupleDesc`, call:

```
TupleDesc BlessTupleDesc(TupleDesc tupdesc)
```

if you plan to work with Datums, or:

```
AttInMetadata *TupleDescGetAttInMetadata(TupleDesc tupdesc)
```

if you plan to work with C strings. If you are writing a function returning set, you can save the results of these functions in the `FuncCallContext` structure — use the `tuple_desc` or `attinmeta` field respectively.

When working with Datums, use:

```
HeapTuple heap_form_tuple(TupleDesc tupdesc, Datum *values, bool *isnull)
```

to build a `HeapTuple` given user data in Datum form.

When working with C strings, use:

```
HeapTuple BuildTupleFromCStrings(AttInMetadata *attinmeta, char **values)
```

to build a `HeapTuple` given user data in C string form. *`values`* is an array of C strings, one for each attribute of the return row. Each C string should be in the form expected by the input function of the attribute data type. In order to return a null value for one of the attributes, the corresponding pointer in the *`values`* array should be set to `NULL`. This function will need to be called again for each row you return.

Once you have built a tuple to return from your function, it must be converted into a `Datum`. Use:

```
HeapTupleGetDatum(HeapTuple tuple)
```

to convert a `HeapTuple` into a valid Datum. This `Datum` can be returned directly if you intend to return just a single row, or it can be used as the current return value in a set-returning function.

An example appears in the next section.

40.10.8. Returning Sets

C-language functions have two options for returning sets (multiple rows). In one method, called *Value-PerCall* mode, a set-returning function is called repeatedly (passing the same arguments each time) and it returns one new row on each call, until it has no more rows to return and signals that by returning NULL. The set-returning function (SRF) must therefore save enough state across calls to remember what it was doing and return the correct next item on each call. In the other method, called *Materialize* mode, an SRF fills and returns a tuplestore object containing its entire result; then only one call occurs for the whole result, and no inter-call state is needed.

When using ValuePerCall mode, it is important to remember that the query is not guaranteed to be run to completion; that is, due to options such as `LIMIT`, the executor might stop making calls to the set-returning function before all rows have been fetched. This means it is not safe to perform cleanup activities in the last call, because that might not ever happen. It's recommended to use Materialize mode for functions that need access to external resources, such as file descriptors.

The remainder of this section documents a set of helper macros that are commonly used (though not required to be used) for SRFs using ValuePerCall mode.

To use the ValuePerCall support macros described here, include `funcapi.h`. These macros work with a structure `FuncCallContext` that contains the state that needs to be saved across calls. Within the calling SRF, `fcinfo->flinfo->fn_extra` is used to hold a pointer to `FuncCallContext` across calls. The macros automatically fill that field on first use, and expect to find the same pointer there on subsequent uses.

```
typedef struct FuncCallContext
{
    /*
     * Number of times we've been called before
     *
     * call_cntr is initialized to 0 for you by SRF_FIRSTCALL_INIT(), and
     * incremented for you every time SRF_RETURN_NEXT() is called.
     */
    uint64 call_cntr;
```

```
    /*
     * OPTIONAL maximum number of calls
     *
     * max_calls is here for convenience only and setting it is optional.
     * If not set, you must provide alternative means to know when the
     * function is done.
     */
    uint64 max_calls;

    /*
     * OPTIONAL pointer to miscellaneous user-provided context information
     *
     * user_fctx is for use as a pointer to your own data to retain
     * arbitrary context information between calls of your function.
     */
    void *user_fctx;

    /*
     * OPTIONAL pointer to struct containing attribute type input metadata
     *
     * attinmeta is for use when returning tuples (i.e., composite data types)
     * and is not used when returning base data types. It is only needed
     * if you intend to use BuildTupleFromCStrings() to create the return
     * tuple.
     */
    AttInMetadata *attinmeta;

    /*
     * memory context used for structures that must live for multiple calls
     *
     * multi_call_memory_ctx is set by SRF_FIRSTCALL_INIT() for you, and used
     * by SRF_RETURN_DONE() for cleanup. It is the most appropriate memory
     * context for any memory that is to be reused across multiple calls
     * of the SRF.
     */
    MemoryContext multi_call_memory_ctx;

    /*
     * OPTIONAL pointer to struct containing tuple description
     *
     * tuple_desc is for use when returning tuples (i.e., composite data types)
     * and is only needed if you are going to build the tuples with
     * heap_form_tuple() rather than with BuildTupleFromCStrings().  Note that
     * the TupleDesc pointer stored here should usually have been run through
     * BlessTupleDesc() first.
     */
    TupleDesc tuple_desc;

} FuncCallContext;
```

The macros to be used by an SRF using this infrastructure are:

`SRF_IS_FIRSTCALL()`

Use this to determine if your function is being called for the first or a subsequent time. On the first call (only), call:

`SRF_FIRSTCALL_INIT()`

to initialize the `FuncCallContext`. On every function call, including the first, call:

`SRF_PERCALL_SETUP()`

to set up for using the `FuncCallContext`.

If your function has data to return in the current call, use:

`SRF_RETURN_NEXT(funcctx, result)`

to return it to the caller. (`result` must be of type `Datum`, either a single value or a tuple prepared as described above.) Finally, when your function is finished returning data, use:

`SRF_RETURN_DONE(funcctx)`

to clean up and end the SRF.

The memory context that is current when the SRF is called is a transient context that will be cleared between calls. This means that you do not need to call `pfree` on everything you allocated using `palloc`; it will go away anyway. However, if you want to allocate any data structures to live across calls, you need to put them somewhere else. The memory context referenced by `multi_call_memory_ctx` is a suitable location for any data that needs to survive until the SRF is finished running. In most cases, this means that you should switch into `multi_call_memory_ctx` while doing the first-call setup. Use `funcctx->user_fctx` to hold a pointer to any such cross-call data structures. (Data you allocate in `multi_call_memory_ctx` will go away automatically when the query ends, so it is not necessary to free that data manually, either.)

> **Warning**
>
> While the actual arguments to the function remain unchanged between calls, if you detoast the argument values (which is normally done transparently by the `PG_GETARG_xxx` macro) in the transient context then the detoasted copies will be freed on each cycle. Accordingly, if you keep references to such values in your `user_fctx`, you must either copy them into the `multi_call_memory_ctx` after detoasting, or ensure that you detoast the values only in that context.

A complete pseudo-code example looks like the following:

```
Datum
my_set_returning_function(PG_FUNCTION_ARGS)
{
    FuncCallContext  *funcctx;
    Datum             result;
    further declarations as needed

    if (SRF_IS_FIRSTCALL())
    {
        MemoryContext oldcontext;

        funcctx = SRF_FIRSTCALL_INIT();
        oldcontext = MemoryContextSwitchTo(funcctx->multi_call_memory_ctx);
        /* One-time setup code appears here: */
        user code
        if returning composite
            build TupleDesc, and perhaps AttInMetadata
        endif returning composite
        user code
        MemoryContextSwitchTo(oldcontext);
    }

    /* Each-time setup code appears here: */
    user code
```

```
    funcctx = SRF_PERCALL_SETUP();
    user code

    /* this is just one way we might test whether we are done: */
    if (funcctx->call_cntr < funcctx->max_calls)
    {
        /* Here we want to return another item: */
        user code
        obtain result Datum
        SRF_RETURN_NEXT(funcctx, result);
    }
    else
    {
        /* Here we are done returning items, so just report that fact. */
        /* (Resist the temptation to put cleanup code here.) */
        SRF_RETURN_DONE(funcctx);
    }
}
```

A complete example of a simple SRF returning a composite type looks like:

```
PG_FUNCTION_INFO_V1(retcomposite);

Datum
retcomposite(PG_FUNCTION_ARGS)
{
    FuncCallContext     *funcctx;
    int                  call_cntr;
    int                  max_calls;
    TupleDesc            tupdesc;
    AttInMetadata       *attinmeta;

    /* stuff done only on the first call of the function */
    if (SRF_IS_FIRSTCALL())
    {
        MemoryContext   oldcontext;

        /* create a function context for cross-call persistence */
        funcctx = SRF_FIRSTCALL_INIT();

        /* switch to memory context appropriate for multiple function calls */
        oldcontext = MemoryContextSwitchTo(funcctx->multi_call_memory_ctx);

        /* total number of tuples to be returned */
        funcctx->max_calls = PG_GETARG_UINT32(0);

        /* Build a tuple descriptor for our result type */
        if (get_call_result_type(fcinfo, NULL, &tupdesc) != TYPEFUNC_COMPOSITE)
            ereport(ERROR,
                    (errcode(ERRCODE_FEATURE_NOT_SUPPORTED),
                     errmsg("function returning record called in context "
                            "that cannot accept type record")));

        /*
         * generate attribute metadata needed later to produce tuples from raw
         * C strings
         */
        attinmeta = TupleDescGetAttInMetadata(tupdesc);
        funcctx->attinmeta = attinmeta;
```

```
        MemoryContextSwitchTo(oldcontext);
    }

    /* stuff done on every call of the function */
    funcctx = SRF_PERCALL_SETUP();

    call_cntr = funcctx->call_cntr;
    max_calls = funcctx->max_calls;
    attinmeta = funcctx->attinmeta;

    if (call_cntr < max_calls)    /* do when there is more left to send */
    {
        char       **values;
        HeapTuple    tuple;
        Datum        result;

        /*
         * Prepare a values array for building the returned tuple.
         * This should be an array of C strings which will
         * be processed later by the type input functions.
         */
        values = (char **) palloc(3 * sizeof(char *));
        values[0] = (char *) palloc(16 * sizeof(char));
        values[1] = (char *) palloc(16 * sizeof(char));
        values[2] = (char *) palloc(16 * sizeof(char));

        snprintf(values[0], 16, "%d", 1 * PG_GETARG_INT32(1));
        snprintf(values[1], 16, "%d", 2 * PG_GETARG_INT32(1));
        snprintf(values[2], 16, "%d", 3 * PG_GETARG_INT32(1));

        /* build a tuple */
        tuple = BuildTupleFromCStrings(attinmeta, values);

        /* make the tuple into a datum */
        result = HeapTupleGetDatum(tuple);

        /* clean up (this is not really necessary) */
        pfree(values[0]);
        pfree(values[1]);
        pfree(values[2]);
        pfree(values);

        SRF_RETURN_NEXT(funcctx, result);
    }
    else    /* do when there is no more left */
    {
        SRF_RETURN_DONE(funcctx);
    }
}
```

One way to declare this function in SQL is:

```
CREATE TYPE __retcomposite AS (f1 integer, f2 integer, f3 integer);

CREATE OR REPLACE FUNCTION retcomposite(integer, integer)
    RETURNS SETOF __retcomposite
    AS 'filename', 'retcomposite'
```

```
    LANGUAGE C IMMUTABLE STRICT;
```

A different way is to use OUT parameters:

```
CREATE OR REPLACE FUNCTION retcomposite(IN integer, IN integer,
    OUT f1 integer, OUT f2 integer, OUT f3 integer)
    RETURNS SETOF record
    AS 'filename', 'retcomposite'
    LANGUAGE C IMMUTABLE STRICT;
```

Notice that in this method the output type of the function is formally an anonymous `record` type.

40.10.9. Polymorphic Arguments and Return Types

C-language functions can be declared to accept and return the polymorphic types described in Section 40.2.5. When a function's arguments or return types are defined as polymorphic types, the function author cannot know in advance what data type it will be called with, or need to return. There are two routines provided in `fmgr.h` to allow a version-1 C function to discover the actual data types of its arguments and the type it is expected to return. The routines are called `get_fn_expr_rettype(FmgrInfo *flinfo)` and `get_fn_expr_argtype(FmgrInfo *flinfo, int argnum)`. They return the result or argument type OID, or `InvalidOid` if the information is not available. The structure `flinfo` is normally accessed as `fcinfo->flinfo`. The parameter `argnum` is zero based. `get_call_result_type` can also be used as an alternative to `get_fn_expr_rettype`. There is also `get_fn_expr_variadic`, which can be used to find out whether variadic arguments have been merged into an array. This is primarily useful for `VARIADIC "any"` functions, since such merging will always have occurred for variadic functions taking ordinary array types.

For example, suppose we want to write a function to accept a single element of any type, and return a one-dimensional array of that type:

```
PG_FUNCTION_INFO_V1(make_array);
Datum
make_array(PG_FUNCTION_ARGS)
{
    ArrayType  *result;
    Oid         element_type = get_fn_expr_argtype(fcinfo->flinfo, 0);
    Datum       element;
    bool        isnull;
    int16       typlen;
    bool        typbyval;
    char        typalign;
    int         ndims;
    int         dims[MAXDIM];
    int         lbs[MAXDIM];

    if (!OidIsValid(element_type))
        elog(ERROR, "could not determine data type of input");

    /* get the provided element, being careful in case it's NULL */
    isnull = PG_ARGISNULL(0);
    if (isnull)
        element = (Datum) 0;
    else
        element = PG_GETARG_DATUM(0);

    /* we have one dimension */
    ndims = 1;
    /* and one element */
    dims[0] = 1;
    /* and lower bound is 1 */
```

```
    lbs[0] = 1;

    /* get required info about the element type */
    get_typlenbyvalalign(element_type, &typlen, &typbyval, &typalign);

    /* now build the array */
    result = construct_md_array(&element, &isnull, ndims, dims, lbs,
                                element_type, typlen, typbyval, typalign);

    PG_RETURN_ARRAYTYPE_P(result);
}
```

The following command declares the function `make_array` in SQL:

```
CREATE FUNCTION make_array(anyelement) RETURNS anyarray
    AS 'DIRECTORY/funcs', 'make_array'
    LANGUAGE C IMMUTABLE;
```

There is a variant of polymorphism that is only available to C-language functions: they can be declared to take parameters of type `"any"`. (Note that this type name must be double-quoted, since it's also an SQL reserved word.) This works like `anyelement` except that it does not constrain different `"any"` arguments to be the same type, nor do they help determine the function's result type. A C-language function can also declare its final parameter to be `VARIADIC "any"`. This will match one or more actual arguments of any type (not necessarily the same type). These arguments will *not* be gathered into an array as happens with normal variadic functions; they will just be passed to the function separately. The `PG_NARGS()` macro and the methods described above must be used to determine the number of actual arguments and their types when using this feature. Also, users of such a function might wish to use the `VARIADIC` keyword in their function call, with the expectation that the function would treat the array elements as separate arguments. The function itself must implement that behavior if wanted, after using `get_fn_expr_variadic` to detect that the actual argument was marked with `VARIADIC`.

40.10.10. Shared Memory and LWLocks

Add-ins can reserve LWLocks and an allocation of shared memory on server startup. The add-in's shared library must be preloaded by specifying it in shared_preload_libraries. Shared memory is reserved by calling:

```
void RequestAddinShmemSpace(int size)
```

from your `_PG_init` function.

LWLocks are reserved by calling:

```
void RequestNamedLWLockTranche(const char *tranche_name, int num_lwlocks)
```

from `_PG_init`. This will ensure that an array of `num_lwlocks` LWLocks is available under the name `tranche_name`. Use `GetNamedLWLockTranche` to get a pointer to this array.

To avoid possible race-conditions, each backend should use the LWLock `AddinShmemInitLock` when connecting to and initializing its allocation of shared memory, as shown here:

```
static mystruct *ptr = NULL;

if (!ptr)
{
        bool    found;

        LWLockAcquire(AddinShmemInitLock, LW_EXCLUSIVE);
        ptr = ShmemInitStruct("my struct name", size, &found);
        if (!found)
        {
```

```
                initialize contents of shmem area;
                acquire any requested LWLocks using:
                ptr->locks = GetNamedLWLockTranche("my tranche name");
        }
        LWLockRelease(AddinShmemInitLock);
}
```

40.10.11. Using C++ for Extensibility

Although the Postgres Pro backend is written in C, it is possible to write extensions in C++ if these guidelines are followed:

- All functions accessed by the backend must present a C interface to the backend; these C functions can then call C++ functions. For example, `extern C` linkage is required for backend-accessed functions. This is also necessary for any functions that are passed as pointers between the backend and C++ code.
- Free memory using the appropriate deallocation method. For example, most backend memory is allocated using `palloc()`, so use `pfree()` to free it. Using C++ `delete` in such cases will fail.
- Prevent exceptions from propagating into the C code (use a catch-all block at the top level of all `extern C` functions). This is necessary even if the C++ code does not explicitly throw any exceptions, because events like out-of-memory can still throw exceptions. Any exceptions must be caught and appropriate errors passed back to the C interface. If possible, compile C++ with `-fno-exceptions` to eliminate exceptions entirely; in such cases, you must check for failures in your C++ code, e.g., check for NULL returned by `new()`.
- If calling backend functions from C++ code, be sure that the C++ call stack contains only plain old data structures (POD). This is necessary because backend errors generate a distant `longjmp()` that does not properly unroll a C++ call stack with non-POD objects.

In summary, it is best to place C++ code behind a wall of `extern C` functions that interface to the backend, and avoid exception, memory, and call stack leakage.

40.11. Function Optimization Information

By default, a function is just a “black box” that the database system knows very little about the behavior of. However, that means that queries using the function may be executed much less efficiently than they could be. It is possible to supply additional knowledge that helps the planner optimize function calls.

Some basic facts can be supplied by declarative annotations provided in the `CREATE FUNCTION` command. Most important of these is the function's volatility category (`IMMUTABLE`, `STABLE`, or `VOLATILE`); one should always be careful to specify this correctly when defining a function. The parallel safety property (`PARALLEL UNSAFE`, `PARALLEL RESTRICTED`, or `PARALLEL SAFE`) must also be specified if you hope to use the function in parallelized queries. It can also be useful to specify the function's estimated execution cost, and/or the number of rows a set-returning function is estimated to return. However, the declarative way of specifying those two facts only allows specifying a constant value, which is often inadequate.

It is also possible to attach a *planner support function* to an SQL-callable function (called its *target function*), and thereby provide knowledge about the target function that is too complex to be represented declaratively. Planner support functions have to be written in C (although their target functions might not be), so this is an advanced feature that relatively few people will use.

A planner support function must have the SQL signature

```
supportfn(internal) returns internal
```

It is attached to its target function by specifying the `SUPPORT` clause when creating the target function.

Here we provide an overview of what planner support functions can do. The set of possible requests to a support function is extensible, so more things might be possible in future versions.

Some function calls can be simplified during planning based on properties specific to the function. For example, `int4mul(n, 1)` could be simplified to just `n`. This type of transformation can be performed by a planner support function, by having it implement the `SupportRequestSimplify` request type. The support function will be called for each instance of its target function found in a query parse tree. If it finds that the particular call can be simplified into some other form, it can build and return a parse tree representing that expression. This will automatically work for operators based on the function, too — in the example just given, `n * 1` would also be simplified to `n`. (But note that this is just an example; this particular optimization is not actually performed by standard Postgres Pro.) We make no guarantee that Postgres Pro will never call the target function in cases that the support function could simplify. Ensure rigorous equivalence between the simplified expression and an actual execution of the target function.

For target functions that return `boolean`, it is often useful to estimate the fraction of rows that will be selected by a `WHERE` clause using that function. This can be done by a support function that implements the `SupportRequestSelectivity` request type.

If the target function's run time is highly dependent on its inputs, it may be useful to provide a non-constant cost estimate for it. This can be done by a support function that implements the `SupportRequestCost` request type.

For target functions that return sets, it is often useful to provide a non-constant estimate for the number of rows that will be returned. This can be done by a support function that implements the `SupportRequestRows` request type.

For target functions that return `boolean`, it may be possible to convert a function call appearing in `WHERE` into an indexable operator clause or clauses. The converted clauses might be exactly equivalent to the function's condition, or they could be somewhat weaker (that is, they might accept some values that the function condition does not). In the latter case the index condition is said to be *lossy*; it can still be used to scan an index, but the function call will have to be executed for each row returned by the index to see if it really passes the `WHERE` condition or not. To create such conditions, the support function must implement the `SupportRequestIndexCondition` request type.

40.12. User-Defined Aggregates

Aggregate functions in Postgres Pro are defined in terms of *state values* and *state transition functions*. That is, an aggregate operates using a state value that is updated as each successive input row is processed. To define a new aggregate function, one selects a data type for the state value, an initial value for the state, and a state transition function. The state transition function takes the previous state value and the aggregate's input value(s) for the current row, and returns a new state value. A *final function* can also be specified, in case the desired result of the aggregate is different from the data that needs to be kept in the running state value. The final function takes the ending state value and returns whatever is wanted as the aggregate result. In principle, the transition and final functions are just ordinary functions that could also be used outside the context of the aggregate. (In practice, it's often helpful for performance reasons to create specialized transition functions that can only work when called as part of an aggregate.)

Thus, in addition to the argument and result data types seen by a user of the aggregate, there is an internal state-value data type that might be different from both the argument and result types.

If we define an aggregate that does not use a final function, we have an aggregate that computes a running function of the column values from each row. `sum` is an example of this kind of aggregate. `sum` starts at zero and always adds the current row's value to its running total. For example, if we want to make a `sum` aggregate to work on a data type for complex numbers, we only need the addition function for that data type. The aggregate definition would be:

```
CREATE AGGREGATE sum (complex)
(
    sfunc = complex_add,
    stype = complex,
```

```
    initcond = '(0,0)'
);
```

which we might use like this:

```
SELECT sum(a) FROM test_complex;

   sum
-----------
 (34,53.9)
```

(Notice that we are relying on function overloading: there is more than one aggregate named `sum`, but Postgres Pro can figure out which kind of sum applies to a column of type `complex`.)

The above definition of `sum` will return zero (the initial state value) if there are no nonnull input values. Perhaps we want to return null in that case instead — the SQL standard expects `sum` to behave that way. We can do this simply by omitting the `initcond` phrase, so that the initial state value is null. Ordinarily this would mean that the `sfunc` would need to check for a null state-value input. But for `sum` and some other simple aggregates like `max` and `min`, it is sufficient to insert the first nonnull input value into the state variable and then start applying the transition function at the second nonnull input value. Postgres Pro will do that automatically if the initial state value is null and the transition function is marked “strict” (i.e., not to be called for null inputs).

Another bit of default behavior for a “strict” transition function is that the previous state value is retained unchanged whenever a null input value is encountered. Thus, null values are ignored. If you need some other behavior for null inputs, do not declare your transition function as strict; instead code it to test for null inputs and do whatever is needed.

`avg` (average) is a more complex example of an aggregate. It requires two pieces of running state: the sum of the inputs and the count of the number of inputs. The final result is obtained by dividing these quantities. Average is typically implemented by using an array as the state value. For example, the built-in implementation of `avg(float8)` looks like:

```
CREATE AGGREGATE avg (float8)
(
    sfunc = float8_accum,
    stype = float8[],
    finalfunc = float8_avg,
    initcond = '{0,0,0}'
);
```

> **Note**
>
> `float8_accum` requires a three-element array, not just two elements, because it accumulates the sum of squares as well as the sum and count of the inputs. This is so that it can be used for some other aggregates as well as `avg`.

Aggregate function calls in SQL allow `DISTINCT` and `ORDER BY` options that control which rows are fed to the aggregate's transition function and in what order. These options are implemented behind the scenes and are not the concern of the aggregate's support functions.

For further details see the CREATE AGGREGATE command.

40.12.1. Moving-Aggregate Mode

Aggregate functions can optionally support *moving-aggregate mode*, which allows substantially faster execution of aggregate functions within windows with moving frame starting points. (See Section 3.5 and Section 4.2.8 for information about use of aggregate functions as window functions.) The basic idea

is that in addition to a normal “forward” transition function, the aggregate provides an *inverse transition function*, which allows rows to be removed from the aggregate's running state value when they exit the window frame. For example a `sum` aggregate, which uses addition as the forward transition function, would use subtraction as the inverse transition function. Without an inverse transition function, the window function mechanism must recalculate the aggregate from scratch each time the frame starting point moves, resulting in run time proportional to the number of input rows times the average frame length. With an inverse transition function, the run time is only proportional to the number of input rows.

The inverse transition function is passed the current state value and the aggregate input value(s) for the earliest row included in the current state. It must reconstruct what the state value would have been if the given input row had never been aggregated, but only the rows following it. This sometimes requires that the forward transition function keep more state than is needed for plain aggregation mode. Therefore, the moving-aggregate mode uses a completely separate implementation from the plain mode: it has its own state data type, its own forward transition function, and its own final function if needed. These can be the same as the plain mode's data type and functions, if there is no need for extra state.

As an example, we could extend the `sum` aggregate given above to support moving-aggregate mode like this:

```
CREATE AGGREGATE sum (complex)
(
    sfunc = complex_add,
    stype = complex,
    initcond = '(0,0)',
    msfunc = complex_add,
    minvfunc = complex_sub,
    mstype = complex,
    minitcond = '(0,0)'
);
```

The parameters whose names begin with `m` define the moving-aggregate implementation. Except for the inverse transition function `minvfunc`, they correspond to the plain-aggregate parameters without `m`.

The forward transition function for moving-aggregate mode is not allowed to return null as the new state value. If the inverse transition function returns null, this is taken as an indication that the inverse function cannot reverse the state calculation for this particular input, and so the aggregate calculation will be redone from scratch for the current frame starting position. This convention allows moving-aggregate mode to be used in situations where there are some infrequent cases that are impractical to reverse out of the running state value. The inverse transition function can “punt” on these cases, and yet still come out ahead so long as it can work for most cases. As an example, an aggregate working with floating-point numbers might choose to punt when a `NaN` (not a number) input has to be removed from the running state value.

When writing moving-aggregate support functions, it is important to be sure that the inverse transition function can reconstruct the correct state value exactly. Otherwise there might be user-visible differences in results depending on whether the moving-aggregate mode is used. An example of an aggregate for which adding an inverse transition function seems easy at first, yet where this requirement cannot be met is `sum` over `float4` or `float8` inputs. A naive declaration of `sum(float8)` could be

```
CREATE AGGREGATE unsafe_sum (float8)
(
    stype = float8,
    sfunc = float8pl,
    mstype = float8,
    msfunc = float8pl,
    minvfunc = float8mi
);
```

This aggregate, however, can give wildly different results than it would have without the inverse transition function. For example, consider

```
SELECT
  unsafe_sum(x) OVER (ORDER BY n ROWS BETWEEN CURRENT ROW AND 1 FOLLOWING)
FROM (VALUES (1, 1.0e20::float8),
             (2, 1.0::float8)) AS v (n,x);
```

This query returns `0` as its second result, rather than the expected answer of `1`. The cause is the limited precision of floating-point values: adding `1` to `1e20` results in `1e20` again, and so subtracting `1e20` from that yields `0`, not `1`. Note that this is a limitation of floating-point arithmetic in general, not a limitation of Postgres Pro.

40.12.2. Polymorphic and Variadic Aggregates

Aggregate functions can use polymorphic state transition functions or final functions, so that the same functions can be used to implement multiple aggregates. See Section 40.2.5 for an explanation of polymorphic functions. Going a step further, the aggregate function itself can be specified with polymorphic input type(s) and state type, allowing a single aggregate definition to serve for multiple input data types. Here is an example of a polymorphic aggregate:

```
CREATE AGGREGATE array_accum (anycompatible)
(
    sfunc = array_append,
    stype = anycompatiblearray,
    initcond = '{}'
);
```

Here, the actual state type for any given aggregate call is the array type having the actual input type as elements. The behavior of the aggregate is to concatenate all the inputs into an array of that type. (Note: the built-in aggregate `array_agg` provides similar functionality, with better performance than this definition would have.)

Here's the output using two different actual data types as arguments:

```
SELECT attrelid::regclass, array_accum(attname)
    FROM pg_attribute
    WHERE attnum > 0 AND attrelid = 'pg_tablespace'::regclass
    GROUP BY attrelid;

   attrelid    |              array_accum
---------------+---------------------------------------
 pg_tablespace | {spcname,spcowner,spcacl,spcoptions}
(1 row)

SELECT attrelid::regclass, array_accum(atttypid::regtype)
    FROM pg_attribute
    WHERE attnum > 0 AND attrelid = 'pg_tablespace'::regclass
    GROUP BY attrelid;

   attrelid    |        array_accum
---------------+---------------------------
 pg_tablespace | {name,oid,aclitem[],text[]}
(1 row)
```

Ordinarily, an aggregate function with a polymorphic result type has a polymorphic state type, as in the above example. This is necessary because otherwise the final function cannot be declared sensibly: it would need to have a polymorphic result type but no polymorphic argument type, which `CREATE FUNCTION` will reject on the grounds that the result type cannot be deduced from a call. But sometimes it is inconvenient to use a polymorphic state type. The most common case is where the aggregate support functions are to be written in C and the state type should be declared as `internal` because there is no SQL-level equivalent for it. To address this case, it is possible to declare the final function as taking extra “dummy” arguments that match the input arguments of the aggregate. Such dummy arguments

are always passed as null values since no specific value is available when the final function is called. Their only use is to allow a polymorphic final function's result type to be connected to the aggregate's input type(s). For example, the definition of the built-in aggregate `array_agg` is equivalent to

```
CREATE FUNCTION array_agg_transfn(internal, anynonarray)
  RETURNS internal ...;
CREATE FUNCTION array_agg_finalfn(internal, anynonarray)
  RETURNS anyarray ...;

CREATE AGGREGATE array_agg (anynonarray)
(
    sfunc = array_agg_transfn,
    stype = internal,
    finalfunc = array_agg_finalfn,
    finalfunc_extra
);
```

Here, the `finalfunc_extra` option specifies that the final function receives, in addition to the state value, extra dummy argument(s) corresponding to the aggregate's input argument(s). The extra `anynonarray` argument allows the declaration of `array_agg_finalfn` to be valid.

An aggregate function can be made to accept a varying number of arguments by declaring its last argument as a `VARIADIC` array, in much the same fashion as for regular functions; see Section 40.5.6. The aggregate's transition function(s) must have the same array type as their last argument. The transition function(s) typically would also be marked `VARIADIC`, but this is not strictly required.

> **Note**
>
> Variadic aggregates are easily misused in connection with the `ORDER BY` option (see Section 4.2.7), since the parser cannot tell whether the wrong number of actual arguments have been given in such a combination. Keep in mind that everything to the right of `ORDER BY` is a sort key, not an argument to the aggregate. For example, in
>
> ```
> SELECT myaggregate(a ORDER BY a, b, c) FROM ...
> ```
>
> the parser will see this as a single aggregate function argument and three sort keys. However, the user might have intended
>
> ```
> SELECT myaggregate(a, b, c ORDER BY a) FROM ...
> ```
>
> If `myaggregate` is variadic, both these calls could be perfectly valid.
>
> For the same reason, it's wise to think twice before creating aggregate functions with the same names and different numbers of regular arguments.

40.12.3. Ordered-Set Aggregates

The aggregates we have been describing so far are “normal” aggregates. Postgres Pro also supports *ordered-set aggregates*, which differ from normal aggregates in two key ways. First, in addition to ordinary aggregated arguments that are evaluated once per input row, an ordered-set aggregate can have “direct” arguments that are evaluated only once per aggregation operation. Second, the syntax for the ordinary aggregated arguments specifies a sort ordering for them explicitly. An ordered-set aggregate is usually used to implement a computation that depends on a specific row ordering, for instance rank or percentile, so that the sort ordering is a required aspect of any call. For example, the built-in definition of `percentile_disc` is equivalent to:

```
CREATE FUNCTION ordered_set_transition(internal, anyelement)
  RETURNS internal ...;
CREATE FUNCTION percentile_disc_final(internal, float8, anyelement)
```

```
  RETURNS anyelement ...;

CREATE AGGREGATE percentile_disc (float8 ORDER BY anyelement)
(
    sfunc = ordered_set_transition,
    stype = internal,
    finalfunc = percentile_disc_final,
    finalfunc_extra
);
```

This aggregate takes a `float8` direct argument (the percentile fraction) and an aggregated input that can be of any sortable data type. It could be used to obtain a median household income like this:

```
SELECT percentile_disc(0.5) WITHIN GROUP (ORDER BY income) FROM households;
 percentile_disc
-----------------
           50489
```

Here, `0.5` is a direct argument; it would make no sense for the percentile fraction to be a value varying across rows.

Unlike the case for normal aggregates, the sorting of input rows for an ordered-set aggregate is *not* done behind the scenes, but is the responsibility of the aggregate's support functions. The typical implementation approach is to keep a reference to a “tuplesort” object in the aggregate's state value, feed the incoming rows into that object, and then complete the sorting and read out the data in the final function. This design allows the final function to perform special operations such as injecting additional “hypothetical” rows into the data to be sorted. While normal aggregates can often be implemented with support functions written in PL/pgSQL or another PL language, ordered-set aggregates generally have to be written in C, since their state values aren't definable as any SQL data type. (In the above example, notice that the state value is declared as type `internal` — this is typical.) Also, because the final function performs the sort, it is not possible to continue adding input rows by executing the transition function again later. This means the final function is not `READ_ONLY`; it must be declared in `CREATE AGGREGATE` as `READ_WRITE`, or as `SHAREABLE` if it's possible for additional final-function calls to make use of the already-sorted state.

The state transition function for an ordered-set aggregate receives the current state value plus the aggregated input values for each row, and returns the updated state value. This is the same definition as for normal aggregates, but note that the direct arguments (if any) are not provided. The final function receives the last state value, the values of the direct arguments if any, and (if `finalfunc_extra` is specified) null values corresponding to the aggregated input(s). As with normal aggregates, `finalfunc_extra` is only really useful if the aggregate is polymorphic; then the extra dummy argument(s) are needed to connect the final function's result type to the aggregate's input type(s).

Currently, ordered-set aggregates cannot be used as window functions, and therefore there is no need for them to support moving-aggregate mode.

40.12.4. Partial Aggregation

Optionally, an aggregate function can support *partial aggregation*. The idea of partial aggregation is to run the aggregate's state transition function over different subsets of the input data independently, and then to combine the state values resulting from those subsets to produce the same state value that would have resulted from scanning all the input in a single operation. This mode can be used for parallel aggregation by having different worker processes scan different portions of a table. Each worker produces a partial state value, and at the end those state values are combined to produce a final state value. (In the future this mode might also be used for purposes such as combining aggregations over local and remote tables; but that is not implemented yet.)

To support partial aggregation, the aggregate definition must provide a *combine function*, which takes two values of the aggregate's state type (representing the results of aggregating over two subsets of the input rows) and produces a new value of the state type, representing what the state would have been

after aggregating over the combination of those sets of rows. It is unspecified what the relative order of the input rows from the two sets would have been. This means that it's usually impossible to define a useful combine function for aggregates that are sensitive to input row order.

As simple examples, `MAX` and `MIN` aggregates can be made to support partial aggregation by specifying the combine function as the same greater-of-two or lesser-of-two comparison function that is used as their transition function. `SUM` aggregates just need an addition function as combine function. (Again, this is the same as their transition function, unless the state value is wider than the input data type.)

The combine function is treated much like a transition function that happens to take a value of the state type, not of the underlying input type, as its second argument. In particular, the rules for dealing with null values and strict functions are similar. Also, if the aggregate definition specifies a non-null `initcond`, keep in mind that that will be used not only as the initial state for each partial aggregation run, but also as the initial state for the combine function, which will be called to combine each partial result into that state.

If the aggregate's state type is declared as `internal`, it is the combine function's responsibility that its result is allocated in the correct memory context for aggregate state values. This means in particular that when the first input is `NULL` it's invalid to simply return the second input, as that value will be in the wrong context and will not have sufficient lifespan.

When the aggregate's state type is declared as `internal`, it is usually also appropriate for the aggregate definition to provide a *serialization function* and a *deserialization function*, which allow such a state value to be copied from one process to another. Without these functions, parallel aggregation cannot be performed, and future applications such as local/remote aggregation will probably not work either.

A serialization function must take a single argument of type `internal` and return a result of type `bytea`, which represents the state value packaged up into a flat blob of bytes. Conversely, a deserialization function reverses that conversion. It must take two arguments of types `bytea` and `internal`, and return a result of type `internal`. (The second argument is unused and is always zero, but it is required for type-safety reasons.) The result of the deserialization function should simply be allocated in the current memory context, as unlike the combine function's result, it is not long-lived.

Worth noting also is that for an aggregate to be executed in parallel, the aggregate itself must be marked `PARALLEL SAFE`. The parallel-safety markings on its support functions are not consulted.

40.12.5. Support Functions for Aggregates

A function written in C can detect that it is being called as an aggregate support function by calling `AggCheckCallContext`, for example:

```
if (AggCheckCallContext(fcinfo, NULL))
```

One reason for checking this is that when it is true, the first input must be a temporary state value and can therefore safely be modified in-place rather than allocating a new copy. See `int8inc()` for an example. (While aggregate transition functions are always allowed to modify the transition value in-place, aggregate final functions are generally discouraged from doing so; if they do so, the behavior must be declared when creating the aggregate. See CREATE AGGREGATE for more detail.)

The second argument of `AggCheckCallContext` can be used to retrieve the memory context in which aggregate state values are being kept. This is useful for transition functions that wish to use “expanded” objects (see Section 40.13.1) as their state values. On first call, the transition function should return an expanded object whose memory context is a child of the aggregate state context, and then keep returning the same expanded object on subsequent calls. See `array_append()` for an example. (`array_append()` is not the transition function of any built-in aggregate, but it is written to behave efficiently when used as transition function of a custom aggregate.)

Another support routine available to aggregate functions written in C is `AggGetAggref`, which returns the `Aggref` parse node that defines the aggregate call. This is mainly useful for ordered-set aggregates,

which can inspect the substructure of the `Aggref` node to find out what sort ordering they are supposed to implement.

40.13. User-Defined Types

As described in Section 40.2, Postgres Pro can be extended to support new data types. This section describes how to define new base types, which are data types defined below the level of the SQL language. Creating a new base type requires implementing functions to operate on the type in a low-level language, usually C.

A user-defined type must always have input and output functions. These functions determine how the type appears in strings (for input by the user and output to the user) and how the type is organized in memory. The input function takes a null-terminated character string as its argument and returns the internal (in memory) representation of the type. The output function takes the internal representation of the type as argument and returns a null-terminated character string. If we want to do anything more with the type than merely store it, we must provide additional functions to implement whatever operations we'd like to have for the type.

Suppose we want to define a type `complex` that represents complex numbers. A natural way to represent a complex number in memory would be the following C structure:

```
typedef struct Complex {
    double      x;
    double      y;
} Complex;
```

We will need to make this a pass-by-reference type, since it's too large to fit into a single `Datum` value.

As the external string representation of the type, we choose a string of the form `(x,y)`.

The input and output functions are usually not hard to write, especially the output function. But when defining the external string representation of the type, remember that you must eventually write a complete and robust parser for that representation as your input function. For instance:

```
PG_FUNCTION_INFO_V1(complex_in);

Datum
complex_in(PG_FUNCTION_ARGS)
{
    char       *str = PG_GETARG_CSTRING(0);
    double      x,
                y;
    Complex    *result;

    if (sscanf(str, " ( %lf , %lf )", &x, &y) != 2)
        ereport(ERROR,
                (errcode(ERRCODE_INVALID_TEXT_REPRESENTATION),
                 errmsg("invalid input syntax for type %s: \"%s\"",
                        "complex", str)));

    result = (Complex *) palloc(sizeof(Complex));
    result->x = x;
    result->y = y;
    PG_RETURN_POINTER(result);
}
```

The output function can simply be:

```
PG_FUNCTION_INFO_V1(complex_out);
```

```
Datum
complex_out(PG_FUNCTION_ARGS)
{
    Complex    *complex = (Complex *) PG_GETARG_POINTER(0);
    char       *result;

    result = psprintf("(%g,%g)", complex->x, complex->y);
    PG_RETURN_CSTRING(result);
}
```

You should be careful to make the input and output functions inverses of each other. If you do not, you will have severe problems when you need to dump your data into a file and then read it back in. This is a particularly common problem when floating-point numbers are involved.

Optionally, a user-defined type can provide binary input and output routines. Binary I/O is normally faster but less portable than textual I/O. As with textual I/O, it is up to you to define exactly what the external binary representation is. Most of the built-in data types try to provide a machine-independent binary representation. For `complex`, we will piggy-back on the binary I/O converters for type `float8`:

```
PG_FUNCTION_INFO_V1(complex_recv);

Datum
complex_recv(PG_FUNCTION_ARGS)
{
    StringInfo  buf = (StringInfo) PG_GETARG_POINTER(0);
    Complex    *result;

    result = (Complex *) palloc(sizeof(Complex));
    result->x = pq_getmsgfloat8(buf);
    result->y = pq_getmsgfloat8(buf);
    PG_RETURN_POINTER(result);
}

PG_FUNCTION_INFO_V1(complex_send);

Datum
complex_send(PG_FUNCTION_ARGS)
{
    Complex    *complex = (Complex *) PG_GETARG_POINTER(0);
    StringInfoData buf;

    pq_begintypsend(&buf);
    pq_sendfloat8(&buf, complex->x);
    pq_sendfloat8(&buf, complex->y);
    PG_RETURN_BYTEA_P(pq_endtypsend(&buf));
}
```

Once we have written the I/O functions and compiled them into a shared library, we can define the `complex` type in SQL. First we declare it as a shell type:

```
CREATE TYPE complex;
```

This serves as a placeholder that allows us to reference the type while defining its I/O functions. Now we can define the I/O functions:

```
CREATE FUNCTION complex_in(cstring)
    RETURNS complex
```

```
    AS 'filename'
    LANGUAGE C IMMUTABLE STRICT;

CREATE FUNCTION complex_out(complex)
    RETURNS cstring
    AS 'filename'
    LANGUAGE C IMMUTABLE STRICT;

CREATE FUNCTION complex_recv(internal)
   RETURNS complex
   AS 'filename'
   LANGUAGE C IMMUTABLE STRICT;

CREATE FUNCTION complex_send(complex)
   RETURNS bytea
   AS 'filename'
   LANGUAGE C IMMUTABLE STRICT;
```

Finally, we can provide the full definition of the data type:

```
CREATE TYPE complex (
   internallength = 16,
   input = complex_in,
   output = complex_out,
   receive = complex_recv,
   send = complex_send,
   alignment = double
);
```

When you define a new base type, Postgres Pro automatically provides support for arrays of that type. The array type typically has the same name as the base type with the underscore character (_) prepended.

Once the data type exists, we can declare additional functions to provide useful operations on the data type. Operators can then be defined atop the functions, and if needed, operator classes can be created to support indexing of the data type. These additional layers are discussed in following sections.

If the internal representation of the data type is variable-length, the internal representation must follow the standard layout for variable-length data: the first four bytes must be a `char[4]` field which is never accessed directly (customarily named `vl_len_`). You must use the `SET_VARSIZE()` macro to store the total size of the datum (including the length field itself) in this field and `VARSIZE()` to retrieve it. (These macros exist because the length field may be encoded depending on platform.)

For further details see the description of the CREATE TYPE command.

40.13.1. TOAST Considerations

If the values of your data type vary in size (in internal form), it's usually desirable to make the data type TOAST-able (see Section 70.2). You should do this even if the values are always too small to be compressed or stored externally, because TOAST can save space on small data too, by reducing header overhead.

To support TOAST storage, the C functions operating on the data type must always be careful to unpack any toasted values they are handed by using `PG_DETOAST_DATUM`. (This detail is customarily hidden by defining type-specific `GETARG_DATATYPE_P` macros.) Then, when running the `CREATE TYPE` command, specify the internal length as `variable` and select some appropriate storage option other than `plain`.

If data alignment is unimportant (either just for a specific function or because the data type specifies byte alignment anyway) then it's possible to avoid some of the overhead of `PG_DETOAST_DATUM`. You can use

PG_DETOAST_DATUM_PACKED instead (customarily hidden by defining a GETARG_DATATYPE_PP macro) and using the macros VARSIZE_ANY_EXHDR and VARDATA_ANY to access a potentially-packed datum. Again, the data returned by these macros is not aligned even if the data type definition specifies an alignment. If the alignment is important you must go through the regular PG_DETOAST_DATUM interface.

> **Note**
>
> Older code frequently declares vl_len_ as an int32 field instead of char[4]. This is OK as long as the struct definition has other fields that have at least int32 alignment. But it is dangerous to use such a struct definition when working with a potentially unaligned datum; the compiler may take it as license to assume the datum actually is aligned, leading to core dumps on architectures that are strict about alignment.

Another feature that's enabled by TOAST support is the possibility of having an *expanded* in-memory data representation that is more convenient to work with than the format that is stored on disk. The regular or "flat" varlena storage format is ultimately just a blob of bytes; it cannot for example contain pointers, since it may get copied to other locations in memory. For complex data types, the flat format may be quite expensive to work with, so Postgres Pro provides a way to "expand" the flat format into a representation that is more suited to computation, and then pass that format in-memory between functions of the data type.

To use expanded storage, a data type must define an expanded format that follows the rules given in *src/include/utils/expandeddatum.h*, and provide functions to "expand" a flat varlena value into expanded format and "flatten" the expanded format back to the regular varlena representation. Then ensure that all C functions for the data type can accept either representation, possibly by converting one into the other immediately upon receipt. This does not require fixing all existing functions for the data type at once, because the standard PG_DETOAST_DATUM macro is defined to convert expanded inputs into regular flat format. Therefore, existing functions that work with the flat varlena format will continue to work, though slightly inefficiently, with expanded inputs; they need not be converted until and unless better performance is important.

C functions that know how to work with an expanded representation typically fall into two categories: those that can only handle expanded format, and those that can handle either expanded or flat varlena inputs. The former are easier to write but may be less efficient overall, because converting a flat input to expanded form for use by a single function may cost more than is saved by operating on the expanded format. When only expanded format need be handled, conversion of flat inputs to expanded form can be hidden inside an argument-fetching macro, so that the function appears no more complex than one working with traditional varlena input. To handle both types of input, write an argument-fetching function that will detoast external, short-header, and compressed varlena inputs, but not expanded inputs. Such a function can be defined as returning a pointer to a union of the flat varlena format and the expanded format. Callers can use the VARATT_IS_EXPANDED_HEADER() macro to determine which format they received.

The TOAST infrastructure not only allows regular varlena values to be distinguished from expanded values, but also distinguishes "read-write" and "read-only" pointers to expanded values. C functions that only need to examine an expanded value, or will only change it in safe and non-semantically-visible ways, need not care which type of pointer they receive. C functions that produce a modified version of an input value are allowed to modify an expanded input value in-place if they receive a read-write pointer, but must not modify the input if they receive a read-only pointer; in that case they have to copy the value first, producing a new value to modify. A C function that has constructed a new expanded value should always return a read-write pointer to it. Also, a C function that is modifying a read-write expanded value in-place should take care to leave the value in a sane state if it fails partway through.

40.14. User-Defined Operators

Every operator is "syntactic sugar" for a call to an underlying function that does the real work; so you must first create the underlying function before you can create the operator. However, an operator is *not*

merely syntactic sugar, because it carries additional information that helps the query planner optimize queries that use the operator. The next section will be devoted to explaining that additional information.

Postgres Pro supports prefix and infix operators. Operators can be overloaded; that is, the same operator name can be used for different operators that have different numbers and types of operands. When a query is executed, the system determines the operator to call from the number and types of the provided operands.

Here is an example of creating an operator for adding two complex numbers. We assume we've already created the definition of type `complex` (see Section 40.13). First we need a function that does the work, then we can define the operator:

```
CREATE FUNCTION complex_add(complex, complex)
    RETURNS complex
    AS 'filename', 'complex_add'
    LANGUAGE C IMMUTABLE STRICT;

CREATE OPERATOR + (
    leftarg = complex,
    rightarg = complex,
    function = complex_add,
    commutator = +
);
```

Now we could execute a query like this:

```
SELECT (a + b) AS c FROM test_complex;

        c
-----------------
 (5.2,6.05)
 (133.42,144.95)
```

We've shown how to create a binary operator here. To create a prefix operator, just omit the `leftarg`. The `function` clause and the argument clauses are the only required items in `CREATE OPERATOR`. The `commutator` clause shown in the example is an optional hint to the query optimizer. Further details about `commutator` and other optimizer hints appear in the next section.

40.15. Operator Optimization Information

A Postgres Pro operator definition can include several optional clauses that tell the system useful things about how the operator behaves. These clauses should be provided whenever appropriate, because they can make for considerable speedups in execution of queries that use the operator. But if you provide them, you must be sure that they are right! Incorrect use of an optimization clause can result in slow queries, subtly wrong output, or other Bad Things. You can always leave out an optimization clause if you are not sure about it; the only consequence is that queries might run slower than they need to.

Additional optimization clauses might be added in future versions of Postgres Pro. The ones described here are all the ones that release 14.18.1 understands.

It is also possible to attach a planner support function to the function that underlies an operator, providing another way of telling the system about the behavior of the operator. See Section 40.11 for more information.

40.15.1. `COMMUTATOR`

The `COMMUTATOR` clause, if provided, names an operator that is the commutator of the operator being defined. We say that operator A is the commutator of operator B if (x A y) equals (y B x) for all possible input values x, y. Notice that B is also the commutator of A. For example, operators < and > for a particular

data type are usually each others' commutators, and operator + is usually commutative with itself. But operator – is usually not commutative with anything.

The left operand type of a commutable operator is the same as the right operand type of its commutator, and vice versa. So the name of the commutator operator is all that Postgres Pro needs to be given to look up the commutator, and that's all that needs to be provided in the COMMUTATOR clause.

It's critical to provide commutator information for operators that will be used in indexes and join clauses, because this allows the query optimizer to "flip around" such a clause to the forms needed for different plan types. For example, consider a query with a WHERE clause like tab1.x = tab2.y, where tab1.x and tab2.y are of a user-defined type, and suppose that tab2.y is indexed. The optimizer cannot generate an index scan unless it can determine how to flip the clause around to tab2.y = tab1.x, because the index-scan machinery expects to see the indexed column on the left of the operator it is given. Postgres Pro will *not* simply assume that this is a valid transformation — the creator of the = operator must specify that it is valid, by marking the operator with commutator information.

When you are defining a self-commutative operator, you just do it. When you are defining a pair of commutative operators, things are a little trickier: how can the first one to be defined refer to the other one, which you haven't defined yet? There are two solutions to this problem:

- One way is to omit the COMMUTATOR clause in the first operator that you define, and then provide one in the second operator's definition. Since Postgres Pro knows that commutative operators come in pairs, when it sees the second definition it will automatically go back and fill in the missing COMMUTATOR clause in the first definition.
- The other, more straightforward way is just to include COMMUTATOR clauses in both definitions. When Postgres Pro processes the first definition and realizes that COMMUTATOR refers to a nonexistent operator, the system will make a dummy entry for that operator in the system catalog. This dummy entry will have valid data only for the operator name, left and right operand types, and result type, since that's all that Postgres Pro can deduce at this point. The first operator's catalog entry will link to this dummy entry. Later, when you define the second operator, the system updates the dummy entry with the additional information from the second definition. If you try to use the dummy operator before it's been filled in, you'll just get an error message.

40.15.2. NEGATOR

The NEGATOR clause, if provided, names an operator that is the negator of the operator being defined. We say that operator A is the negator of operator B if both return Boolean results and (x A y) equals NOT (x B y) for all possible inputs x, y. Notice that B is also the negator of A. For example, < and >= are a negator pair for most data types. An operator can never validly be its own negator.

Unlike commutators, a pair of unary operators could validly be marked as each other's negators; that would mean (A x) equals NOT (B x) for all x.

An operator's negator must have the same left and/or right operand types as the operator to be defined, so just as with COMMUTATOR, only the operator name need be given in the NEGATOR clause.

Providing a negator is very helpful to the query optimizer since it allows expressions like NOT (x = y) to be simplified into x <> y. This comes up more often than you might think, because NOT operations can be inserted as a consequence of other rearrangements.

Pairs of negator operators can be defined using the same methods explained above for commutator pairs.

40.15.3. RESTRICT

The RESTRICT clause, if provided, names a restriction selectivity estimation function for the operator. (Note that this is a function name, not an operator name.) RESTRICT clauses only make sense for binary operators that return boolean. The idea behind a restriction selectivity estimator is to guess what fraction of the rows in a table will satisfy a WHERE-clause condition of the form:

```
column OP constant
```

for the current operator and a particular constant value. This assists the optimizer by giving it some idea of how many rows will be eliminated by WHERE clauses that have this form. (What happens if the constant is on the left, you might be wondering? Well, that's one of the things that COMMUTATOR is for...)

Writing new restriction selectivity estimation functions is far beyond the scope of this chapter, but fortunately you can usually just use one of the system's standard estimators for many of your own operators. These are the standard restriction estimators:

eqsel for =
neqsel for <>
scalarltsel for <
scalarlesel for <=
scalargtsel for >
scalargesel for >=

You can frequently get away with using either eqsel or neqsel for operators that have very high or very low selectivity, even if they aren't really equality or inequality. For example, the approximate-equality geometric operators use eqsel on the assumption that they'll usually only match a small fraction of the entries in a table.

You can use scalarltsel, scalarlesel, scalargtsel and scalargesel for comparisons on data types that have some sensible means of being converted into numeric scalars for range comparisons.

Another useful built-in selectivity estimation function is matchingsel, which will work for almost any binary operator, if standard MCV and/or histogram statistics are collected for the input data type(s). Its default estimate is set to twice the default estimate used in eqsel, making it most suitable for comparison operators that are somewhat less strict than equality. (Or you could call the underlying generic_restriction_selectivity function, providing a different default estimate.)

40.15.4. JOIN

The JOIN clause, if provided, names a join selectivity estimation function for the operator. (Note that this is a function name, not an operator name.) JOIN clauses only make sense for binary operators that return boolean. The idea behind a join selectivity estimator is to guess what fraction of the rows in a pair of tables will satisfy a WHERE-clause condition of the form:

```
table1.column1 OP table2.column2
```

for the current operator. As with the RESTRICT clause, this helps the optimizer very substantially by letting it figure out which of several possible join sequences is likely to take the least work.

As before, this chapter will make no attempt to explain how to write a join selectivity estimator function, but will just suggest that you use one of the standard estimators if one is applicable:

eqjoinsel for =
neqjoinsel for <>
scalarltjoinsel for <
scalarlejoinsel for <=
scalargtjoinsel for >
scalargejoinsel for >=
matchingjoinsel for generic matching operators
areajoinsel for 2D area-based comparisons
positionjoinsel for 2D position-based comparisons
contjoinsel for 2D containment-based comparisons

40.15.5. HASHES

The HASHES clause, if present, tells the system that it is permissible to use the hash join method for a join based on this operator. HASHES only makes sense for a binary operator that returns boolean, and in practice the operator must represent equality for some data type or pair of data types.

The assumption underlying hash join is that the join operator can only return true for pairs of left and right values that hash to the same hash code. If two values get put in different hash buckets, the join will never compare them at all, implicitly assuming that the result of the join operator must be false. So it never makes sense to specify HASHES for operators that do not represent some form of equality. In most cases it is only practical to support hashing for operators that take the same data type on both sides. However, sometimes it is possible to design compatible hash functions for two or more data types; that is, functions that will generate the same hash codes for “equal” values, even though the values have different representations. For example, it's fairly simple to arrange this property when hashing integers of different widths.

To be marked HASHES, the join operator must appear in a hash index operator family. This is not enforced when you create the operator, since of course the referencing operator family couldn't exist yet. But attempts to use the operator in hash joins will fail at run time if no such operator family exists. The system needs the operator family to find the data-type-specific hash function(s) for the operator's input data type(s). Of course, you must also create suitable hash functions before you can create the operator family.

Care should be exercised when preparing a hash function, because there are machine-dependent ways in which it might fail to do the right thing. For example, if your data type is a structure in which there might be uninteresting pad bits, you cannot simply pass the whole structure to hash_any. (Unless you write your other operators and functions to ensure that the unused bits are always zero, which is the recommended strategy.) Another example is that on machines that meet the IEEE floating-point standard, negative zero and positive zero are different values (different bit patterns) but they are defined to compare equal. If a float value might contain negative zero then extra steps are needed to ensure it generates the same hash value as positive zero.

A hash-joinable operator must have a commutator (itself if the two operand data types are the same, or a related equality operator if they are different) that appears in the same operator family. If this is not the case, planner errors might occur when the operator is used. Also, it is a good idea (but not strictly required) for a hash operator family that supports multiple data types to provide equality operators for every combination of the data types; this allows better optimization.

> **Note**
>
> The function underlying a hash-joinable operator must be marked immutable or stable. If it is volatile, the system will never attempt to use the operator for a hash join.

> **Note**
>
> If a hash-joinable operator has an underlying function that is marked strict, the function must also be complete: that is, it should return true or false, never null, for any two nonnull inputs. If this rule is not followed, hash-optimization of IN operations might generate wrong results. (Specifically, IN might return false where the correct answer according to the standard would be null; or it might yield an error complaining that it wasn't prepared for a null result.)

40.15.6. MERGES

The MERGES clause, if present, tells the system that it is permissible to use the merge-join method for a join based on this operator. MERGES only makes sense for a binary operator that returns boolean, and in practice the operator must represent equality for some data type or pair of data types.

Merge join is based on the idea of sorting the left- and right-hand tables into order and then scanning them in parallel. So, both data types must be capable of being fully ordered, and the join operator must be one that can only succeed for pairs of values that fall at the “same place” in the sort order. In practice

this means that the join operator must behave like equality. But it is possible to merge-join two distinct data types so long as they are logically compatible. For example, the `smallint`-versus-`integer` equality operator is merge-joinable. We only need sorting operators that will bring both data types into a logically compatible sequence.

To be marked `MERGES`, the join operator must appear as an equality member of a `btree` index operator family. This is not enforced when you create the operator, since of course the referencing operator family couldn't exist yet. But the operator will not actually be used for merge joins unless a matching operator family can be found. The `MERGES` flag thus acts as a hint to the planner that it's worth looking for a matching operator family.

A merge-joinable operator must have a commutator (itself if the two operand data types are the same, or a related equality operator if they are different) that appears in the same operator family. If this is not the case, planner errors might occur when the operator is used. Also, it is a good idea (but not strictly required) for a `btree` operator family that supports multiple data types to provide equality operators for every combination of the data types; this allows better optimization.

> **Note**
>
> The function underlying a merge-joinable operator must be marked immutable or stable. If it is volatile, the system will never attempt to use the operator for a merge join.

40.16. Interfacing Extensions to Indexes

The procedures described thus far let you define new types, new functions, and new operators. However, we cannot yet define an index on a column of a new data type. To do this, we must define an *operator class* for the new data type. Later in this section, we will illustrate this concept in an example: a new operator class for the B-tree index method that stores and sorts complex numbers in ascending absolute value order.

Operator classes can be grouped into *operator families* to show the relationships between semantically compatible classes. When only a single data type is involved, an operator class is sufficient, so we'll focus on that case first and then return to operator families.

40.16.1. Index Methods and Operator Classes

The `pg_am` table contains one row for every index method (internally known as access method). Support for regular access to tables is built into Postgres Pro, but all index methods are described in `pg_am`. It is possible to add a new index access method by writing the necessary code and then creating an entry in `pg_am` — but that is beyond the scope of this chapter (see Chapter 62).

The routines for an index method do not directly know anything about the data types that the index method will operate on. Instead, an *operator class*identifies the set of operations that the index method needs to use to work with a particular data type. Operator classes are so called because one thing they specify is the set of `WHERE`-clause operators that can be used with an index (i.e., can be converted into an index-scan qualification). An operator class can also specify some *support function* that are needed by the internal operations of the index method, but do not directly correspond to any `WHERE`-clause operator that can be used with the index.

It is possible to define multiple operator classes for the same data type and index method. By doing this, multiple sets of indexing semantics can be defined for a single data type. For example, a B-tree index requires a sort ordering to be defined for each data type it works on. It might be useful for a complex-number data type to have one B-tree operator class that sorts the data by complex absolute value, another that sorts by real part, and so on. Typically, one of the operator classes will be deemed most commonly useful and will be marked as the default operator class for that data type and index method.

The same operator class name can be used for several different index methods (for example, both B-tree and hash index methods have operator classes named `int4_ops`), but each such class is an independent entity and must be defined separately.

40.16.2. Index Method Strategies

The operators associated with an operator class are identified by “strategy numbers”, which serve to identify the semantics of each operator within the context of its operator class. For example, B-trees impose a strict ordering on keys, lesser to greater, and so operators like “less than” and “greater than or equal to” are interesting with respect to a B-tree. Because Postgres Pro allows the user to define operators, Postgres Pro cannot look at the name of an operator (e.g., `<` or `>=`) and tell what kind of comparison it is. Instead, the index method defines a set of “strategies”, which can be thought of as generalized operators. Each operator class specifies which actual operator corresponds to each strategy for a particular data type and interpretation of the index semantics.

The B-tree index method defines six strategies, shown in Table 40.3.

Table 40.3. B-Tree Strategies

Operation	Strategy Number
less than	1
less than or equal	2
equal	3
greater than or equal	4
greater than	5
distance	6

Hash indexes support only equality comparisons, and so they use only one strategy, shown in Table 40.4.

Table 40.4. Hash Strategies

Operation	Strategy Number
equal	1

GiST indexes are more flexible: they do not have a fixed set of strategies at all. Instead, the “consistency” support routine of each particular GiST operator class interprets the strategy numbers however it likes. As an example, several of the built-in GiST index operator classes index two-dimensional geometric objects, providing the “R-tree” strategies shown in Table 40.5. Four of these are true two-dimensional tests (overlaps, same, contains, contained by); four of them consider only the X direction; and the other four provide the same tests in the Y direction.

Table 40.5. GiST Two-Dimensional “R-tree” Strategies

Operation	Strategy Number
strictly left of	1
does not extend to right of	2
overlaps	3
does not extend to left of	4
strictly right of	5
same	6
contains	7
contained by	8
does not extend above	9

Operation	Strategy Number
strictly below	10
strictly above	11
does not extend below	12

SP-GiST indexes are similar to GiST indexes in flexibility: they don't have a fixed set of strategies. Instead the support routines of each operator class interpret the strategy numbers according to the operator class's definition. As an example, the strategy numbers used by the built-in operator classes for points are shown in Table 40.6.

Table 40.6. SP-GiST Point Strategies

Operation	Strategy Number
strictly left of	1
strictly right of	5
same	6
contained by	8
strictly below	10
strictly above	11

GIN indexes are similar to GiST and SP-GiST indexes, in that they don't have a fixed set of strategies either. Instead the support routines of each operator class interpret the strategy numbers according to the operator class's definition. As an example, the strategy numbers used by the built-in operator class for arrays are shown in Table 40.7.

Table 40.7. GIN Array Strategies

Operation	Strategy Number
overlap	1
contains	2
is contained by	3
equal	4

BRIN indexes are similar to GiST, SP-GiST and GIN indexes in that they don't have a fixed set of strategies either. Instead the support routines of each operator class interpret the strategy numbers according to the operator class's definition. As an example, the strategy numbers used by the built-in `Minmax` operator classes are shown in Table 40.8.

Table 40.8. BRIN Minmax Strategies

Operation	Strategy Number
less than	1
less than or equal	2
equal	3
greater than or equal	4
greater than	5

Notice that all the operators listed above return Boolean values. In practice, all operators defined as index method search operators must return type `boolean`, since they must appear at the top level of a `WHERE` clause to be used with an index. (Some index access methods also support *ordering operators*, which typically don't return Boolean values; that feature is discussed in Section 40.16.7.)

40.16.3. Index Method Support Routines

Strategies aren't usually enough information for the system to figure out how to use an index. In practice, the index methods require additional support routines in order to work. For example, the B-tree index method must be able to compare two keys and determine whether one is greater than, equal to, or less than the other. Similarly, the hash index method must be able to compute hash codes for key values. These operations do not correspond to operators used in qualifications in SQL commands; they are administrative routines used by the index methods, internally.

Just as with strategies, the operator class identifies which specific functions should play each of these roles for a given data type and semantic interpretation. The index method defines the set of functions it needs, and the operator class identifies the correct functions to use by assigning them to the "support function numbers" specified by the index method.

Additionally, some opclasses allow users to specify parameters which control their behavior. Each builtin index access method has an optional `options` support function, which defines a set of opclass-specific parameters.

B-trees require a comparison support function, and allow four additional support functions to be supplied at the operator class author's option, as shown in Table 40.9. The requirements for these support functions are explained further in Section 64.3.

Table 40.9. B-Tree Support Functions

Function	Support Number
Compare two keys and return an integer less than zero, zero, or greater than zero, indicating whether the first key is less than, equal to, or greater than the second	1
Return the addresses of C-callable sort support function(s) (optional)	2
Compare a test value to a base value plus/minus an offset, and return true or false according to the comparison result (optional)	3
Determine if it is safe for indexes that use the operator class to apply the btree deduplication optimization (optional)	4
Define options that are specific to this operator class (optional)	5

Hash indexes require one support function, and allow two additional ones to be supplied at the operator class author's option, as shown in Table 40.10.

Table 40.10. Hash Support Functions

Function	Support Number
Compute the 32-bit hash value for a key	1
Compute the 64-bit hash value for a key given a 64-bit salt; if the salt is 0, the low 32 bits of the result must match the value that would have been computed by function 1 (optional)	2
Define options that are specific to this operator class (optional)	3

GiST indexes have eleven support functions, six of which are optional, as shown in Table 40.11. (For more information see Chapter 65.)

Table 40.11. GiST Support Functions

Function	Description	Support Number
`consistent`	determine whether key satisfies the query qualifier	1

Function	Description	Support Number
union	compute union of a set of keys	2
compress	compute a compressed representation of a key or value to be indexed (optional)	3
decompress	compute a decompressed representation of a compressed key (optional)	4
penalty	compute penalty for inserting new key into subtree with given subtree's key	5
picksplit	determine which entries of a page are to be moved to the new page and compute the union keys for resulting pages	6
same	compare two keys and return true if they are equal	7
distance	determine distance from key to query value (optional)	8
fetch	compute original representation of a compressed key for index-only scans (optional)	9
options	define options that are specific to this operator class (optional)	10
sortsupport	provide a sort comparator to be used in fast index builds (optional)	11

SP-GiST indexes have six support functions, one of which is optional, as shown in Table 40.12. (For more information see Chapter 66.)

Table 40.12. SP-GiST Support Functions

Function	Description	Support Number
config	provide basic information about the operator class	1
choose	determine how to insert a new value into an inner tuple	2
picksplit	determine how to partition a set of values	3
inner_consistent	determine which sub-partitions need to be searched for a query	4
leaf_consistent	determine whether key satisfies the query qualifier	5
options	define options that are specific to this operator class (optional)	6

GIN indexes have seven support functions, four of which are optional, as shown in Table 40.13. (For more information see Chapter 67.)

Table 40.13. GIN Support Functions

Function	Description	Support Number
compare	compare two keys and return an integer less than zero, zero, or greater than zero, indicating whether the first key is less than, equal to, or greater than the second	1

Function	Description	Support Number
extractValue	extract keys from a value to be indexed	2
extractQuery	extract keys from a query condition	3
consistent	determine whether value matches query condition (Boolean variant) (optional if support function 6 is present)	4
comparePartial	compare partial key from query and key from index, and return an integer less than zero, zero, or greater than zero, indicating whether GIN should ignore this index entry, treat the entry as a match, or stop the index scan (optional)	5
triConsistent	determine whether value matches query condition (ternary variant) (optional if support function 4 is present)	6
options	define options that are specific to this operator class (optional)	7

BRIN indexes have five basic support functions, one of which is optional, as shown in Table 40.14. Some versions of the basic functions require additional support functions to be provided. (For more information see Section 68.3.)

Table 40.14. BRIN Support Functions

Function	Description	Support Number
opcInfo	return internal information describing the indexed columns' summary data	1
add_value	add a new value to an existing summary index tuple	2
consistent	determine whether value matches query condition	3
union	compute union of two summary tuples	4
options	define options that are specific to this operator class (optional)	5

Unlike search operators, support functions return whichever data type the particular index method expects; for example in the case of the comparison function for B-trees, a signed integer. The number and types of the arguments to each support function are likewise dependent on the index method. For B-tree and hash the comparison and hashing support functions take the same input data types as do the operators included in the operator class, but this is not the case for most GiST, SP-GiST, GIN, and BRIN support functions.

40.16.4. An Example

Now that we have seen the ideas, here is the promised example of creating a new operator class. The operator class encapsulates operators that sort complex numbers in absolute value order, so we choose the name complex_abs_ops. First, we need a set of operators. The procedure for defining operators was discussed in Section 40.14. For an operator class on B-trees, the operators we require are:

- absolute-value less-than (strategy 1)
- absolute-value less-than-or-equal (strategy 2)
- absolute-value equal (strategy 3)
- absolute-value greater-than-or-equal (strategy 4)
- absolute-value greater-than (strategy 5)

The least error-prone way to define a related set of comparison operators is to write the B-tree comparison support function first, and then write the other functions as one-line wrappers around the support function. This reduces the odds of getting inconsistent results for corner cases. Following this approach, we first write:

```
#define Mag(c)  ((c)->x*(c)->x + (c)->y*(c)->y)

static int
complex_abs_cmp_internal(Complex *a, Complex *b)
{
    double      amag = Mag(a),
                bmag = Mag(b);

    if (amag < bmag)
        return -1;
    if (amag > bmag)
        return 1;
    return 0;
}
```

Now the less-than function looks like:

```
PG_FUNCTION_INFO_V1(complex_abs_lt);

Datum
complex_abs_lt(PG_FUNCTION_ARGS)
{
    Complex    *a = (Complex *) PG_GETARG_POINTER(0);
    Complex    *b = (Complex *) PG_GETARG_POINTER(1);

    PG_RETURN_BOOL(complex_abs_cmp_internal(a, b) < 0);
}
```

The other four functions differ only in how they compare the internal function's result to zero.

Next we declare the functions and the operators based on the functions to SQL:

```
CREATE FUNCTION complex_abs_lt(complex, complex) RETURNS bool
    AS 'filename', 'complex_abs_lt'
    LANGUAGE C IMMUTABLE STRICT;

CREATE OPERATOR < (
   leftarg = complex, rightarg = complex, procedure = complex_abs_lt,
   commutator = > , negator = >= ,
   restrict = scalarltsel, join = scalarltjoinsel
);
```

It is important to specify the correct commutator and negator operators, as well as suitable restriction and join selectivity functions, otherwise the optimizer will be unable to make effective use of the index.

Other things worth noting are happening here:

- There can only be one operator named, say, = and taking type `complex` for both operands. In this case we don't have any other operator = for `complex`, but if we were building a practical data type we'd probably want = to be the ordinary equality operation for complex numbers (and not the equality of the absolute values). In that case, we'd need to use some other operator name for `complex_abs_eq`.
- Although Postgres Pro can cope with functions having the same SQL name as long as they have different argument data types, C can only cope with one global function having a given name. So we

shouldn't name the C function something simple like `abs_eq`. Usually it's a good practice to include the data type name in the C function name, so as not to conflict with functions for other data types.

- We could have made the SQL name of the function `abs_eq`, relying on Postgres Pro to distinguish it by argument data types from any other SQL function of the same name. To keep the example simple, we make the function have the same names at the C level and SQL level.

The next step is the registration of the support routine required by B-trees. The example C code that implements this is in the same file that contains the operator functions. This is how we declare the function:

```
CREATE FUNCTION complex_abs_cmp(complex, complex)
    RETURNS integer
    AS 'filename'
    LANGUAGE C IMMUTABLE STRICT;
```

Now that we have the required operators and support routine, we can finally create the operator class:

```
CREATE OPERATOR CLASS complex_abs_ops
    DEFAULT FOR TYPE complex USING btree AS
        OPERATOR        1       < ,
        OPERATOR        2       <= ,
        OPERATOR        3       = ,
        OPERATOR        4       >= ,
        OPERATOR        5       > ,
        FUNCTION        1       complex_abs_cmp(complex, complex);
```

And we're done! It should now be possible to create and use B-tree indexes on `complex` columns.

We could have written the operator entries more verbosely, as in:

```
        OPERATOR        1       < (complex, complex) ,
```

but there is no need to do so when the operators take the same data type we are defining the operator class for.

The above example assumes that you want to make this new operator class the default B-tree operator class for the `complex` data type. If you don't, just leave out the word `DEFAULT`.

40.16.5. Operator Classes and Operator Families

So far we have implicitly assumed that an operator class deals with only one data type. While there certainly can be only one data type in a particular index column, it is often useful to index operations that compare an indexed column to a value of a different data type. Also, if there is use for a cross-data-type operator in connection with an operator class, it is often the case that the other data type has a related operator class of its own. It is helpful to make the connections between related classes explicit, because this can aid the planner in optimizing SQL queries (particularly for B-tree operator classes, since the planner contains a great deal of knowledge about how to work with them).

To handle these needs, Postgres Pro uses the concept of an *operator family*. An operator family contains one or more operator classes, and can also contain indexable operators and corresponding support functions that belong to the family as a whole but not to any single class within the family. We say that such operators and functions are “loose” within the family, as opposed to being bound into a specific class. Typically each operator class contains single-data-type operators while cross-data-type operators are loose in the family.

All the operators and functions in an operator family must have compatible semantics, where the compatibility requirements are set by the index method. You might therefore wonder why bother to single out particular subsets of the family as operator classes; and indeed for many purposes the class divisions are irrelevant and the family is the only interesting grouping. The reason for defining operator classes is that they specify how much of the family is needed to support any particular index. If there is an index

using an operator class, then that operator class cannot be dropped without dropping the index — but other parts of the operator family, namely other operator classes and loose operators, could be dropped. Thus, an operator class should be specified to contain the minimum set of operators and functions that are reasonably needed to work with an index on a specific data type, and then related but non-essential operators can be added as loose members of the operator family.

As an example, Postgres Pro has a built-in B-tree operator family `integer_ops`, which includes operator classes `int8_ops`, `int4_ops`, and `int2_ops` for indexes on `bigint` (`int8`), `integer` (`int4`), and `smallint` (`int2`) columns respectively. The family also contains cross-data-type comparison operators allowing any two of these types to be compared, so that an index on one of these types can be searched using a comparison value of another type. The family could be duplicated by these definitions:

```
CREATE OPERATOR FAMILY integer_ops USING btree;

CREATE OPERATOR CLASS int8_ops
DEFAULT FOR TYPE int8 USING btree FAMILY integer_ops AS
  -- standard int8 comparisons
  OPERATOR 1 < ,
  OPERATOR 2 <= ,
  OPERATOR 3 = ,
  OPERATOR 4 >= ,
  OPERATOR 5 > ,
  FUNCTION 1 btint8cmp(int8, int8) ,
  FUNCTION 2 btint8sortsupport(internal) ,
  FUNCTION 3 in_range(int8, int8, int8, boolean, boolean) ,
  FUNCTION 4 btequalimage(oid) ;

CREATE OPERATOR CLASS int4_ops
DEFAULT FOR TYPE int4 USING btree FAMILY integer_ops AS
  -- standard int4 comparisons
  OPERATOR 1 < ,
  OPERATOR 2 <= ,
  OPERATOR 3 = ,
  OPERATOR 4 >= ,
  OPERATOR 5 > ,
  FUNCTION 1 btint4cmp(int4, int4) ,
  FUNCTION 2 btint4sortsupport(internal) ,
  FUNCTION 3 in_range(int4, int4, int4, boolean, boolean) ,
  FUNCTION 4 btequalimage(oid) ;

CREATE OPERATOR CLASS int2_ops
DEFAULT FOR TYPE int2 USING btree FAMILY integer_ops AS
  -- standard int2 comparisons
  OPERATOR 1 < ,
  OPERATOR 2 <= ,
  OPERATOR 3 = ,
  OPERATOR 4 >= ,
  OPERATOR 5 > ,
  FUNCTION 1 btint2cmp(int2, int2) ,
  FUNCTION 2 btint2sortsupport(internal) ,
  FUNCTION 3 in_range(int2, int2, int2, boolean, boolean) ,
  FUNCTION 4 btequalimage(oid) ;

ALTER OPERATOR FAMILY integer_ops USING btree ADD
  -- cross-type comparisons int8 vs int2
  OPERATOR 1 < (int8, int2) ,
  OPERATOR 2 <= (int8, int2) ,
  OPERATOR 3 = (int8, int2) ,
  OPERATOR 4 >= (int8, int2) ,
```

```
OPERATOR 5 > (int8, int2) ,
FUNCTION 1 btint82cmp(int8, int2) ,

-- cross-type comparisons int8 vs int4
OPERATOR 1 < (int8, int4) ,
OPERATOR 2 <= (int8, int4) ,
OPERATOR 3 = (int8, int4) ,
OPERATOR 4 >= (int8, int4) ,
OPERATOR 5 > (int8, int4) ,
FUNCTION 1 btint84cmp(int8, int4) ,

-- cross-type comparisons int4 vs int2
OPERATOR 1 < (int4, int2) ,
OPERATOR 2 <= (int4, int2) ,
OPERATOR 3 = (int4, int2) ,
OPERATOR 4 >= (int4, int2) ,
OPERATOR 5 > (int4, int2) ,
FUNCTION 1 btint42cmp(int4, int2) ,

-- cross-type comparisons int4 vs int8
OPERATOR 1 < (int4, int8) ,
OPERATOR 2 <= (int4, int8) ,
OPERATOR 3 = (int4, int8) ,
OPERATOR 4 >= (int4, int8) ,
OPERATOR 5 > (int4, int8) ,
FUNCTION 1 btint48cmp(int4, int8) ,

-- cross-type comparisons int2 vs int8
OPERATOR 1 < (int2, int8) ,
OPERATOR 2 <= (int2, int8) ,
OPERATOR 3 = (int2, int8) ,
OPERATOR 4 >= (int2, int8) ,
OPERATOR 5 > (int2, int8) ,
FUNCTION 1 btint28cmp(int2, int8) ,

-- cross-type comparisons int2 vs int4
OPERATOR 1 < (int2, int4) ,
OPERATOR 2 <= (int2, int4) ,
OPERATOR 3 = (int2, int4) ,
OPERATOR 4 >= (int2, int4) ,
OPERATOR 5 > (int2, int4) ,
FUNCTION 1 btint24cmp(int2, int4) ,

-- cross-type in_range functions
FUNCTION 3 in_range(int4, int4, int8, boolean, boolean) ,
FUNCTION 3 in_range(int4, int4, int2, boolean, boolean) ,
FUNCTION 3 in_range(int2, int2, int8, boolean, boolean) ,
FUNCTION 3 in_range(int2, int2, int4, boolean, boolean) ;
```

Notice that this definition “overloads” the operator strategy and support function numbers: each number occurs multiple times within the family. This is allowed so long as each instance of a particular number has distinct input data types. The instances that have both input types equal to an operator class's input type are the primary operators and support functions for that operator class, and in most cases should be declared as part of the operator class rather than as loose members of the family.

In a B-tree operator family, all the operators in the family must sort compatibly, as is specified in detail in Section 64.2. For each operator in the family there must be a support function having the same two input data types as the operator. It is recommended that a family be complete, i.e., for each combination

of data types, all operators are included. Each operator class should include just the non-cross-type operators and support function for its data type.

To build a multiple-data-type hash operator family, compatible hash support functions must be created for each data type supported by the family. Here compatibility means that the functions are guaranteed to return the same hash code for any two values that are considered equal by the family's equality operators, even when the values are of different types. This is usually difficult to accomplish when the types have different physical representations, but it can be done in some cases. Furthermore, casting a value from one data type represented in the operator family to another data type also represented in the operator family via an implicit or binary coercion cast must not change the computed hash value. Notice that there is only one support function per data type, not one per equality operator. It is recommended that a family be complete, i.e., provide an equality operator for each combination of data types. Each operator class should include just the non-cross-type equality operator and the support function for its data type.

GiST, SP-GiST, and GIN indexes do not have any explicit notion of cross-data-type operations. The set of operators supported is just whatever the primary support functions for a given operator class can handle.

In BRIN, the requirements depends on the framework that provides the operator classes. For operator classes based on `minmax`, the behavior required is the same as for B-tree operator families: all the operators in the family must sort compatibly, and casts must not change the associated sort ordering.

> **Note**
>
> Prior to PostgreSQL 8.3, there was no concept of operator families, and so any cross-data-type operators intended to be used with an index had to be bound directly into the index's operator class. While this approach still works, it is deprecated because it makes an index's dependencies too broad, and because the planner can handle cross-data-type comparisons more effectively when both data types have operators in the same operator family.

40.16.6. System Dependencies on Operator Classes

Postgres Pro uses operator classes to infer the properties of operators in more ways than just whether they can be used with indexes. Therefore, you might want to create operator classes even if you have no intention of indexing any columns of your data type.

In particular, there are SQL features such as `ORDER BY` and `DISTINCT` that require comparison and sorting of values. To implement these features on a user-defined data type, Postgres Pro looks for the default B-tree operator class for the data type. The “equals” member of this operator class defines the system's notion of equality of values for `GROUP BY` and `DISTINCT`, and the sort ordering imposed by the operator class defines the default `ORDER BY` ordering.

If there is no default B-tree operator class for a data type, the system will look for a default hash operator class. But since that kind of operator class only provides equality, it is only able to support grouping not sorting.

When there is no default operator class for a data type, you will get errors like “could not identify an ordering operator” if you try to use these SQL features with the data type.

> **Note**
>
> In PostgreSQL versions before 7.4, sorting and grouping operations would implicitly use operators named =, <, and >. The new behavior of relying on default operator classes avoids having to make any assumption about the behavior of operators with particular names.

Sorting by a non-default B-tree operator class is possible by specifying the class's less-than operator in a `USING` option, for example

```
SELECT * FROM mytable ORDER BY somecol USING ~<~;
```

Alternatively, specifying the class's greater-than operator in `USING` selects a descending-order sort.

Comparison of arrays of a user-defined type also relies on the semantics defined by the type's default B-tree operator class. If there is no default B-tree operator class, but there is a default hash operator class, then array equality is supported, but not ordering comparisons.

Another SQL feature that requires even more data-type-specific knowledge is the `RANGE` *`offset`* `PRECEDING`/`FOLLOWING` framing option for window functions (see Section 4.2.8). For a query such as

```
SELECT sum(x) OVER (ORDER BY x RANGE BETWEEN 5 PRECEDING AND 10 FOLLOWING)
  FROM mytable;
```

it is not sufficient to know how to order by `x`; the database must also understand how to "subtract 5" or "add 10" to the current row's value of `x` to identify the bounds of the current window frame. Comparing the resulting bounds to other rows' values of `x` is possible using the comparison operators provided by the B-tree operator class that defines the `ORDER BY` ordering — but addition and subtraction operators are not part of the operator class, so which ones should be used? Hard-wiring that choice would be undesirable, because different sort orders (different B-tree operator classes) might need different behavior. Therefore, a B-tree operator class can specify an *in_range* support function that encapsulates the addition and subtraction behaviors that make sense for its sort order. It can even provide more than one in_range support function, in case there is more than one data type that makes sense to use as the offset in `RANGE` clauses. If the B-tree operator class associated with the window's `ORDER BY` clause does not have a matching in_range support function, the `RANGE` *`offset`* `PRECEDING`/`FOLLOWING` option is not supported.

Another important point is that an equality operator that appears in a hash operator family is a candidate for hash joins, hash aggregation, and related optimizations. The hash operator family is essential here since it identifies the hash function(s) to use.

40.16.7. Ordering Operators

Some index access methods (currently, only B-tree, GiST and SP-GiST) support the concept of *ordering operators*. What we have been discussing so far are *search operators*. A search operator is one for which the index can be searched to find all rows satisfying `WHERE` *`indexed_column operator constant`*. Note that nothing is promised about the order in which the matching rows will be returned. In contrast, an ordering operator does not restrict the set of rows that can be returned, but instead determines their order. An ordering operator is one for which the index can be scanned to return rows in the order represented by `ORDER BY` *`indexed_column operator constant`*. The reason for defining ordering operators that way is that it supports nearest-neighbor searches, if the operator is one that measures distance. For example, a query like

```
SELECT * FROM places ORDER BY location <-> point '(101,456)' LIMIT 10;
```

finds the ten places closest to a given target point. A GiST index on the location column can do this efficiently because `<->` is an ordering operator.

While search operators have to return Boolean results, ordering operators usually return some other type, such as float or numeric for distances. This type is normally not the same as the data type being indexed. To avoid hard-wiring assumptions about the behavior of different data types, the definition of an ordering operator is required to name a B-tree operator family that specifies the sort ordering of the result data type. As was stated in the previous section, B-tree operator families define Postgres Pro's notion of ordering, so this is a natural representation. Since the point `<->` operator returns `float8`, it could be specified in an operator class creation command like this:

```
OPERATOR 15    <-> (point, point) FOR ORDER BY float_ops
```

where `float_ops` is the built-in operator family that includes operations on `float8`. This declaration states that the index is able to return rows in order of increasing values of the `<->` operator.

40.16.8. Special Features of Operator Classes

There are two special features of operator classes that we have not discussed yet, mainly because they are not useful with the most commonly used index methods.

Normally, declaring an operator as a member of an operator class (or family) means that the index method can retrieve exactly the set of rows that satisfy a `WHERE` condition using the operator. For example:

```
SELECT * FROM table WHERE integer_column < 4;
```

can be satisfied exactly by a B-tree index on the integer column. But there are cases where an index is useful as an inexact guide to the matching rows. For example, if a GiST index stores only bounding boxes for geometric objects, then it cannot exactly satisfy a `WHERE` condition that tests overlap between nonrectangular objects such as polygons. Yet we could use the index to find objects whose bounding box overlaps the bounding box of the target object, and then do the exact overlap test only on the objects found by the index. If this scenario applies, the index is said to be “lossy” for the operator. Lossy index searches are implemented by having the index method return a *recheck* flag when a row might or might not really satisfy the query condition. The core system will then test the original query condition on the retrieved row to see whether it should be returned as a valid match. This approach works if the index is guaranteed to return all the required rows, plus perhaps some additional rows, which can be eliminated by performing the original operator invocation. The index methods that support lossy searches (currently, GiST, SP-GiST and GIN) allow the support functions of individual operator classes to set the recheck flag, and so this is essentially an operator-class feature.

Consider again the situation where we are storing in the index only the bounding box of a complex object such as a polygon. In this case there's not much value in storing the whole polygon in the index entry — we might as well store just a simpler object of type `box`. This situation is expressed by the `STORAGE` option in `CREATE OPERATOR CLASS`: we'd write something like:

```
CREATE OPERATOR CLASS polygon_ops
    DEFAULT FOR TYPE polygon USING gist AS
        ...
        STORAGE box;
```

At present, only the GiST, SP-GiST, GIN and BRIN index methods support a `STORAGE` type that's different from the column data type. The GiST `compress` and `decompress` support routines must deal with data-type conversion when `STORAGE` is used. SP-GiST likewise requires a `compress` support function to convert to the storage type, when that is different; if an SP-GiST opclass also supports retrieving data, the reverse conversion must be handled by the `consistent` function. In GIN, the `STORAGE` type identifies the type of the “key” values, which normally is different from the type of the indexed column — for example, an operator class for integer-array columns might have keys that are just integers. The GIN `extractValue` and `extractQuery` support routines are responsible for extracting keys from indexed values. BRIN is similar to GIN: the `STORAGE` type identifies the type of the stored summary values, and operator classes' support procedures are responsible for interpreting the summary values correctly.

40.17. Packaging Related Objects into an Extension

A useful extension to Postgres Pro typically includes multiple SQL objects; for example, a new data type will require new functions, new operators, and probably new index operator classes. It is helpful to collect all these objects into a single package to simplify database management. Postgres Pro calls such a package an *extension*. To define an extension, you need at least a *script file* that contains the SQL commands to create the extension's objects, and a *control file* that specifies a few basic properties of the extension itself. If the extension includes C code, there will typically also be a shared library file into which the C code has been built. Once you have these files, a simple `CREATE EXTENSION` command loads the objects into your database.

The main advantage of using an extension, rather than just running the SQL script to load a bunch of “loose” objects into your database, is that Postgres Pro will then understand that the objects of the extension go together. You can drop all the objects with a single `DROP EXTENSION` command (no need

to maintain a separate “uninstall” script). Even more useful, pg_dump knows that it should not dump the individual member objects of the extension — it will just include a CREATE EXTENSION command in dumps, instead. This vastly simplifies migration to a new version of the extension that might contain more or different objects than the old version. Note however that you must have the extension's control, script, and other files available when loading such a dump into a new database.

Postgres Pro will not let you drop an individual object contained in an extension, except by dropping the whole extension. Also, while you can change the definition of an extension member object (for example, via CREATE OR REPLACE FUNCTION for a function), bear in mind that the modified definition will not be dumped by pg_dump. Such a change is usually only sensible if you concurrently make the same change in the extension's script file. (But there are special provisions for tables containing configuration data; see Section 40.17.3.) In production situations, it's generally better to create an extension update script to perform changes to extension member objects.

The extension script may set privileges on objects that are part of the extension, using GRANT and REVOKE statements. The final set of privileges for each object (if any are set) will be stored in the pg_init_privs system catalog. When pg_dump is used, the CREATE EXTENSION command will be included in the dump, followed by the set of GRANT and REVOKE statements necessary to set the privileges on the objects to what they were at the time the dump was taken.

Postgres Pro does not currently support extension scripts issuing CREATE POLICY or SECURITY LABEL statements. These are expected to be set after the extension has been created. All RLS policies and security labels on extension objects will be included in dumps created by pg_dump.

The extension mechanism also has provisions for packaging modification scripts that adjust the definitions of the SQL objects contained in an extension. For example, if version 1.1 of an extension adds one function and changes the body of another function compared to 1.0, the extension author can provide an *update script* that makes just those two changes. The ALTER EXTENSION UPDATE command can then be used to apply these changes and track which version of the extension is actually installed in a given database.

The kinds of SQL objects that can be members of an extension are shown in the description of ALTER EXTENSION. Notably, objects that are database-cluster-wide, such as databases, roles, and tablespaces, cannot be extension members since an extension is only known within one database. (Although an extension script is not prohibited from creating such objects, if it does so they will not be tracked as part of the extension.) Also notice that while a table can be a member of an extension, its subsidiary objects such as indexes are not directly considered members of the extension. Another important point is that schemas can belong to extensions, but not vice versa: an extension as such has an unqualified name and does not exist “within” any schema. The extension's member objects, however, will belong to schemas whenever appropriate for their object types. It may or may not be appropriate for an extension to own the schema(s) its member objects are within.

If an extension's script creates any temporary objects (such as temp tables), those objects are treated as extension members for the remainder of the current session, but are automatically dropped at session end, as any temporary object would be. This is an exception to the rule that extension member objects cannot be dropped without dropping the whole extension.

40.17.1. Extension Files

The CREATE EXTENSION command relies on a control file for each extension, which must be named the same as the extension with a suffix of `.control`, and must be placed in the installation's SHAREDIR/extension directory. There must also be at least one SQL script file, which follows the naming pattern *extension*`--`*version*`.sql` (for example, `foo--1.0.sql` for version `1.0` of extension `foo`). By default, the script file(s) are also placed in the SHAREDIR/extension directory; but the control file can specify a different directory for the script file(s).

The file format for an extension control file is the same as for the `postgresql.conf` file, namely a list of *parameter_name* `=` *value* assignments, one per line. Blank lines and comments introduced by `#` are allowed. Be sure to quote any value that is not a single word or number.

A control file can set the following parameters:

`directory` (`string`)

The directory containing the extension's SQL script file(s). Unless an absolute path is given, the name is relative to the installation's `SHAREDIR` directory. The default behavior is equivalent to specifying `directory = 'extension'`.

`default_version` (`string`)

The default version of the extension (the one that will be installed if no version is specified in `CREATE EXTENSION`). Although this can be omitted, that will result in `CREATE EXTENSION` failing if no `VERSION` option appears, so you generally don't want to do that.

`comment` (`string`)

A comment (any string) about the extension. The comment is applied when initially creating an extension, but not during extension updates (since that might override user-added comments). Alternatively, the extension's comment can be set by writing a COMMENT command in the script file.

`encoding` (`string`)

The character set encoding used by the script file(s). This should be specified if the script files contain any non-ASCII characters. Otherwise the files will be assumed to be in the database encoding.

`module_pathname` (`string`)

The value of this parameter will be substituted for each occurrence of `MODULE_PATHNAME` in the script file(s). If it is not set, no substitution is made. Typically, this is set to `$libdir/`*`shared_library_name`* and then `MODULE_PATHNAME` is used in `CREATE FUNCTION` commands for C-language functions, so that the script files do not need to hard-wire the name of the shared library.

`requires` (`string`)

A list of names of extensions that this extension depends on, for example `requires = 'foo, bar'`. Those extensions must be installed before this one can be installed.

`superuser` (`boolean`)

If this parameter is `true` (which is the default), only superusers can create the extension or update it to a new version (but see also `trusted`, below). If it is set to `false`, just the privileges required to execute the commands in the installation or update script are required. This should normally be set to `true` if any of the script commands require superuser privileges. (Such commands would fail anyway, but it's more user-friendly to give the error up front.)

`trusted` (`boolean`)

This parameter, if set to `true` (which is not the default), allows some non-superusers to install an extension that has `superuser` set to `true`. Specifically, installation will be permitted for anyone who has `CREATE` privilege on the current database. When the user executing `CREATE EXTENSION` is not a superuser but is allowed to install by virtue of this parameter, then the installation or update script is run as the bootstrap superuser, not as the calling user. This parameter is irrelevant if `superuser` is `false`. Generally, this should not be set true for extensions that could allow access to otherwise-superuser-only abilities, such as file system access. Also, marking an extension trusted requires significant extra effort to write the extension's installation and update script(s) securely; see Section 40.17.6.

`relocatable` (`boolean`)

An extension is *relocatable* if it is possible to move its contained objects into a different schema after initial creation of the extension. The default is `false`, i.e., the extension is not relocatable. See Section 40.17.2 for more information.

`schema` (`string`)

This parameter can only be set for non-relocatable extensions. It forces the extension to be loaded into exactly the named schema and not any other. The `schema` parameter is consulted only when initially creating an extension, not during extension updates. See Section 40.17.2 for more information.

In addition to the primary control file *`extension`*`.control`, an extension can have secondary control files named in the style *`extension`*`--`*`version`*`.control`. If supplied, these must be located in the script file directory. Secondary control files follow the same format as the primary control file. Any parameters set in a secondary control file override the primary control file when installing or updating to that version of the extension. However, the parameters `directory` and `default_version` cannot be set in a secondary control file.

An extension's SQL script files can contain any SQL commands, except for transaction control commands (`BEGIN`, `COMMIT`, etc) and commands that cannot be executed inside a transaction block (such as `VACUUM`). This is because the script files are implicitly executed within a transaction block.

An extension's SQL script files can also contain lines beginning with `\echo`, which will be ignored (treated as comments) by the extension mechanism. This provision is commonly used to throw an error if the script file is fed to psql rather than being loaded via `CREATE EXTENSION` (see example script in Section 40.17.7). Without that, users might accidentally load the extension's contents as “loose” objects rather than as an extension, a state of affairs that's a bit tedious to recover from.

If the extension script contains the string `@extowner@`, that string is replaced with the (suitably quoted) name of the user calling `CREATE EXTENSION` or `ALTER EXTENSION`. Typically this feature is used by extensions that are marked trusted to assign ownership of selected objects to the calling user rather than the bootstrap superuser. (One should be careful about doing so, however. For example, assigning ownership of a C-language function to a non-superuser would create a privilege escalation path for that user.)

While the script files can contain any characters allowed by the specified encoding, control files should contain only plain ASCII, because there is no way for Postgres Pro to know what encoding a control file is in. In practice this is only an issue if you want to use non-ASCII characters in the extension's comment. Recommended practice in that case is to not use the control file `comment` parameter, but instead use `COMMENT ON EXTENSION` within a script file to set the comment.

40.17.2. Extension Relocatability

Users often wish to load the objects contained in an extension into a different schema than the extension's author had in mind. There are three supported levels of relocatability:

- A fully relocatable extension can be moved into another schema at any time, even after it's been loaded into a database. This is done with the `ALTER EXTENSION SET SCHEMA` command, which automatically renames all the member objects into the new schema. Normally, this is only possible if the extension contains no internal assumptions about what schema any of its objects are in. Also, the extension's objects must all be in one schema to begin with (ignoring objects that do not belong to any schema, such as procedural languages). Mark a fully relocatable extension by setting `relocatable = true` in its control file.
- An extension might be relocatable during installation but not afterwards. This is typically the case if the extension's script file needs to reference the target schema explicitly, for example in setting `search_path` properties for SQL functions. For such an extension, set `relocatable = false` in its control file, and use `@extschema@` to refer to the target schema in the script file. All occurrences of this string will be replaced by the actual target schema's name before the script is executed. The user can set the target schema using the `SCHEMA` option of `CREATE EXTENSION`.
- If the extension does not support relocation at all, set `relocatable = false` in its control file, and also set `schema` to the name of the intended target schema. This will prevent use of the `SCHEMA` option of `CREATE EXTENSION`, unless it specifies the same schema named in the control file. This choice is typically necessary if the extension contains internal assumptions about schema names that can't be replaced by uses of `@extschema@`. The `@extschema@` substitution mechanism is avail-

able in this case too, although it is of limited use since the schema name is determined by the control file.

In all cases, the script file will be executed with search_path initially set to point to the target schema; that is, `CREATE EXTENSION` does the equivalent of this:

```
SET LOCAL search_path TO @extschema@, pg_temp;
```

This allows the objects created by the script file to go into the target schema. The script file can change `search_path` if it wishes, but that is generally undesirable. `search_path` is restored to its previous setting upon completion of `CREATE EXTENSION`.

The target schema is determined by the `schema` parameter in the control file if that is given, otherwise by the `SCHEMA` option of `CREATE EXTENSION` if that is given, otherwise the current default object creation schema (the first one in the caller's `search_path`). When the control file `schema` parameter is used, the target schema will be created if it doesn't already exist, but in the other two cases it must already exist.

If any prerequisite extensions are listed in `requires` in the control file, their target schemas are added to the initial setting of `search_path`, following the new extension's target schema. This allows their objects to be visible to the new extension's script file.

For security, `pg_temp` is automatically appended to the end of `search_path` in all cases.

Although a non-relocatable extension can contain objects spread across multiple schemas, it is usually desirable to place all the objects meant for external use into a single schema, which is considered the extension's target schema. Such an arrangement works conveniently with the default setting of `search_path` during creation of dependent extensions.

40.17.3. Extension Configuration Tables

Some extensions include configuration tables, which contain data that might be added or changed by the user after installation of the extension. Ordinarily, if a table is part of an extension, neither the table's definition nor its content will be dumped by pg_dump. But that behavior is undesirable for a configuration table; any data changes made by the user need to be included in dumps, or the extension will behave differently after a dump and restore.

To solve this problem, an extension's script file can mark a table or a sequence it has created as a configuration relation, which will cause pg_dump to include the table's or the sequence's contents (not its definition) in dumps. To do that, call the function `pg_extension_config_dump(regclass, text)` after creating the table or the sequence, for example

```
CREATE TABLE my_config (key text, value text);
CREATE SEQUENCE my_config_seq;

SELECT pg_catalog.pg_extension_config_dump('my_config', '');
SELECT pg_catalog.pg_extension_config_dump('my_config_seq', '');
```

Any number of tables or sequences can be marked this way. Sequences associated with `serial` or `bigserial` columns can be marked as well.

When the second argument of `pg_extension_config_dump` is an empty string, the entire contents of the table are dumped by pg_dump. This is usually only correct if the table is initially empty as created by the extension script. If there is a mixture of initial data and user-provided data in the table, the second argument of `pg_extension_config_dump` provides a `WHERE` condition that selects the data to be dumped. For example, you might do

```
CREATE TABLE my_config (key text, value text, standard_entry boolean);

SELECT pg_catalog.pg_extension_config_dump('my_config', 'WHERE NOT standard_entry');
```

and then make sure that `standard_entry` is true only in the rows created by the extension's script.

For sequences, the second argument of `pg_extension_config_dump` has no effect.

More complicated situations, such as initially-provided rows that might be modified by users, can be handled by creating triggers on the configuration table to ensure that modified rows are marked correctly.

You can alter the filter condition associated with a configuration table by calling `pg_extension_config_dump` again. (This would typically be useful in an extension update script.) The only way to mark a table as no longer a configuration table is to dissociate it from the extension with `ALTER EXTENSION ... DROP TABLE`.

Note that foreign key relationships between these tables will dictate the order in which the tables are dumped out by pg_dump. Specifically, pg_dump will attempt to dump the referenced-by table before the referencing table. As the foreign key relationships are set up at CREATE EXTENSION time (prior to data being loaded into the tables) circular dependencies are not supported. When circular dependencies exist, the data will still be dumped out but the dump will not be able to be restored directly and user intervention will be required.

Sequences associated with `serial` or `bigserial` columns need to be directly marked to dump their state. Marking their parent relation is not enough for this purpose.

40.17.4. Extension Updates

One advantage of the extension mechanism is that it provides convenient ways to manage updates to the SQL commands that define an extension's objects. This is done by associating a version name or number with each released version of the extension's installation script. In addition, if you want users to be able to update their databases dynamically from one version to the next, you should provide *update scripts* that make the necessary changes to go from one version to the next. Update scripts have names following the pattern *`extension--old_version--target_version`*`.sql` (for example, `foo--1.0--1.1.sql` contains the commands to modify version `1.0` of extension `foo` into version `1.1`).

Given that a suitable update script is available, the command `ALTER EXTENSION UPDATE` will update an installed extension to the specified new version. The update script is run in the same environment that `CREATE EXTENSION` provides for installation scripts: in particular, `search_path` is set up in the same way, and any new objects created by the script are automatically added to the extension. Also, if the script chooses to drop extension member objects, they are automatically dissociated from the extension.

If an extension has secondary control files, the control parameters that are used for an update script are those associated with the script's target (new) version.

`ALTER EXTENSION` is able to execute sequences of update script files to achieve a requested update. For example, if only `foo--1.0--1.1.sql` and `foo--1.1--2.0.sql` are available, `ALTER EXTENSION` will apply them in sequence if an update to version `2.0` is requested when `1.0` is currently installed.

Postgres Pro doesn't assume anything about the properties of version names: for example, it does not know whether `1.1` follows `1.0`. It just matches up the available version names and follows the path that requires applying the fewest update scripts. (A version name can actually be any string that doesn't contain `--` or leading or trailing `-`.)

Sometimes it is useful to provide “downgrade” scripts, for example `foo--1.1--1.0.sql` to allow reverting the changes associated with version `1.1`. If you do that, be careful of the possibility that a downgrade script might unexpectedly get applied because it yields a shorter path. The risky case is where there is a “fast path” update script that jumps ahead several versions as well as a downgrade script to the fast path's start point. It might take fewer steps to apply the downgrade and then the fast path than to move ahead one version at a time. If the downgrade script drops any irreplaceable objects, this will yield undesirable results.

To check for unexpected update paths, use this command:

```
SELECT * FROM pg_extension_update_paths('extension_name');
```

This shows each pair of distinct known version names for the specified extension, together with the update path sequence that would be taken to get from the source version to the target version, or `NULL`

if there is no available update path. The path is shown in textual form with `--` separators. You can use `regexp_split_to_array(path,'--')` if you prefer an array format.

40.17.5. Installing Extensions Using Update Scripts

An extension that has been around for awhile will probably exist in several versions, for which the author will need to write update scripts. For example, if you have released a `foo` extension in versions `1.0`, `1.1`, and `1.2`, there should be update scripts `foo--1.0--1.1.sql` and `foo--1.1--1.2.sql`. Before Postgres Pro 10, it was necessary to also create new script files `foo--1.1.sql` and `foo--1.2.sql` that directly build the newer extension versions, or else the newer versions could not be installed directly, only by installing `1.0` and then updating. That was tedious and duplicative, but now it's unnecessary, because `CREATE EXTENSION` can follow update chains automatically. For example, if only the script files `foo--1.0.sql`, `foo--1.0--1.1.sql`, and `foo--1.1--1.2.sql` are available then a request to install version `1.2` is honored by running those three scripts in sequence. The processing is the same as if you'd first installed `1.0` and then updated to `1.2`. (As with `ALTER EXTENSION UPDATE`, if multiple pathways are available then the shortest is preferred.) Arranging an extension's script files in this style can reduce the amount of maintenance effort needed to produce small updates.

If you use secondary (version-specific) control files with an extension maintained in this style, keep in mind that each version needs a control file even if it has no stand-alone installation script, as that control file will determine how the implicit update to that version is performed. For example, if `foo--1.0.control` specifies `requires = 'bar'` but `foo`'s other control files do not, the extension's dependency on `bar` will be dropped when updating from `1.0` to another version.

40.17.6. Security Considerations for Extensions

Widely-distributed extensions should assume little about the database they occupy. Therefore, it's appropriate to write functions provided by an extension in a secure style that cannot be compromised by search-path-based attacks.

An extension that has the `superuser` property set to true must also consider security hazards for the actions taken within its installation and update scripts. It is not terribly difficult for a malicious user to create trojan-horse objects that will compromise later execution of a carelessly-written extension script, allowing that user to acquire superuser privileges.

If an extension is marked `trusted`, then its installation schema can be selected by the installing user, who might intentionally use an insecure schema in hopes of gaining superuser privileges. Therefore, a trusted extension is extremely exposed from a security standpoint, and all its script commands must be carefully examined to ensure that no compromise is possible.

Advice about writing functions securely is provided in Section 40.17.6.1 below, and advice about writing installation scripts securely is provided in Section 40.17.6.2.

40.17.6.1. Security Considerations for Extension Functions

SQL-language and PL-language functions provided by extensions are at risk of search-path-based attacks when they are executed, since parsing of these functions occurs at execution time not creation time.

The `CREATE FUNCTION` reference page contains advice about writing `SECURITY DEFINER` functions safely. It's good practice to apply those techniques for any function provided by an extension, since the function might be called by a high-privilege user.

If you cannot set the `search_path` to contain only secure schemas, assume that each unqualified name could resolve to an object that a malicious user has defined. Beware of constructs that depend on `search_path` implicitly; for example, `IN` and `CASE` *`expression`* `WHEN` always select an operator using the search path. In their place, use `OPERATOR(`*`schema`*`.=) ANY` and `CASE WHEN` *`expression`*.

A general-purpose extension usually should not assume that it's been installed into a secure schema, which means that even schema-qualified references to its own objects are not entirely risk-free.

For example, if the extension has defined a function `myschema.myfunc(bigint)` then a call such as `myschema.myfunc(42)` could be captured by a hostile function `myschema.myfunc(integer)`. Be careful that the data types of function and operator parameters exactly match the declared argument types, using explicit casts where necessary.

40.17.6.2. Security Considerations for Extension Scripts

An extension installation or update script should be written to guard against search-path-based attacks occurring when the script executes. If an object reference in the script can be made to resolve to some other object than the script author intended, then a compromise might occur immediately, or later when the mis-defined extension object is used.

DDL commands such as `CREATE FUNCTION` and `CREATE OPERATOR CLASS` are generally secure, but beware of any command having a general-purpose expression as a component. For example, `CREATE VIEW` needs to be vetted, as does a `DEFAULT` expression in `CREATE FUNCTION`.

Sometimes an extension script might need to execute general-purpose SQL, for example to make catalog adjustments that aren't possible via DDL. Be careful to execute such commands with a secure `search_path`; do *not* trust the path provided by `CREATE/ALTER EXTENSION` to be secure. Best practice is to temporarily set `search_path` to `pg_catalog, pg_temp` and insert references to the extension's installation schema explicitly where needed. (This practice might also be helpful for creating views.)

Cross-extension references are extremely difficult to make fully secure, partially because of uncertainty about which schema the other extension is in. The hazards are reduced if both extensions are installed in the same schema, because then a hostile object cannot be placed ahead of the referenced extension in the installation-time `search_path`. However, no mechanism currently exists to require that. For now, best practice is to not mark an extension trusted if it depends on another one, unless that other one is always installed in `pg_catalog`.

40.17.7. Extension Example

Here is a complete example of an SQL-only extension, a two-element composite type that can store any type of value in its slots, which are named “k” and “v”. Non-text values are automatically coerced to text for storage.

The script file `pair--1.0.sql` looks like this:

```
-- complain if script is sourced in psql, rather than via CREATE EXTENSION
\echo Use "CREATE EXTENSION pair" to load this file. \quit

CREATE TYPE pair AS ( k text, v text );

CREATE FUNCTION pair(text, text)
RETURNS pair LANGUAGE SQL AS 'SELECT ROW($1, $2)::@extschema@.pair;';

CREATE OPERATOR ~> (LEFTARG = text, RIGHTARG = text, FUNCTION = pair);

-- "SET search_path" is easy to get right, but qualified names perform better.
CREATE FUNCTION lower(pair)
RETURNS pair LANGUAGE SQL
AS 'SELECT ROW(lower($1.k), lower($1.v))::@extschema@.pair;'
SET search_path = pg_temp;

CREATE FUNCTION pair_concat(pair, pair)
RETURNS pair LANGUAGE SQL
AS 'SELECT ROW($1.k OPERATOR(pg_catalog.||) $2.k,
              $1.v OPERATOR(pg_catalog.||) $2.v)::@extschema@.pair;';
```

The control file `pair.control` looks like this:

```
# pair extension
comment = 'A key/value pair data type'
default_version = '1.0'
# cannot be relocatable because of use of @extschema@
relocatable = false
```

While you hardly need a makefile to install these two files into the correct directory, you could use a `Makefile` containing this:

```
EXTENSION = pair
DATA = pair--1.0.sql

PG_CONFIG = pg_config
PGXS := $(shell $(PG_CONFIG) --pgxs)
include $(PGXS)
```

This makefile relies on PGXS, which is described in Section 40.18. The command `make install` will install the control and script files into the correct directory as reported by pg_config.

Once the files are installed, use the `CREATE EXTENSION` command to load the objects into any particular database.

40.18. Extension Building Infrastructure

If you are thinking about distributing your Postgres Pro extension modules, setting up a portable build system for them can be fairly difficult. Therefore the Postgres Pro installation provides a build infrastructure for extensions, called PGXS, so that simple extension modules can be built simply against an already installed server. PGXS is mainly intended for extensions that include C code, although it can be used for pure-SQL extensions too. Note that PGXS is not intended to be a universal build system framework that can be used to build any software interfacing to Postgres Pro; it simply automates common build rules for simple server extension modules. For more complicated packages, you might need to write your own build system.

To use the PGXS infrastructure for your extension, you must write a simple makefile. In the makefile, you need to set some variables and include the global PGXS makefile. Here is an example that builds an extension module named `isbn_issn`, consisting of a shared library containing some C code, an extension control file, an SQL script, an include file (only needed if other modules might need to access the extension functions without going via SQL), and a documentation text file:

```
MODULES = isbn_issn
EXTENSION = isbn_issn
DATA = isbn_issn--1.0.sql
DOCS = README.isbn_issn
HEADERS_isbn_issn = isbn_issn.h

PG_CONFIG = pg_config
PGXS := $(shell $(PG_CONFIG) --pgxs)
include $(PGXS)
```

The last three lines should always be the same. Earlier in the file, you assign variables or add custom make rules.

Set one of these three variables to specify what is built:

`MODULES`

list of shared-library objects to be built from source files with same stem (do not include library suffixes in this list)

`MODULE_big`

a shared library to build from multiple source files (list object files in `OBJS`)

PROGRAM

an executable program to build (list object files in OBJS)

The following variables can also be set:

EXTENSION

extension name(s); for each name you must provide an *extension*.control file, which will be installed into *prefix*/share/extension

MODULEDIR

subdirectory of *prefix*/share into which DATA and DOCS files should be installed (if not set, default is extension if EXTENSION is set, or contrib if not)

DATA

random files to install into *prefix*/share/$MODULEDIR

DATA_built

random files to install into *prefix*/share/$MODULEDIR, which need to be built first

DATA_TSEARCH

random files to install under *prefix*/share/tsearch_data

DOCS

random files to install under *prefix*/doc/$MODULEDIR

HEADERS
HEADERS_built

Files to (optionally build and) install under *prefix*/include/server/$MODULEDIR/$MODULE_big.

Unlike DATA_built, files in HEADERS_built are not removed by the clean target; if you want them removed, also add them to EXTRA_CLEAN or add your own rules to do it.

HEADERS_$MODULE
HEADERS_built_$MODULE

Files to install (after building if specified) under *prefix*/include/server/$MODULEDIR/$MODULE, where $MODULE must be a module name used in MODULES or MODULE_big.

Unlike DATA_built, files in HEADERS_built_$MODULE are not removed by the clean target; if you want them removed, also add them to EXTRA_CLEAN or add your own rules to do it.

It is legal to use both variables for the same module, or any combination, unless you have two module names in the MODULES list that differ only by the presence of a prefix built_, which would cause ambiguity. In that (hopefully unlikely) case, you should use only the HEADERS_built_$MODULE variables.

SCRIPTS

script files (not binaries) to install into *prefix*/bin

SCRIPTS_built

script files (not binaries) to install into *prefix*/bin, which need to be built first

REGRESS

list of regression test cases (without suffix), see below

REGRESS_OPTS

additional switches to pass to pg_regress

`ISOLATION`

list of isolation test cases, see below for more details

`ISOLATION_OPTS`

additional switches to pass to pg_isolation_regress

`TAP_TESTS`

switch defining if TAP tests need to be run, see below

`NO_INSTALL`

don't define an `install` target, useful for test modules that don't need their build products to be installed

`NO_INSTALLCHECK`

don't define an `installcheck` target, useful e.g., if tests require special configuration, or don't use pg_regress

`EXTRA_CLEAN`

extra files to remove in `make clean`

`PG_CPPFLAGS`

will be prepended to `CPPFLAGS`

`PG_CFLAGS`

will be appended to `CFLAGS`

`PG_CXXFLAGS`

will be appended to `CXXFLAGS`

`PG_LDFLAGS`

will be prepended to `LDFLAGS`

`PG_LIBS`

will be added to `PROGRAM` link line

`SHLIB_LINK`

will be added to `MODULE_big` link line

`PG_CONFIG`

path to pg_config program for the Postgres Pro installation to build against (typically just `pg_config` to use the first one in your `PATH`)

Put this makefile as `Makefile` in the directory which holds your extension. Then you can do `make` to compile, and then `make install` to install your module. By default, the extension is compiled and installed for the Postgres Pro installation that corresponds to the first `pg_config` program found in your `PATH`. You can use a different installation by setting `PG_CONFIG` to point to its `pg_config` program, either within the makefile or on the `make` command line.

You can also run `make` in a directory outside the source tree of your extension, if you want to keep the build directory separate. This procedure is also called a *VPATH* build. Here's how:

```
mkdir build_dir
cd build_dir
```

```
make -f /path/to/extension/source/tree/Makefile
make -f /path/to/extension/source/tree/Makefile install
```

Alternatively, you can set up a directory for a VPATH build in a similar way to how it is done for the core code. One way to do this is using the core script `config/prep_buildtree`. Once this has been done you can build by setting the `make` variable `VPATH` like this:

```
make VPATH=/path/to/extension/source/tree
make VPATH=/path/to/extension/source/tree install
```

This procedure can work with a greater variety of directory layouts.

The scripts listed in the `REGRESS` variable are used for regression testing of your module, which can be invoked by `make installcheck` after doing `make install`. For this to work you must have a running Postgres Pro server. The script files listed in `REGRESS` must appear in a subdirectory named `sql/` in your extension's directory. These files must have extension `.sql`, which must not be included in the `REGRESS` list in the makefile. For each test there should also be a file containing the expected output in a subdirectory named `expected/`, with the same stem and extension `.out`. `make installcheck` executes each test script with psql, and compares the resulting output to the matching expected file. Any differences will be written to the file `regression.diffs` in `diff -c` format. Note that trying to run a test that is missing its expected file will be reported as “trouble”, so make sure you have all expected files.

The scripts listed in the `ISOLATION` variable are used for tests stressing behavior of concurrent session with your module, which can be invoked by `make installcheck` after doing `make install`. For this to work you must have a running Postgres Pro server. The script files listed in `ISOLATION` must appear in a subdirectory named `specs/` in your extension's directory. These files must have extension `.spec`, which must not be included in the `ISOLATION` list in the makefile. For each test there should also be a file containing the expected output in a subdirectory named `expected/`, with the same stem and extension `.out`. `make installcheck` executes each test script, and compares the resulting output to the matching expected file. Any differences will be written to the file `output_iso/regression.diffs` in `diff -c` format. Note that trying to run a test that is missing its expected file will be reported as “trouble”, so make sure you have all expected files.

`TAP_TESTS` enables the use of TAP tests. Data from each run is present in a subdirectory named `tmp_check/`.

> **Tip**
>
> The easiest way to create the expected files is to create empty files, then do a test run (which will of course report differences). Inspect the actual result files found in the `results/` directory (for tests in `REGRESS`), or `output_iso/results/` directory (for tests in `ISOLATION`), then copy them to `expected/` if they match what you expect from the test.

Chapter 41. Triggers

This chapter provides general information about writing trigger functions. Trigger functions can be written in most of the available procedural languages, including PL/pgSQL (Chapter 45), PL/Tcl (Chapter 46), PL/Perl (Chapter 47), and PL/Python (Chapter 48). After reading this chapter, you should consult the chapter for your favorite procedural language to find out the language-specific details of writing a trigger in it.

It is also possible to write a trigger function in C, although most people find it easier to use one of the procedural languages. It is not currently possible to write a trigger function in the plain SQL function language.

41.1. Overview of Trigger Behavior

A trigger is a specification that the database should automatically execute a particular function whenever a certain type of operation is performed. Triggers can be attached to tables (partitioned or not), views, and foreign tables.

On tables and foreign tables, triggers can be defined to execute either before or after any `INSERT`, `UPDATE`, or `DELETE` operation, either once per modified row, or once per SQL statement. `UPDATE` triggers can moreover be set to fire only if certain columns are mentioned in the `SET` clause of the `UPDATE` statement. Triggers can also fire for `TRUNCATE` statements. If a trigger event occurs, the trigger's function is called at the appropriate time to handle the event.

On views, triggers can be defined to execute instead of `INSERT`, `UPDATE`, or `DELETE` operations. Such `INSTEAD OF` triggers are fired once for each row that needs to be modified in the view. It is the responsibility of the trigger's function to perform the necessary modifications to the view's underlying base table(s) and, where appropriate, return the modified row as it will appear in the view. Triggers on views can also be defined to execute once per SQL statement, before or after `INSERT`, `UPDATE`, or `DELETE` operations. However, such triggers are fired only if there is also an `INSTEAD OF` trigger on the view. Otherwise, any statement targeting the view must be rewritten into a statement affecting its underlying base table(s), and then the triggers that will be fired are the ones attached to the base table(s).

The trigger function must be defined before the trigger itself can be created. The trigger function must be declared as a function taking no arguments and returning type `trigger`. (The trigger function receives its input through a specially-passed `TriggerData` structure, not in the form of ordinary function arguments.)

Once a suitable trigger function has been created, the trigger is established with CREATE TRIGGER. The same trigger function can be used for multiple triggers.

Postgres Pro offers both *per-row* triggers and *per-statement* triggers. With a per-row trigger, the trigger function is invoked once for each row that is affected by the statement that fired the trigger. In contrast, a per-statement trigger is invoked only once when an appropriate statement is executed, regardless of the number of rows affected by that statement. In particular, a statement that affects zero rows will still result in the execution of any applicable per-statement triggers. These two types of triggers are sometimes called *row-level* triggers and *statement-level* triggers, respectively. Triggers on `TRUNCATE` may only be defined at statement level, not per-row.

Triggers are also classified according to whether they fire *before*, *after*, or *instead of* the operation. These are referred to as `BEFORE` triggers, `AFTER` triggers, and `INSTEAD OF` triggers respectively. Statement-level `BEFORE` triggers naturally fire before the statement starts to do anything, while statement-level `AFTER` triggers fire at the very end of the statement. These types of triggers may be defined on tables, views, or foreign tables. Row-level `BEFORE` triggers fire immediately before a particular row is operated on, while row-level `AFTER` triggers fire at the end of the statement (but before any statement-level `AFTER` triggers). These types of triggers may only be defined on tables and foreign tables, not views. `INSTEAD OF` triggers may only be defined on views, and only at row level; they fire immediately as each row in the view is identified as needing to be operated on.

The execution of an AFTER trigger can be deferred to the end of the transaction, rather than the end of the statement, if it was defined as a *constraint trigger*. In all cases, a trigger is executed as part of the same transaction as the statement that triggered it, so if either the statement or the trigger causes an error, the effects of both will be rolled back.

A statement that targets a parent table in an inheritance or partitioning hierarchy does not cause the statement-level triggers of affected child tables to be fired; only the parent table's statement-level triggers are fired. However, row-level triggers of any affected child tables will be fired.

If an INSERT contains an ON CONFLICT DO UPDATE clause, it is possible that the effects of row-level BEFORE INSERT triggers and row-level BEFORE UPDATE triggers can both be applied in a way that is apparent from the final state of the updated row, if an EXCLUDED column is referenced. There need not be an EXCLUDED column reference for both sets of row-level BEFORE triggers to execute, though. The possibility of surprising outcomes should be considered when there are both BEFORE INSERT and BEFORE UPDATE row-level triggers that change a row being inserted/updated (this can be problematic even if the modifications are more or less equivalent, if they're not also idempotent). Note that statement-level UPDATE triggers are executed when ON CONFLICT DO UPDATE is specified, regardless of whether or not any rows were affected by the UPDATE (and regardless of whether the alternative UPDATE path was ever taken). An INSERT with an ON CONFLICT DO UPDATE clause will execute statement-level BEFORE INSERT triggers first, then statement-level BEFORE UPDATE triggers, followed by statement-level AFTER UPDATE triggers and finally statement-level AFTER INSERT triggers.

If an UPDATE on a partitioned table causes a row to move to another partition, it will be performed as a DELETE from the original partition followed by an INSERT into the new partition. In this case, all row-level BEFORE UPDATE triggers and all row-level BEFORE DELETE triggers are fired on the original partition. Then all row-level BEFORE INSERT triggers are fired on the destination partition. The possibility of surprising outcomes should be considered when all these triggers affect the row being moved. As far as AFTER ROW triggers are concerned, AFTER DELETE and AFTER INSERT triggers are applied; but AFTER UPDATE triggers are not applied because the UPDATE has been converted to a DELETE and an INSERT. As far as statement-level triggers are concerned, none of the DELETE or INSERT triggers are fired, even if row movement occurs; only the UPDATE triggers defined on the target table used in the UPDATE statement will be fired.

Trigger functions invoked by per-statement triggers should always return NULL. Trigger functions invoked by per-row triggers can return a table row (a value of type HeapTuple) to the calling executor, if they choose. A row-level trigger fired before an operation has the following choices:

- It can return NULL to skip the operation for the current row. This instructs the executor to not perform the row-level operation that invoked the trigger (the insertion, modification, or deletion of a particular table row).
- For row-level INSERT and UPDATE triggers only, the returned row becomes the row that will be inserted or will replace the row being updated. This allows the trigger function to modify the row being inserted or updated.

A row-level BEFORE trigger that does not intend to cause either of these behaviors must be careful to return as its result the same row that was passed in (that is, the NEW row for INSERT and UPDATE triggers, the OLD row for DELETE triggers).

A row-level INSTEAD OF trigger should either return NULL to indicate that it did not modify any data from the view's underlying base tables, or it should return the view row that was passed in (the NEW row for INSERT and UPDATE operations, or the OLD row for DELETE operations). A nonnull return value is used to signal that the trigger performed the necessary data modifications in the view. This will cause the count of the number of rows affected by the command to be incremented. For INSERT and UPDATE operations only, the trigger may modify the NEW row before returning it. This will change the data returned by INSERT RETURNING or UPDATE RETURNING, and is useful when the view will not show exactly the same data that was provided.

The return value is ignored for row-level triggers fired after an operation, and so they can return NULL.

Some considerations apply for generated columns. Stored generated columns are computed after BEFORE triggers and before AFTER triggers. Therefore, the generated value can be inspected in AFTER triggers. In BEFORE triggers, the OLD row contains the old generated value, as one would expect, but the NEW row does not yet contain the new generated value and should not be accessed. In the C language interface, the content of the column is undefined at this point; a higher-level programming language should prevent access to a stored generated column in the NEW row in a BEFORE trigger. Changes to the value of a generated column in a BEFORE trigger are ignored and will be overwritten.

If more than one trigger is defined for the same event on the same relation, the triggers will be fired in alphabetical order by trigger name. In the case of BEFORE and INSTEAD OF triggers, the possibly-modified row returned by each trigger becomes the input to the next trigger. If any BEFORE or INSTEAD OF trigger returns NULL, the operation is abandoned for that row and subsequent triggers are not fired (for that row).

A trigger definition can also specify a Boolean WHEN condition, which will be tested to see whether the trigger should be fired. In row-level triggers the WHEN condition can examine the old and/or new values of columns of the row. (Statement-level triggers can also have WHEN conditions, although the feature is not so useful for them.) In a BEFORE trigger, the WHEN condition is evaluated just before the function is or would be executed, so using WHEN is not materially different from testing the same condition at the beginning of the trigger function. However, in an AFTER trigger, the WHEN condition is evaluated just after the row update occurs, and it determines whether an event is queued to fire the trigger at the end of statement. So when an AFTER trigger's WHEN condition does not return true, it is not necessary to queue an event nor to re-fetch the row at end of statement. This can result in significant speedups in statements that modify many rows, if the trigger only needs to be fired for a few of the rows. INSTEAD OF triggers do not support WHEN conditions.

Typically, row-level BEFORE triggers are used for checking or modifying the data that will be inserted or updated. For example, a BEFORE trigger might be used to insert the current time into a timestamp column, or to check that two elements of the row are consistent. Row-level AFTER triggers are most sensibly used to propagate the updates to other tables, or make consistency checks against other tables. The reason for this division of labor is that an AFTER trigger can be certain it is seeing the final value of the row, while a BEFORE trigger cannot; there might be other BEFORE triggers firing after it. If you have no specific reason to make a trigger BEFORE or AFTER, the BEFORE case is more efficient, since the information about the operation doesn't have to be saved until end of statement.

If a trigger function executes SQL commands then these commands might fire triggers again. This is known as cascading triggers. There is no direct limitation on the number of cascade levels. It is possible for cascades to cause a recursive invocation of the same trigger; for example, an INSERT trigger might execute a command that inserts an additional row into the same table, causing the INSERT trigger to be fired again. It is the trigger programmer's responsibility to avoid infinite recursion in such scenarios.

When a trigger is being defined, arguments can be specified for it. The purpose of including arguments in the trigger definition is to allow different triggers with similar requirements to call the same function. As an example, there could be a generalized trigger function that takes as its arguments two column names and puts the current user in one and the current time stamp in the other. Properly written, this trigger function would be independent of the specific table it is triggering on. So the same function could be used for INSERT events on any table with suitable columns, to automatically track creation of records in a transaction table for example. It could also be used to track last-update events if defined as an UPDATE trigger.

Each programming language that supports triggers has its own method for making the trigger input data available to the trigger function. This input data includes the type of trigger event (e.g., INSERT or UPDATE) as well as any arguments that were listed in CREATE TRIGGER. For a row-level trigger, the input data also includes the NEW row for INSERT and UPDATE triggers, and/or the OLD row for UPDATE and DELETE triggers.

By default, statement-level triggers do not have any way to examine the individual row(s) modified by the statement. But an AFTER STATEMENT trigger can request that *transition tables* be created to make the sets

of affected rows available to the trigger. AFTER ROW triggers can also request transition tables, so that they can see the total changes in the table as well as the change in the individual row they are currently being fired for. The method for examining the transition tables again depends on the programming language that is being used, but the typical approach is to make the transition tables act like read-only temporary tables that can be accessed by SQL commands issued within the trigger function.

41.2. Visibility of Data Changes

If you execute SQL commands in your trigger function, and these commands access the table that the trigger is for, then you need to be aware of the data visibility rules, because they determine whether these SQL commands will see the data change that the trigger is fired for. Briefly:

- Statement-level triggers follow simple visibility rules: none of the changes made by a statement are visible to statement-level BEFORE triggers, whereas all modifications are visible to statement-level AFTER triggers.
- The data change (insertion, update, or deletion) causing the trigger to fire is naturally *not* visible to SQL commands executed in a row-level BEFORE trigger, because it hasn't happened yet.
- However, SQL commands executed in a row-level BEFORE trigger *will* see the effects of data changes for rows previously processed in the same outer command. This requires caution, since the ordering of these change events is not in general predictable; an SQL command that affects multiple rows can visit the rows in any order.
- Similarly, a row-level INSTEAD OF trigger will see the effects of data changes made by previous firings of INSTEAD OF triggers in the same outer command.
- When a row-level AFTER trigger is fired, all data changes made by the outer command are already complete, and are visible to the invoked trigger function.

If your trigger function is written in any of the standard procedural languages, then the above statements apply only if the function is declared VOLATILE. Functions that are declared STABLE or IMMUTABLE will not see changes made by the calling command in any case.

Further information about data visibility rules can be found in Section 49.5. The example in Section 41.4 contains a demonstration of these rules.

41.3. Writing Trigger Functions in C

This section describes the low-level details of the interface to a trigger function. This information is only needed when writing trigger functions in C. If you are using a higher-level language then these details are handled for you. In most cases you should consider using a procedural language before writing your triggers in C. The documentation of each procedural language explains how to write a trigger in that language.

Trigger functions must use the “version 1” function manager interface.

When a function is called by the trigger manager, it is not passed any normal arguments, but it is passed a “context” pointer pointing to a TriggerData structure. C functions can check whether they were called from the trigger manager or not by executing the macro:

```
CALLED_AS_TRIGGER(fcinfo)
```

which expands to:

```
((fcinfo)->context != NULL && IsA((fcinfo)->context, TriggerData))
```

If this returns true, then it is safe to cast fcinfo->context to type TriggerData * and make use of the pointed-to TriggerData structure. The function must *not* alter the TriggerData structure or any of the data it points to.

struct TriggerData is defined in commands/trigger.h:

```
typedef struct TriggerData
```

```
{
    NodeTag          type;
    TriggerEvent     tg_event;
    Relation         tg_relation;
    HeapTuple        tg_trigtuple;
    HeapTuple        tg_newtuple;
    Trigger         *tg_trigger;
    TupleTableSlot  *tg_trigslot;
    TupleTableSlot  *tg_newslot;
    Tuplestorestate *tg_oldtable;
    Tuplestorestate *tg_newtable;
    const Bitmapset *tg_updatedcols;
} TriggerData;
```

where the members are defined as follows:

`type`

Always `T_TriggerData`.

`tg_event`

Describes the event for which the function is called. You can use the following macros to examine `tg_event`:

`TRIGGER_FIRED_BEFORE(tg_event)`

Returns true if the trigger fired before the operation.

`TRIGGER_FIRED_AFTER(tg_event)`

Returns true if the trigger fired after the operation.

`TRIGGER_FIRED_INSTEAD(tg_event)`

Returns true if the trigger fired instead of the operation.

`TRIGGER_FIRED_FOR_ROW(tg_event)`

Returns true if the trigger fired for a row-level event.

`TRIGGER_FIRED_FOR_STATEMENT(tg_event)`

Returns true if the trigger fired for a statement-level event.

`TRIGGER_FIRED_BY_INSERT(tg_event)`

Returns true if the trigger was fired by an `INSERT` command.

`TRIGGER_FIRED_BY_UPDATE(tg_event)`

Returns true if the trigger was fired by an `UPDATE` command.

`TRIGGER_FIRED_BY_DELETE(tg_event)`

Returns true if the trigger was fired by a `DELETE` command.

`TRIGGER_FIRED_BY_TRUNCATE(tg_event)`

Returns true if the trigger was fired by a `TRUNCATE` command.

`tg_relation`

A pointer to a structure describing the relation that the trigger fired for. Look at `utils/rel.h` for details about this structure. The most interesting things are `tg_relation->rd_att` (descriptor of the relation tuples) and `tg_relation->rd_rel->relname` (relation name; the type is not `char*` but `NameData`; use `SPI_getrelname(tg_relation)` to get a `char*` if you need a copy of the name).

`tg_trigtuple`

A pointer to the row for which the trigger was fired. This is the row being inserted, updated, or deleted. If this trigger was fired for an `INSERT` or `DELETE` then this is what you should return from the function if you don't want to replace the row with a different one (in the case of `INSERT`) or skip the operation. For triggers on foreign tables, values of system columns herein are unspecified.

`tg_newtuple`

A pointer to the new version of the row, if the trigger was fired for an `UPDATE`, and `NULL` if it is for an `INSERT` or a `DELETE`. This is what you have to return from the function if the event is an `UPDATE` and you don't want to replace this row by a different one or skip the operation. For triggers on foreign tables, values of system columns herein are unspecified.

`tg_trigger`

A pointer to a structure of type `Trigger`, defined in `utils/reltrigger.h`:

```
typedef struct Trigger
{
    Oid         tgoid;
    char       *tgname;
    Oid         tgfoid;
    int16       tgtype;
    char        tgenabled;
    bool        tgisinternal;
    bool        tgisclone;
    Oid         tgconstrrelid;
    Oid         tgconstrindid;
    Oid         tgconstraint;
    bool        tgdeferrable;
    bool        tginitdeferred;
    int16       tgnargs;
    int16       tgnattr;
    int16      *tgattr;
    char      **tgargs;
    char       *tgqual;
    char       *tgoldtable;
    char       *tgnewtable;
} Trigger;
```

where `tgname` is the trigger's name, `tgnargs` is the number of arguments in `tgargs`, and `tgargs` is an array of pointers to the arguments specified in the `CREATE TRIGGER` statement. The other members are for internal use only.

`tg_trigslot`

The slot containing `tg_trigtuple`, or a `NULL` pointer if there is no such tuple.

`tg_newslot`

The slot containing `tg_newtuple`, or a `NULL` pointer if there is no such tuple.

`tg_oldtable`

A pointer to a structure of type `Tuplestorestate` containing zero or more rows in the format specified by `tg_relation`, or a `NULL` pointer if there is no `OLD TABLE` transition relation.

`tg_newtable`

A pointer to a structure of type `Tuplestorestate` containing zero or more rows in the format specified by `tg_relation`, or a `NULL` pointer if there is no `NEW TABLE` transition relation.

`tg_updatedcols`

For `UPDATE` triggers, a bitmap set indicating the columns that were updated by the triggering command. Generic trigger functions can use this to optimize actions by not having to deal with columns that were not changed.

As an example, to determine whether a column with attribute number `attnum` (1-based) is a member of this bitmap set, call `bms_is_member(attnum - FirstLowInvalidHeapAttributeNumber, trigdata->tg_updatedcols))`.

For triggers other than `UPDATE` triggers, this will be `NULL`.

To allow queries issued through SPI to reference transition tables, see SPI_register_trigger_data.

A trigger function must return either a `HeapTuple` pointer or a `NULL` pointer (*not* an SQL null value, that is, do not set *`isNull`* true). Be careful to return either `tg_trigtuple` or `tg_newtuple`, as appropriate, if you don't want to modify the row being operated on.

41.4. A Complete Trigger Example

Here is a very simple example of a trigger function written in C. (Examples of triggers written in procedural languages can be found in the documentation of the procedural languages.)

The function `trigf` reports the number of rows in the table `ttest` and skips the actual operation if the command attempts to insert a null value into the column `x`. (So the trigger acts as a not-null constraint but doesn't abort the transaction.)

First, the table definition:

```
CREATE TABLE ttest (
    x integer
);
```

This is the source code of the trigger function:

```
#include "postgres.h"
#include "fmgr.h"
#include "executor/spi.h"       /* this is what you need to work with SPI */
#include "commands/trigger.h"   /* ... triggers ... */
#include "utils/rel.h"          /* ... and relations */

PG_MODULE_MAGIC;

PG_FUNCTION_INFO_V1(trigf);

Datum
trigf(PG_FUNCTION_ARGS)
{
    TriggerData *trigdata = (TriggerData *) fcinfo->context;
    TupleDesc   tupdesc;
    HeapTuple   rettuple;
    char       *when;
    bool        checknull = false;
    bool        isnull;
    int         ret, i;

    /* make sure it's called as a trigger at all */
    if (!CALLED_AS_TRIGGER(fcinfo))
        elog(ERROR, "trigf: not called by trigger manager");
```

```
    /* tuple to return to executor */
    if (TRIGGER_FIRED_BY_UPDATE(trigdata->tg_event))
        rettuple = trigdata->tg_newtuple;
    else
        rettuple = trigdata->tg_trigtuple;

    /* check for null values */
    if (!TRIGGER_FIRED_BY_DELETE(trigdata->tg_event)
        && TRIGGER_FIRED_BEFORE(trigdata->tg_event))
        checknull = true;

    if (TRIGGER_FIRED_BEFORE(trigdata->tg_event))
        when = "before";
    else
        when = "after ";

    tupdesc = trigdata->tg_relation->rd_att;

    /* connect to SPI manager */
    if ((ret = SPI_connect()) < 0)
        elog(ERROR, "trigf (fired %s): SPI_connect returned %d", when, ret);

    /* get number of rows in table */
    ret = SPI_exec("SELECT count(*) FROM ttest", 0);

    if (ret < 0)
        elog(ERROR, "trigf (fired %s): SPI_exec returned %d", when, ret);

    /* count(*) returns int8, so be careful to convert */
    i = DatumGetInt64(SPI_getbinval(SPI_tuptable->vals[0],
                                    SPI_tuptable->tupdesc,
                                    1,
                                    &isnull));

    elog (INFO, "trigf (fired %s): there are %d rows in ttest", when, i);

    SPI_finish();

    if (checknull)
    {
        SPI_getbinval(rettuple, tupdesc, 1, &isnull);
        if (isnull)
            rettuple = NULL;
    }

    return PointerGetDatum(rettuple);
}
```

After you have compiled the source code (see Section 40.10.5), declare the function and the triggers:

```
CREATE FUNCTION trigf() RETURNS trigger
    AS 'filename'
    LANGUAGE C;

CREATE TRIGGER tbefore BEFORE INSERT OR UPDATE OR DELETE ON ttest
    FOR EACH ROW EXECUTE FUNCTION trigf();

CREATE TRIGGER tafter AFTER INSERT OR UPDATE OR DELETE ON ttest
```

```
    FOR EACH ROW EXECUTE FUNCTION trigf();
```

Now you can test the operation of the trigger:

```
=> INSERT INTO ttest VALUES (NULL);
INFO:  trigf (fired before): there are 0 rows in ttest
INSERT 0 0

-- Insertion skipped and AFTER trigger is not fired

=> SELECT * FROM ttest;
 x
---
(0 rows)

=> INSERT INTO ttest VALUES (1);
INFO:  trigf (fired before): there are 0 rows in ttest
INFO:  trigf (fired after ): there are 1 rows in ttest
                                       ^^^^^^^^
                             remember what we said about visibility.
INSERT 167793 1
vac=> SELECT * FROM ttest;
 x
---
 1
(1 row)

=> INSERT INTO ttest SELECT x * 2 FROM ttest;
INFO:  trigf (fired before): there are 1 rows in ttest
INFO:  trigf (fired after ): there are 2 rows in ttest
                                       ^^^^^^
                             remember what we said about visibility.
INSERT 167794 1
=> SELECT * FROM ttest;
 x
---
 1
 2
(2 rows)

=> UPDATE ttest SET x = NULL WHERE x = 2;
INFO:  trigf (fired before): there are 2 rows in ttest
UPDATE 0
=> UPDATE ttest SET x = 4 WHERE x = 2;
INFO:  trigf (fired before): there are 2 rows in ttest
INFO:  trigf (fired after ): there are 2 rows in ttest
UPDATE 1
vac=> SELECT * FROM ttest;
 x
---
 1
 4
(2 rows)

=> DELETE FROM ttest;
INFO:  trigf (fired before): there are 2 rows in ttest
INFO:  trigf (fired before): there are 1 rows in ttest
INFO:  trigf (fired after ): there are 0 rows in ttest
INFO:  trigf (fired after ): there are 0 rows in ttest
```

```
                                        ^^^^^^
                                remember what we said about visibility.
DELETE 2
=> SELECT * FROM ttest;
 x
---
(0 rows)
```

Chapter 42. Event Triggers

To supplement the trigger mechanism discussed in Chapter 41, Postgres Pro also provides event triggers. Unlike regular triggers, which are attached to a single table and capture only DML events, event triggers are global to a particular database and are capable of capturing DDL events.

Like regular triggers, event triggers can be written in any procedural language that includes event trigger support, or in C, but not in plain SQL.

42.1. Overview of Event Trigger Behavior

An event trigger fires whenever the event with which it is associated occurs in the database in which it is defined. Currently, the only supported events are `login`, `ddl_command_start`, `ddl_command_end`, `table_rewrite` and `sql_drop`. Support for additional events may be added in future releases.

The `login` event occurs when an authenticated user logs in to the system. Any bugs in a trigger procedure for this event may prevent successful login to the system. Such bugs may be fixed after first reconnecting to the system with event triggers disabled (see ignore_event_trigger) or by restarting the system in single-user mode (as event triggers are disabled in this mode). See the postgres reference page for details about using single-user mode. The `login` event will also fire on standby servers. To prevent servers from becoming inaccessible, such triggers must avoid writing anything to the database when running on a standby.

The `ddl_command_start` event occurs just before the execution of a `CREATE`, `ALTER`, `DROP`, `SECURITY LABEL`, `COMMENT`, `GRANT` or `REVOKE` command. No check whether the affected object exists or doesn't exist is performed before the event trigger fires. As an exception, however, this event does not occur for DDL commands targeting shared objects — databases, roles, and tablespaces — or for commands targeting event triggers themselves. The event trigger mechanism does not support these object types. `ddl_command_start` also occurs just before the execution of a `SELECT INTO` command, since this is equivalent to `CREATE TABLE AS`.

The `ddl_command_end` event occurs just after the execution of this same set of commands. To obtain more details on the DDL operations that took place, use the set-returning function `pg_event_trigger_ddl_commands()` from the `ddl_command_end` event trigger code (see Section 9.29). Note that the trigger fires after the actions have taken place (but before the transaction commits), and thus the system catalogs can be read as already changed.

The `sql_drop` event occurs just before the `ddl_command_end` event trigger for any operation that drops database objects. To list the objects that have been dropped, use the set-returning function `pg_event_trigger_dropped_objects()` from the `sql_drop` event trigger code (see Section 9.29). Note that the trigger is executed after the objects have been deleted from the system catalogs, so it's not possible to look them up anymore.

The `table_rewrite` event occurs just before a table is rewritten by some actions of the commands `ALTER TABLE` and `ALTER TYPE`. While other control statements are available to rewrite a table, like `CLUSTER` and `VACUUM`, the `table_rewrite` event is not triggered by them. To find the OID of the table that was rewritten, use the function `pg_event_trigger_table_rewrite_oid()` (see Section 9.29). To discover the reason(s) for the rewrite, use the function `pg_event_trigger_table_rewrite_reason()`.

Event triggers (like other functions) cannot be executed in an aborted transaction. Thus, if a DDL command fails with an error, any associated `ddl_command_end` triggers will not be executed. Conversely, if a `ddl_command_start` trigger fails with an error, no further event triggers will fire, and no attempt will be made to execute the command itself. Similarly, if a `ddl_command_end` trigger fails with an error, the effects of the DDL statement will be rolled back, just as they would be in any other case where the containing transaction aborts.

For a complete list of commands supported by the event trigger mechanism, see Section 42.2.

Event triggers are created using the command CREATE EVENT TRIGGER. In order to create an event trigger, you must first create a function with the special return type `event_trigger`. This function need

not (and may not) return a value; the return type serves merely as a signal that the function is to be invoked as an event trigger.

If more than one event trigger is defined for a particular event, they will fire in alphabetical order by trigger name.

A trigger definition can also specify a `WHEN` condition so that, for example, a `ddl_command_start` trigger can be fired only for particular commands which the user wishes to intercept. A common use of such triggers is to restrict the range of DDL operations which users may perform.

42.2. Event Trigger Firing Matrix

Table 42.1 lists all commands for which event triggers are supported.

Table 42.1. Event Trigger Support by Command Tag

Command Tag	ddl_command_start	ddl_command_end	sql_drop	table_rewrite	Notes
ALTER AGGREGATE	X	X	-	-	
ALTER COLLATION	X	X	-	-	
ALTER CONVERSION	X	X	-	-	
ALTER DOMAIN	X	X	-	-	
ALTER DEFAULT PRIVILEGES	X	X	-	-	
ALTER EXTENSION	X	X	-	-	
ALTER FOREIGN DATA WRAPPER	X	X	-	-	
ALTER FOREIGN TABLE	X	X	X	-	
ALTER FUNCTION	X	X	-	-	
ALTER LANGUAGE	X	X	-	-	
ALTER LARGE OBJECT	X	X	-	-	
ALTER MATERIALIZED VIEW	X	X	-	-	
ALTER OPERATOR	X	X	-	-	
ALTER OPERATOR CLASS	X	X	-	-	
ALTER OPERATOR FAMILY	X	X	-	-	
ALTER POLICY	X	X	-	-	
ALTER PROCEDURE	X	X	-	-	
ALTER PUBLICATION	X	X	-	-	
ALTER ROUTINE	X	X	-	-	
ALTER SCHEMA	X	X	-	-	
ALTER SEQUENCE	X	X	-	-	
ALTER SERVER	X	X	-	-	
ALTER STATISTICS	X	X	-	-	
ALTER SUBSCRIPTION	X	X	-	-	
ALTER TABLE	X	X	X	X	
ALTER TEXT SEARCH CONFIGURATION	X	X	-	-	

Command Tag	ddl_command_start	ddl_command_end	sql_drop	table_rewrite	**Notes**
ALTER TEXT SEARCH DICTIONARY	X	X	-	-	
ALTER TEXT SEARCH PARSER	X	X	-	-	
ALTER TEXT SEARCH TEMPLATE	X	X	-	-	
ALTER TRIGGER	X	X	-	-	
ALTER TYPE	X	X	-	X	
ALTER USER MAPPING	X	X	-	-	
ALTER VIEW	X	X	-	-	
COMMENT	X	X	-	-	Only for local objects
CREATE ACCESS METHOD	X	X	-	-	
CREATE AGGREGATE	X	X	-	-	
CREATE CAST	X	X	-	-	
CREATE COLLATION	X	X	-	-	
CREATE CONVERSION	X	X	-	-	
CREATE DOMAIN	X	X	-	-	
CREATE EXTENSION	X	X	-	-	
CREATE FOREIGN DATA WRAPPER	X	X	-	-	
CREATE FOREIGN TABLE	X	X	-	-	
CREATE FUNCTION	X	X	-	-	
CREATE INDEX	X	X	-	-	
CREATE LANGUAGE	X	X	-	-	
CREATE MATERIALIZED VIEW	X	X	-	-	
CREATE OPERATOR	X	X	-	-	
CREATE OPERATOR CLASS	X	X	-	-	
CREATE OPERATOR FAMILY	X	X	-	-	
CREATE POLICY	X	X	-	-	
CREATE PROCEDURE	X	X	-	-	
CREATE PUBLICATION	X	X	-	-	
CREATE RULE	X	X	-	-	
CREATE SCHEMA	X	X	-	-	
CREATE SEQUENCE	X	X	-	-	
CREATE SERVER	X	X	-	-	
CREATE STATISTICS	X	X	-	-	
CREATE SUBSCRIPTION	X	X	-	-	
CREATE TABLE	X	X	-	-	
CREATE TABLE AS	X	X	-	-	

Command Tag	ddl_command_start	ddl_command_end	sql_drop	table_rewrite	**Notes**
CREATE TEXT SEARCH CONFIGURATION	X	X	-	-	
CREATE TEXT SEARCH DICTIONARY	X	X	-	-	
CREATE TEXT SEARCH PARSER	X	X	-	-	
CREATE TEXT SEARCH TEMPLATE	X	X	-	-	
CREATE TRIGGER	X	X	-	-	
CREATE TYPE	X	X	-	-	
CREATE USER MAPPING	X	X	-	-	
CREATE VIEW	X	X	-	-	
DROP ACCESS METHOD	X	X	X	-	
DROP AGGREGATE	X	X	X	-	
DROP CAST	X	X	X	-	
DROP COLLATION	X	X	X	-	
DROP CONVERSION	X	X	X	-	
DROP DOMAIN	X	X	X	-	
DROP EXTENSION	X	X	X	-	
DROP FOREIGN DATA WRAPPER	X	X	X	-	
DROP FOREIGN TABLE	X	X	X	-	
DROP FUNCTION	X	X	X	-	
DROP INDEX	X	X	X	-	
DROP LANGUAGE	X	X	X	-	
DROP MATERIALIZED VIEW	X	X	X	-	
DROP OPERATOR	X	X	X	-	
DROP OPERATOR CLASS	X	X	X	-	
DROP OPERATOR FAMILY	X	X	X	-	
DROP OWNED	X	X	X	-	
DROP POLICY	X	X	X	-	
DROP PROCEDURE	X	X	X	-	
DROP PUBLICATION	X	X	X	-	
DROP ROUTINE	X	X	X	-	
DROP RULE	X	X	X	-	
DROP SCHEMA	X	X	X	-	
DROP SEQUENCE	X	X	X	-	
DROP SERVER	X	X	X	-	
DROP STATISTICS	X	X	X	-	
DROP SUBSCRIPTION	X	X	X	-	

Command Tag	ddl_command_start	ddl_command_end	sql_drop	table_rewrite	Notes
DROP TABLE	X	X	X	-	
DROP TEXT SEARCH CONFIGURATION	X	X	X	-	
DROP TEXT SEARCH DICTIONARY	X	X	X	-	
DROP TEXT SEARCH PARSER	X	X	X	-	
DROP TEXT SEARCH TEMPLATE	X	X	X	-	
DROP TRIGGER	X	X	X	-	
DROP TYPE	X	X	X	-	
DROP USER MAPPING	X	X	X	-	
DROP VIEW	X	X	X	-	
GRANT	X	X	-	-	Only for local objects
IMPORT FOREIGN SCHEMA	X	X	-	-	
REFRESH MATERIALIZED VIEW	X	X	-	-	
REVOKE	X	X	-	-	Only for local objects
SECURITY LABEL	X	X	-	-	Only for local objects
SELECT INTO	X	X	-	-	

42.3. Writing Event Trigger Functions in C

This section describes the low-level details of the interface to an event trigger function. This information is only needed when writing event trigger functions in C. If you are using a higher-level language then these details are handled for you. In most cases you should consider using a procedural language before writing your event triggers in C. The documentation of each procedural language explains how to write an event trigger in that language.

Event trigger functions must use the "version 1" function manager interface.

When a function is called by the event trigger manager, it is not passed any normal arguments, but it is passed a "context" pointer pointing to a `EventTriggerData` structure. C functions can check whether they were called from the event trigger manager or not by executing the macro:

```
CALLED_AS_EVENT_TRIGGER(fcinfo)
```

which expands to:

```
((fcinfo)->context != NULL && IsA((fcinfo)->context, EventTriggerData))
```

If this returns true, then it is safe to cast `fcinfo->context` to type `EventTriggerData *` and make use of the pointed-to `EventTriggerData` structure. The function must *not* alter the `EventTriggerData` structure or any of the data it points to.

`struct EventTriggerData` is defined in `commands/event_trigger.h`:

```
typedef struct EventTriggerData
{
```

```
    NodeTag     type;
    const char *event;      /* event name */
    Node       *parsetree;  /* parse tree */
    CommandTag  tag;        /* command tag */
} EventTriggerData;
```

where the members are defined as follows:

`type`

Always `T_EventTriggerData`.

`event`

Describes the event for which the function is called, one of `"ddl_command_start"`, `"ddl_command_end"`, `"sql_drop"`, `"table_rewrite"`. See Section 42.1 for the meaning of these events.

`parsetree`

A pointer to the parse tree of the command. Check the Postgres Pro source code for details. The parse tree structure is subject to change without notice.

`tag`

The command tag associated with the event for which the event trigger is run, for example `"CREATE FUNCTION"`.

An event trigger function must return a `NULL` pointer (*not* an SQL null value, that is, do not set *`isNull`* true).

42.4. A C language Event Trigger Example

Here is a very simple example of an event trigger function written in C. (Examples of triggers written in procedural languages can be found in the documentation of the procedural languages.)

The function `noddl` raises an exception each time it is called. The event trigger definition associated the function with the `ddl_command_start` event. The effect is that all DDL commands (with the exceptions mentioned in Section 42.1) are prevented from running.

This is the source code of the trigger function:

```
#include "postgres.h"
#include "commands/event_trigger.h"


PG_MODULE_MAGIC;

PG_FUNCTION_INFO_V1(noddl);

Datum
noddl(PG_FUNCTION_ARGS)
{
    EventTriggerData *trigdata;

    if (!CALLED_AS_EVENT_TRIGGER(fcinfo))  /* internal error */
        elog(ERROR, "not fired by event trigger manager");

    trigdata = (EventTriggerData *) fcinfo->context;

    ereport(ERROR,
            (errcode(ERRCODE_INSUFFICIENT_PRIVILEGE),
             errmsg("command \"%s\" denied",
```

```
                    GetCommandTagName(trigdata->tag))));

    PG_RETURN_NULL();
}
```

After you have compiled the source code (see Section 40.10.5), declare the function and the triggers:

```
CREATE FUNCTION noddl() RETURNS event_trigger
    AS 'noddl' LANGUAGE C;

CREATE EVENT TRIGGER noddl ON ddl_command_start
    EXECUTE FUNCTION noddl();
```

Now you can test the operation of the trigger:

```
=# \dy
                     List of event triggers
 Name  |       Event       | Owner | Enabled | Function | Tags
-------+-------------------+-------+---------+----------+------
 noddl | ddl_command_start | dim   | enabled | noddl    |
(1 row)

=# CREATE TABLE foo(id serial);
ERROR:  command "CREATE TABLE" denied
```

In this situation, in order to be able to run some DDL commands when you need to do so, you have to either drop the event trigger or disable it. It can be convenient to disable the trigger for only the duration of a transaction:

```
BEGIN;
ALTER EVENT TRIGGER noddl DISABLE;
CREATE TABLE foo (id serial);
ALTER EVENT TRIGGER noddl ENABLE;
COMMIT;
```

(Recall that DDL commands on event triggers themselves are not affected by event triggers.)

42.5. A Table Rewrite Event Trigger Example

Thanks to the `table_rewrite` event, it is possible to implement a table rewriting policy only allowing the rewrite in maintenance windows.

Here's an example implementing such a policy.

```
CREATE OR REPLACE FUNCTION no_rewrite()
 RETURNS event_trigger
 LANGUAGE plpgsql AS
$$
---
--- Implement local Table Rewriting policy:
---   public.foo is not allowed rewriting, ever
---   other tables are only allowed rewriting between 1am and 6am
---   unless they have more than 100 blocks
---
DECLARE
  table_oid oid := pg_event_trigger_table_rewrite_oid();
  current_hour integer := extract('hour' from current_time);
  pages integer;
  max_pages integer := 100;
BEGIN
  IF pg_event_trigger_table_rewrite_oid() = 'public.foo'::regclass
```

```
  THEN
        RAISE EXCEPTION 'you''re not allowed to rewrite the table %',
                        table_oid::regclass;
  END IF;

  SELECT INTO pages relpages FROM pg_class WHERE oid = table_oid;
  IF pages > max_pages
  THEN
        RAISE EXCEPTION 'rewrites only allowed for table with less than % pages',
                        max_pages;
  END IF;

  IF current_hour NOT BETWEEN 1 AND 6
  THEN
        RAISE EXCEPTION 'rewrites only allowed between 1am and 6am';
  END IF;
END;
$$;

CREATE EVENT TRIGGER no_rewrite_allowed
                  ON table_rewrite
   EXECUTE FUNCTION no_rewrite();
```

42.6. A Database Login Event Trigger Example

The event trigger on the `login` event can be useful for logging user logins, for verifying the connection and assigning roles according to current circumstances, or for session data initialization. It is very important that any event trigger using the `login` event checks whether or not the database is in recovery before performing any writes. Writing to a standby server will make it inaccessible.

The following example demonstrates these options.

```
-- create test tables and roles
CREATE TABLE user_login_log (
  "user" text,
  "session_start" timestamp with time zone
);
CREATE ROLE day_worker;
CREATE ROLE night_worker;

-- the example trigger function
CREATE OR REPLACE FUNCTION init_session()
  RETURNS event_trigger SECURITY DEFINER
  LANGUAGE plpgsql AS
$$
DECLARE
  hour integer = EXTRACT('hour' FROM current_time);
  rec boolean;
BEGIN
-- 1. Forbid logging in during nighttime
IF hour BETWEEN 2 AND 4 THEN
  RAISE EXCEPTION 'Login forbidden';
END IF;

-- The checks below cannot be performed on standby servers so
-- ensure the database is not in recovery
SELECT pg_is_in_recovery() INTO rec;
IF rec THEN
  RETURN;
```

```
END IF

-- 2. Assign some roles
IF hour BETWEEN 8 AND 20 THEN         -- at daytime grant the day_worker role
  EXECUTE 'REVOKE night_worker FROM ' || quote_ident(session_user);
  EXECUTE 'GRANT    day_worker TO '   || quote_ident(session_user);
ELSE                                  -- at other time grant the night_worker role
  EXECUTE 'REVOKE day_worker FROM ' || quote_ident(session_user);
  EXECUTE 'GRANT  night_worker TO ' || quote_ident(session_user);
END IF;

-- 3. Initialize some user session data
CREATE TEMP TABLE session_storage (x float, y integer);

-- 4. Log the connection time
INSERT INTO user_login_log VALUES (session_user, current_timestamp);

END;
$$;

-- trigger definition
CREATE EVENT TRIGGER init_session
  ON login
  EXECUTE FUNCTION init_session();
```

Chapter 43. The Rule System

This chapter discusses the rule system in Postgres Pro. Production rule systems are conceptually simple, but there are many subtle points involved in actually using them.

Some other database systems define active database rules, which are usually stored procedures and triggers. In Postgres Pro, these can be implemented using functions and triggers as well.

The rule system (more precisely speaking, the query rewrite rule system) is totally different from stored procedures and triggers. It modifies queries to take rules into consideration, and then passes the modified query to the query planner for planning and execution. It is very powerful, and can be used for many things such as query language procedures, views, and versions. The theoretical foundations and the power of this rule system are also discussed in ston90b and ong90.

43.1. The Query Tree

To understand how the rule system works it is necessary to know when it is invoked and what its input and results are.

The rule system is located between the parser and the planner. It takes the output of the parser, one query tree, and the user-defined rewrite rules, which are also query trees with some extra information, and creates zero or more query trees as result. So its input and output are always things the parser itself could have produced and thus, anything it sees is basically representable as an SQL statement.

Now what is a query tree? It is an internal representation of an SQL statement where the single parts that it is built from are stored separately. These query trees can be shown in the server log if you set the configuration parameters `debug_print_parse`, `debug_print_rewritten`, or `debug_print_plan`. The rule actions are also stored as query trees, in the system catalog `pg_rewrite`. They are not formatted like the log output, but they contain exactly the same information.

Reading a raw query tree requires some experience. But since SQL representations of query trees are sufficient to understand the rule system, this chapter will not teach how to read them.

When reading the SQL representations of the query trees in this chapter it is necessary to be able to identify the parts the statement is broken into when it is in the query tree structure. The parts of a query tree are

the command type

This is a simple value telling which command (`SELECT`, `INSERT`, `UPDATE`, `DELETE`) produced the query tree.

the range table

The range table is a list of relations that are used in the query. In a `SELECT` statement these are the relations given after the `FROM` key word.

Every range table entry identifies a table or view and tells by which name it is called in the other parts of the query. In the query tree, the range table entries are referenced by number rather than by name, so here it doesn't matter if there are duplicate names as it would in an SQL statement. This can happen after the range tables of rules have been merged in. The examples in this chapter will not have this situation.

the result relation

This is an index into the range table that identifies the relation where the results of the query go.

`SELECT` queries don't have a result relation. (The special case of `SELECT INTO` is mostly identical to `CREATE TABLE` followed by `INSERT ... SELECT`, and is not discussed separately here.)

For `INSERT`, `UPDATE`, and `DELETE` commands, the result relation is the table (or view!) where the changes are to take effect.

the target list

The target list is a list of expressions that define the result of the query. In the case of a SELECT, these expressions are the ones that build the final output of the query. They correspond to the expressions between the key words SELECT and FROM. (* is just an abbreviation for all the column names of a relation. It is expanded by the parser into the individual columns, so the rule system never sees it.)

DELETE commands don't need a normal target list because they don't produce any result. Instead, the planner adds a special CTID entry to the empty target list, to allow the executor to find the row to be deleted. (CTID is added when the result relation is an ordinary table. If it is a view, a whole-row variable is added instead, by the rule system, as described in Section 43.2.4.)

For INSERT commands, the target list describes the new rows that should go into the result relation. It consists of the expressions in the VALUES clause or the ones from the SELECT clause in INSERT ... SELECT. The first step of the rewrite process adds target list entries for any columns that were not assigned to by the original command but have defaults. Any remaining columns (with neither a given value nor a default) will be filled in by the planner with a constant null expression.

For UPDATE commands, the target list describes the new rows that should replace the old ones. In the rule system, it contains just the expressions from the SET column = expression part of the command. The planner will handle missing columns by inserting expressions that copy the values from the old row into the new one. Just as for DELETE, a CTID or whole-row variable is added so that the executor can identify the old row to be updated.

Every entry in the target list contains an expression that can be a constant value, a variable pointing to a column of one of the relations in the range table, a parameter, or an expression tree made of function calls, constants, variables, operators, etc.

the qualification

The query's qualification is an expression much like one of those contained in the target list entries. The result value of this expression is a Boolean that tells whether the operation (INSERT, UPDATE, DELETE, or SELECT) for the final result row should be executed or not. It corresponds to the WHERE clause of an SQL statement.

the join tree

The query's join tree shows the structure of the FROM clause. For a simple query like SELECT ... FROM a, b, c, the join tree is just a list of the FROM items, because we are allowed to join them in any order. But when JOIN expressions, particularly outer joins, are used, we have to join in the order shown by the joins. In that case, the join tree shows the structure of the JOIN expressions. The restrictions associated with particular JOIN clauses (from ON or USING expressions) are stored as qualification expressions attached to those join-tree nodes. It turns out to be convenient to store the top-level WHERE expression as a qualification attached to the top-level join-tree item, too. So really the join tree represents both the FROM and WHERE clauses of a SELECT.

the others

The other parts of the query tree like the ORDER BY clause aren't of interest here. The rule system substitutes some entries there while applying rules, but that doesn't have much to do with the fundamentals of the rule system.

43.2. Views and the Rule System

Views in Postgres Pro are implemented using the rule system. In fact, there is essentially no difference between:

```
CREATE VIEW myview AS SELECT * FROM mytab;
```

compared against the two commands:

```
CREATE TABLE myview (same column list as mytab);
```

```
CREATE RULE "_RETURN" AS ON SELECT TO myview DO INSTEAD
    SELECT * FROM mytab;
```

because this is exactly what the CREATE VIEW command does internally. This has some side effects. One of them is that the information about a view in the Postgres Pro system catalogs is exactly the same as it is for a table. So for the parser, there is absolutely no difference between a table and a view. They are the same thing: relations.

43.2.1. How SELECT Rules Work

Rules ON SELECT are applied to all queries as the last step, even if the command given is an INSERT, UPDATE or DELETE. And they have different semantics from rules on the other command types in that they modify the query tree in place instead of creating a new one. So SELECT rules are described first.

Currently, there can be only one action in an ON SELECT rule, and it must be an unconditional SELECT action that is INSTEAD. This restriction was required to make rules safe enough to open them for ordinary users, and it restricts ON SELECT rules to act like views.

The examples for this chapter are two join views that do some calculations and some more views using them in turn. One of the two first views is customized later by adding rules for INSERT, UPDATE, and DELETE operations so that the final result will be a view that behaves like a real table with some magic functionality. This is not such a simple example to start from and this makes things harder to get into. But it's better to have one example that covers all the points discussed step by step rather than having many different ones that might mix up in mind.

The real tables we need in the first two rule system descriptions are these:

```
CREATE TABLE shoe_data (
    shoename   text,          -- primary key
    sh_avail   integer,       -- available number of pairs
    slcolor    text,          -- preferred shoelace color
    slminlen   real,          -- minimum shoelace length
    slmaxlen   real,          -- maximum shoelace length
    slunit     text           -- length unit
);

CREATE TABLE shoelace_data (
    sl_name    text,          -- primary key
    sl_avail   integer,       -- available number of pairs
    sl_color   text,          -- shoelace color
    sl_len     real,          -- shoelace length
    sl_unit    text           -- length unit
);

CREATE TABLE unit (
    un_name    text,          -- primary key
    un_fact    real           -- factor to transform to cm
);
```

As you can see, they represent shoe-store data.

The views are created as:

```
CREATE VIEW shoe AS
    SELECT sh.shoename,
           sh.sh_avail,
           sh.slcolor,
           sh.slminlen,
           sh.slminlen * un.un_fact AS slminlen_cm,
           sh.slmaxlen,
```

```
            sh.slmaxlen * un.un_fact AS slmaxlen_cm,
            sh.slunit
       FROM shoe_data sh, unit un
      WHERE sh.slunit = un.un_name;

CREATE VIEW shoelace AS
    SELECT s.sl_name,
           s.sl_avail,
           s.sl_color,
           s.sl_len,
           s.sl_unit,
           s.sl_len * u.un_fact AS sl_len_cm
       FROM shoelace_data s, unit u
      WHERE s.sl_unit = u.un_name;

CREATE VIEW shoe_ready AS
    SELECT rsh.shoename,
           rsh.sh_avail,
           rsl.sl_name,
           rsl.sl_avail,
           least(rsh.sh_avail, rsl.sl_avail) AS total_avail
       FROM shoe rsh, shoelace rsl
      WHERE rsl.sl_color = rsh.slcolor
        AND rsl.sl_len_cm >= rsh.slminlen_cm
        AND rsl.sl_len_cm <= rsh.slmaxlen_cm;
```

The `CREATE VIEW` command for the `shoelace` view (which is the simplest one we have) will create a relation `shoelace` and an entry in `pg_rewrite` that tells that there is a rewrite rule that must be applied whenever the relation `shoelace` is referenced in a query's range table. The rule has no rule qualification (discussed later, with the non-`SELECT` rules, since `SELECT` rules currently cannot have them) and it is `INSTEAD`. Note that rule qualifications are not the same as query qualifications. The action of our rule has a query qualification. The action of the rule is one query tree that is a copy of the `SELECT` statement in the view creation command.

> **Note**
>
> The two extra range table entries for `NEW` and `OLD` that you can see in the `pg_rewrite` entry aren't of interest for `SELECT` rules.

Now we populate `unit`, `shoe_data` and `shoelace_data` and run a simple query on a view:

```
INSERT INTO unit VALUES ('cm', 1.0);
INSERT INTO unit VALUES ('m', 100.0);
INSERT INTO unit VALUES ('inch', 2.54);

INSERT INTO shoe_data VALUES ('sh1', 2, 'black', 70.0, 90.0, 'cm');
INSERT INTO shoe_data VALUES ('sh2', 0, 'black', 30.0, 40.0, 'inch');
INSERT INTO shoe_data VALUES ('sh3', 4, 'brown', 50.0, 65.0, 'cm');
INSERT INTO shoe_data VALUES ('sh4', 3, 'brown', 40.0, 50.0, 'inch');

INSERT INTO shoelace_data VALUES ('sl1', 5, 'black', 80.0, 'cm');
INSERT INTO shoelace_data VALUES ('sl2', 6, 'black', 100.0, 'cm');
INSERT INTO shoelace_data VALUES ('sl3', 0, 'black', 35.0 , 'inch');
INSERT INTO shoelace_data VALUES ('sl4', 8, 'black', 40.0 , 'inch');
INSERT INTO shoelace_data VALUES ('sl5', 4, 'brown', 1.0 , 'm');
INSERT INTO shoelace_data VALUES ('sl6', 0, 'brown', 0.9 , 'm');
INSERT INTO shoelace_data VALUES ('sl7', 7, 'brown', 60 , 'cm');
```

```
INSERT INTO shoelace_data VALUES ('sl8', 1, 'brown', 40 , 'inch');

SELECT * FROM shoelace;

 sl_name   | sl_avail | sl_color | sl_len | sl_unit | sl_len_cm
-----------+----------+----------+--------+---------+-----------
 sl1       |        5 | black    |     80 | cm      |        80
 sl2       |        6 | black    |    100 | cm      |       100
 sl7       |        7 | brown    |     60 | cm      |        60
 sl3       |        0 | black    |     35 | inch    |      88.9
 sl4       |        8 | black    |     40 | inch    |     101.6
 sl8       |        1 | brown    |     40 | inch    |     101.6
 sl5       |        4 | brown    |      1 | m       |       100
 sl6       |        0 | brown    |    0.9 | m       |        90
(8 rows)
```

This is the simplest `SELECT` you can do on our views, so we take this opportunity to explain the basics of view rules. The `SELECT * FROM shoelace` was interpreted by the parser and produced the query tree:

```
SELECT shoelace.sl_name, shoelace.sl_avail,
       shoelace.sl_color, shoelace.sl_len,
       shoelace.sl_unit, shoelace.sl_len_cm
  FROM shoelace shoelace;
```

and this is given to the rule system. The rule system walks through the range table and checks if there are rules for any relation. When processing the range table entry for `shoelace` (the only one up to now) it finds the `_RETURN` rule with the query tree:

```
SELECT s.sl_name, s.sl_avail,
       s.sl_color, s.sl_len, s.sl_unit,
       s.sl_len * u.un_fact AS sl_len_cm
  FROM shoelace old, shoelace new,
       shoelace_data s, unit u
 WHERE s.sl_unit = u.un_name;
```

To expand the view, the rewriter simply creates a subquery range-table entry containing the rule's action query tree, and substitutes this range table entry for the original one that referenced the view. The resulting rewritten query tree is almost the same as if you had typed:

```
SELECT shoelace.sl_name, shoelace.sl_avail,
       shoelace.sl_color, shoelace.sl_len,
       shoelace.sl_unit, shoelace.sl_len_cm
  FROM (SELECT s.sl_name,
               s.sl_avail,
               s.sl_color,
               s.sl_len,
               s.sl_unit,
               s.sl_len * u.un_fact AS sl_len_cm
          FROM shoelace_data s, unit u
         WHERE s.sl_unit = u.un_name) shoelace;
```

There is one difference however: the subquery's range table has two extra entries `shoelace old` and `shoelace new`. These entries don't participate directly in the query, since they aren't referenced by the subquery's join tree or target list. The rewriter uses them to store the access privilege check information that was originally present in the range-table entry that referenced the view. In this way, the executor will still check that the user has proper privileges to access the view, even though there's no direct use of the view in the rewritten query.

That was the first rule applied. The rule system will continue checking the remaining range-table entries in the top query (in this example there are no more), and it will recursively check the range-table entries in the added subquery to see if any of them reference views. (But it won't expand `old` or `new` — otherwise

we'd have infinite recursion!) In this example, there are no rewrite rules for `shoelace_data` or `unit`, so rewriting is complete and the above is the final result given to the planner.

Now we want to write a query that finds out for which shoes currently in the store we have the matching shoelaces (color and length) and where the total number of exactly matching pairs is greater than or equal to two.

```
SELECT * FROM shoe_ready WHERE total_avail >= 2;

 shoename | sh_avail | sl_name | sl_avail | total_avail
----------+----------+---------+----------+-------------
 sh1      |        2 | sl1     |        5 |           2
 sh3      |        4 | sl7     |        7 |           4
(2 rows)
```

The output of the parser this time is the query tree:

```
SELECT shoe_ready.shoename, shoe_ready.sh_avail,
       shoe_ready.sl_name, shoe_ready.sl_avail,
       shoe_ready.total_avail
  FROM shoe_ready shoe_ready
 WHERE shoe_ready.total_avail >= 2;
```

The first rule applied will be the one for the `shoe_ready` view and it results in the query tree:

```
SELECT shoe_ready.shoename, shoe_ready.sh_avail,
       shoe_ready.sl_name, shoe_ready.sl_avail,
       shoe_ready.total_avail
  FROM (SELECT rsh.shoename,
               rsh.sh_avail,
               rsl.sl_name,
               rsl.sl_avail,
               least(rsh.sh_avail, rsl.sl_avail) AS total_avail
          FROM shoe rsh, shoelace rsl
         WHERE rsl.sl_color = rsh.slcolor
           AND rsl.sl_len_cm >= rsh.slminlen_cm
           AND rsl.sl_len_cm <= rsh.slmaxlen_cm) shoe_ready
 WHERE shoe_ready.total_avail >= 2;
```

Similarly, the rules for `shoe` and `shoelace` are substituted into the range table of the subquery, leading to a three-level final query tree:

```
SELECT shoe_ready.shoename, shoe_ready.sh_avail,
       shoe_ready.sl_name, shoe_ready.sl_avail,
       shoe_ready.total_avail
  FROM (SELECT rsh.shoename,
               rsh.sh_avail,
               rsl.sl_name,
               rsl.sl_avail,
               least(rsh.sh_avail, rsl.sl_avail) AS total_avail
          FROM (SELECT sh.shoename,
                       sh.sh_avail,
                       sh.slcolor,
                       sh.slminlen,
                       sh.slminlen * un.un_fact AS slminlen_cm,
                       sh.slmaxlen,
                       sh.slmaxlen * un.un_fact AS slmaxlen_cm,
                       sh.slunit
                  FROM shoe_data sh, unit un
                 WHERE sh.slunit = un.un_name) rsh,
               (SELECT s.sl_name,
```

```
                        s.sl_avail,
                        s.sl_color,
                        s.sl_len,
                        s.sl_unit,
                        s.sl_len * u.un_fact AS sl_len_cm
                    FROM shoelace_data s, unit u
                   WHERE s.sl_unit = u.un_name) rsl
          WHERE rsl.sl_color = rsh.slcolor
            AND rsl.sl_len_cm >= rsh.slminlen_cm
            AND rsl.sl_len_cm <= rsh.slmaxlen_cm) shoe_ready
 WHERE shoe_ready.total_avail > 2;
```

This might look inefficient, but the planner will collapse this into a single-level query tree by “pulling up” the subqueries, and then it will plan the joins just as if we'd written them out manually. So collapsing the query tree is an optimization that the rewrite system doesn't have to concern itself with.

43.2.2. View Rules in Non-SELECT Statements

Two details of the query tree aren't touched in the description of view rules above. These are the command type and the result relation. In fact, the command type is not needed by view rules, but the result relation may affect the way in which the query rewriter works, because special care needs to be taken if the result relation is a view.

There are only a few differences between a query tree for a SELECT and one for any other command. Obviously, they have a different command type and for a command other than a SELECT, the result relation points to the range-table entry where the result should go. Everything else is absolutely the same. So having two tables t1 and t2 with columns a and b, the query trees for the two statements:

```
SELECT t2.b FROM t1, t2 WHERE t1.a = t2.a;

UPDATE t1 SET b = t2.b FROM t2 WHERE t1.a = t2.a;
```

are nearly identical. In particular:

- The range tables contain entries for the tables t1 and t2.
- The target lists contain one variable that points to column b of the range table entry for table t2.
- The qualification expressions compare the columns a of both range-table entries for equality.
- The join trees show a simple join between t1 and t2.

The consequence is, that both query trees result in similar execution plans: They are both joins over the two tables. For the UPDATE the missing columns from t1 are added to the target list by the planner and the final query tree will read as:

```
UPDATE t1 SET a = t1.a, b = t2.b FROM t2 WHERE t1.a = t2.a;
```

and thus the executor run over the join will produce exactly the same result set as:

```
SELECT t1.a, t2.b FROM t1, t2 WHERE t1.a = t2.a;
```

But there is a little problem in UPDATE: the part of the executor plan that does the join does not care what the results from the join are meant for. It just produces a result set of rows. The fact that one is a SELECT command and the other is an UPDATE is handled higher up in the executor, where it knows that this is an UPDATE, and it knows that this result should go into table t1. But which of the rows that are there has to be replaced by the new row?

To resolve this problem, another entry is added to the target list in UPDATE (and also in DELETE) statements: the current tuple ID (CTID). This is a system column containing the file block number and position in the block for the row. Knowing the table, the CTID can be used to retrieve the original row of t1 to be updated. After adding the CTID to the target list, the query actually looks like:

```
SELECT t1.a, t2.b, t1.ctid FROM t1, t2 WHERE t1.a = t2.a;
```

Now another detail of Postgres Pro enters the stage. Old table rows aren't overwritten, and this is why ROLLBACK is fast. In an UPDATE, the new result row is inserted into the table (after stripping the CTID) and in the row header of the old row, which the CTID pointed to, the cmax and xmax entries are set to the current command counter and current transaction ID. Thus the old row is hidden, and after the transaction commits the vacuum cleaner can eventually remove the dead row.

Knowing all that, we can simply apply view rules in absolutely the same way to any command. There is no difference.

43.2.3. The Power of Views in Postgres Pro

The above demonstrates how the rule system incorporates view definitions into the original query tree. In the second example, a simple SELECT from one view created a final query tree that is a join of 4 tables (unit was used twice with different names).

The benefit of implementing views with the rule system is that the planner has all the information about which tables have to be scanned plus the relationships between these tables plus the restrictive qualifications from the views plus the qualifications from the original query in one single query tree. And this is still the situation when the original query is already a join over views. The planner has to decide which is the best path to execute the query, and the more information the planner has, the better this decision can be. And the rule system as implemented in Postgres Pro ensures that this is all information available about the query up to that point.

43.2.4. Updating a View

What happens if a view is named as the target relation for an INSERT, UPDATE, or DELETE? Doing the substitutions described above would give a query tree in which the result relation points at a subquery range-table entry, which will not work. There are several ways in which Postgres Pro can support the appearance of updating a view, however. In order of user-experienced complexity those are: automatically substitute in the underlying table for the view, execute a user-defined trigger, or rewrite the query per a user-defined rule. These options are discussed below.

If the subquery selects from a single base relation and is simple enough, the rewriter can automatically replace the subquery with the underlying base relation so that the INSERT, UPDATE, or DELETE is applied to the base relation in the appropriate way. Views that are “simple enough” for this are called *automatically updatable*. For detailed information on the kinds of view that can be automatically updated, see CREATE VIEW.

Alternatively, the operation may be handled by a user-provided INSTEAD OF trigger on the view (see CREATE TRIGGER). Rewriting works slightly differently in this case. For INSERT, the rewriter does nothing at all with the view, leaving it as the result relation for the query. For UPDATE and DELETE, it's still necessary to expand the view query to produce the “old” rows that the command will attempt to update or delete. So the view is expanded as normal, but another unexpanded range-table entry is added to the query to represent the view in its capacity as the result relation.

The problem that now arises is how to identify the rows to be updated in the view. Recall that when the result relation is a table, a special CTID entry is added to the target list to identify the physical locations of the rows to be updated. This does not work if the result relation is a view, because a view does not have any CTID, since its rows do not have actual physical locations. Instead, for an UPDATE or DELETE operation, a special wholerow entry is added to the target list, which expands to include all columns from the view. The executor uses this value to supply the “old” row to the INSTEAD OF trigger. It is up to the trigger to work out what to update based on the old and new row values.

Another possibility is for the user to define INSTEAD rules that specify substitute actions for INSERT, UPDATE, and DELETE commands on a view. These rules will rewrite the command, typically into a command that updates one or more tables, rather than views. That is the topic of Section 43.4.

Note that rules are evaluated first, rewriting the original query before it is planned and executed. Therefore, if a view has INSTEAD OF triggers as well as rules on INSERT, UPDATE, or DELETE, then the rules will be evaluated first, and depending on the result, the triggers may not be used at all.

Automatic rewriting of an INSERT, UPDATE, or DELETE query on a simple view is always tried last. Therefore, if a view has rules or triggers, they will override the default behavior of automatically updatable views.

If there are no INSTEAD rules or INSTEAD OF triggers for the view, and the rewriter cannot automatically rewrite the query as an update on the underlying base relation, an error will be thrown because the executor cannot update a view as such.

43.3. Materialized Views

Materialized views in Postgres Pro use the rule system like views do, but persist the results in a table-like form. The main differences between:

```
CREATE MATERIALIZED VIEW mymatview AS SELECT * FROM mytab;
```

and:

```
CREATE TABLE mymatview AS SELECT * FROM mytab;
```

are that the materialized view cannot subsequently be directly updated and that the query used to create the materialized view is stored in exactly the same way that a view's query is stored, so that fresh data can be generated for the materialized view with:

```
REFRESH MATERIALIZED VIEW mymatview;
```

The information about a materialized view in the Postgres Pro system catalogs is exactly the same as it is for a table or view. So for the parser, a materialized view is a relation, just like a table or a view. When a materialized view is referenced in a query, the data is returned directly from the materialized view, like from a table; the rule is only used for populating the materialized view.

While access to the data stored in a materialized view is often much faster than accessing the underlying tables directly or through a view, the data is not always current; yet sometimes current data is not needed. Consider a table which records sales:

```
CREATE TABLE invoice (
    invoice_no    integer        PRIMARY KEY,
    seller_no     integer,       -- ID of salesperson
    invoice_date  date,          -- date of sale
    invoice_amt   numeric(13,2)  -- amount of sale
);
```

If people want to be able to quickly graph historical sales data, they might want to summarize, and they may not care about the incomplete data for the current date:

```
CREATE MATERIALIZED VIEW sales_summary AS
  SELECT
      seller_no,
      invoice_date,
      sum(invoice_amt)::numeric(13,2) as sales_amt
    FROM invoice
    WHERE invoice_date < CURRENT_DATE
    GROUP BY
      seller_no,
      invoice_date;

CREATE UNIQUE INDEX sales_summary_seller
  ON sales_summary (seller_no, invoice_date);
```

This materialized view might be useful for displaying a graph in the dashboard created for salespeople. A job could be scheduled to update the statistics each night using this SQL statement:

```
REFRESH MATERIALIZED VIEW sales_summary;
```

Another use for a materialized view is to allow faster access to data brought across from a remote system through a foreign data wrapper. A simple example using file_fdw is below, with timings, but since this

is using cache on the local system the performance difference compared to access to a remote system would usually be greater than shown here. Notice we are also exploiting the ability to put an index on the materialized view, whereas `file_fdw` does not support indexes; this advantage might not apply for other sorts of foreign data access.

Setup:

```
CREATE EXTENSION file_fdw;
CREATE SERVER local_file FOREIGN DATA WRAPPER file_fdw;
CREATE FOREIGN TABLE words (word text NOT NULL)
  SERVER local_file
  OPTIONS (filename '/usr/share/dict/words');
CREATE MATERIALIZED VIEW wrd AS SELECT * FROM words;
CREATE UNIQUE INDEX wrd_word ON wrd (word);
CREATE EXTENSION pg_trgm;
CREATE INDEX wrd_trgm ON wrd USING gist (word gist_trgm_ops);
VACUUM ANALYZE wrd;
```

Now let's spell-check a word. Using `file_fdw` directly:

```
SELECT count(*) FROM words WHERE word = 'caterpiler';

 count
-------
     0
(1 row)
```

With `EXPLAIN ANALYZE`, we see:

```
 Aggregate  (cost=21763.99..21764.00 rows=1 width=0) (actual time=188.180..188.181
 rows=1 loops=1)
   ->  Foreign Scan on words  (cost=0.00..21761.41 rows=1032 width=0) (actual
 time=188.177..188.177 rows=0 loops=1)
         Filter: (word = 'caterpiler'::text)
         Rows Removed by Filter: 479829
         Foreign File: /usr/share/dict/words
         Foreign File Size: 4953699
 Planning time: 0.118 ms
 Execution time: 188.273 ms
```

If the materialized view is used instead, the query is much faster:

```
 Aggregate  (cost=4.44..4.45 rows=1 width=0) (actual time=0.042..0.042 rows=1 loops=1)
   ->  Index Only Scan using wrd_word on wrd  (cost=0.42..4.44 rows=1 width=0) (actual
 time=0.039..0.039 rows=0 loops=1)
         Index Cond: (word = 'caterpiler'::text)
         Heap Fetches: 0
 Planning time: 0.164 ms
 Execution time: 0.117 ms
```

Either way, the word is spelled wrong, so let's look for what we might have wanted. Again using `file_fdw` and `pg_trgm`:

```
SELECT word FROM words ORDER BY word <-> 'caterpiler' LIMIT 10;

     word
---------------
 cater
 caterpillar
 Caterpillar
 caterpillars
 caterpillar's
 Caterpillar's
```

```
 caterer
 caterer's
 caters
 catered
(10 rows)

 Limit  (cost=11583.61..11583.64 rows=10 width=32) (actual time=1431.591..1431.594
 rows=10 loops=1)
   ->  Sort  (cost=11583.61..11804.76 rows=88459 width=32) (actual
 time=1431.589..1431.591 rows=10 loops=1)
         Sort Key: ((word <-> 'caterpiler'::text))
         Sort Method: top-N heapsort  Memory: 25kB
         ->  Foreign Scan on words  (cost=0.00..9672.05 rows=88459 width=32) (actual
 time=0.057..1286.455 rows=479829 loops=1)
               Foreign File: /usr/share/dict/words
               Foreign File Size: 4953699
 Planning time: 0.128 ms
 Execution time: 1431.679 ms
```

Using the materialized view:

```
 Limit  (cost=0.29..1.06 rows=10 width=10) (actual time=187.222..188.257 rows=10
 loops=1)
   ->  Index Scan using wrd_trgm on wrd  (cost=0.29..37020.87 rows=479829 width=10)
 (actual time=187.219..188.252 rows=10 loops=1)
         Order By: (word <-> 'caterpiler'::text)
 Planning time: 0.196 ms
 Execution time: 198.640 ms
```

If you can tolerate periodic update of the remote data to the local database, the performance benefit can be substantial.

43.4. Rules on INSERT, UPDATE, and DELETE

Rules that are defined on INSERT, UPDATE, and DELETE are significantly different from the view rules described in the previous section. First, their CREATE RULE command allows more:

- They are allowed to have no action.
- They can have multiple actions.
- They can be INSTEAD or ALSO (the default).
- The pseudorelations NEW and OLD become useful.
- They can have rule qualifications.

Second, they don't modify the query tree in place. Instead they create zero or more new query trees and can throw away the original one.

> **Caution**
>
> In many cases, tasks that could be performed by rules on INSERT/UPDATE/DELETE are better done with triggers. Triggers are notationally a bit more complicated, but their semantics are much simpler to understand. Rules tend to have surprising results when the original query contains volatile functions: volatile functions may get executed more times than expected in the process of carrying out the rules.
>
> Also, there are some cases that are not supported by these types of rules at all, notably including WITH clauses in the original query and multiple-assignment sub-SELECTs in the SET list of UPDATE queries. This is because copying these constructs into a rule query would result in multiple evaluations of the sub-query, contrary to the express intent of the query's author.

43.4.1. How Update Rules Work

Keep the syntax:

```
CREATE [ OR REPLACE ] RULE name AS ON event
    TO table [ WHERE condition ]
    DO [ ALSO | INSTEAD ] { NOTHING | command | ( command ; command ... ) }
```

in mind. In the following, *update rules* means rules that are defined on INSERT, UPDATE, or DELETE.

Update rules get applied by the rule system when the result relation and the command type of a query tree are equal to the object and event given in the CREATE RULE command. For update rules, the rule system creates a list of query trees. Initially the query-tree list is empty. There can be zero (NOTHING key word), one, or multiple actions. To simplify, we will look at a rule with one action. This rule can have a qualification or not and it can be INSTEAD or ALSO (the default).

What is a rule qualification? It is a restriction that tells when the actions of the rule should be done and when not. This qualification can only reference the pseudorelations NEW and/or OLD, which basically represent the relation that was given as object (but with a special meaning).

So we have three cases that produce the following query trees for a one-action rule.

No qualification, with either ALSO or INSTEAD

the query tree from the rule action with the original query tree's qualification added

Qualification given and ALSO

the query tree from the rule action with the rule qualification and the original query tree's qualification added

Qualification given and INSTEAD

the query tree from the rule action with the rule qualification and the original query tree's qualification; and the original query tree with the negated rule qualification added

Finally, if the rule is ALSO, the unchanged original query tree is added to the list. Since only qualified INSTEAD rules already add the original query tree, we end up with either one or two output query trees for a rule with one action.

For ON INSERT rules, the original query (if not suppressed by INSTEAD) is done before any actions added by rules. This allows the actions to see the inserted row(s). But for ON UPDATE and ON DELETE rules, the original query is done after the actions added by rules. This ensures that the actions can see the to-be-updated or to-be-deleted rows; otherwise, the actions might do nothing because they find no rows matching their qualifications.

The query trees generated from rule actions are thrown into the rewrite system again, and maybe more rules get applied resulting in additional or fewer query trees. So a rule's actions must have either a different command type or a different result relation than the rule itself is on, otherwise this recursive process will end up in an infinite loop. (Recursive expansion of a rule will be detected and reported as an error.)

The query trees found in the actions of the pg_rewrite system catalog are only templates. Since they can reference the range-table entries for NEW and OLD, some substitutions have to be made before they can be used. For any reference to NEW, the target list of the original query is searched for a corresponding entry. If found, that entry's expression replaces the reference. Otherwise, NEW means the same as OLD (for an UPDATE) or is replaced by a null value (for an INSERT). Any reference to OLD is replaced by a reference to the range-table entry that is the result relation.

After the system is done applying update rules, it applies view rules to the produced query tree(s). Views cannot insert new update actions so there is no need to apply update rules to the output of view rewriting.

43.4.1.1. A First Rule Step by Step

Say we want to trace changes to the `sl_avail` column in the `shoelace_data` relation. So we set up a log table and a rule that conditionally writes a log entry when an `UPDATE` is performed on `shoelace_data`.

```
CREATE TABLE shoelace_log (
    sl_name    text,          -- shoelace changed
    sl_avail   integer,       -- new available value
    log_who    text,          -- who did it
    log_when   timestamp      -- when
);

CREATE RULE log_shoelace AS ON UPDATE TO shoelace_data
    WHERE NEW.sl_avail <> OLD.sl_avail
    DO INSERT INTO shoelace_log VALUES (
                                    NEW.sl_name,
                                    NEW.sl_avail,
                                    current_user,
                                    current_timestamp
                                );
```

Now someone does:

```
UPDATE shoelace_data SET sl_avail = 6 WHERE sl_name = 'sl7';
```

and we look at the log table:

```
SELECT * FROM shoelace_log;

 sl_name | sl_avail | log_who | log_when
---------+----------+---------+----------------------------------
 sl7     |        6 | Al      | Tue Oct 20 16:14:45 1998 MET DST
(1 row)
```

That's what we expected. What happened in the background is the following. The parser created the query tree:

```
UPDATE shoelace_data SET sl_avail = 6
  FROM shoelace_data shoelace_data
 WHERE shoelace_data.sl_name = 'sl7';
```

There is a rule `log_shoelace` that is `ON UPDATE` with the rule qualification expression:

```
NEW.sl_avail <> OLD.sl_avail
```

and the action:

```
INSERT INTO shoelace_log VALUES (
       new.sl_name, new.sl_avail,
       current_user, current_timestamp )
  FROM shoelace_data new, shoelace_data old;
```

(This looks a little strange since you cannot normally write `INSERT ... VALUES ... FROM`. The `FROM` clause here is just to indicate that there are range-table entries in the query tree for `new` and `old`. These are needed so that they can be referenced by variables in the `INSERT` command's query tree.)

The rule is a qualified `ALSO` rule, so the rule system has to return two query trees: the modified rule action and the original query tree. In step 1, the range table of the original query is incorporated into the rule's action query tree. This results in:

```
INSERT INTO shoelace_log VALUES (
       new.sl_name, new.sl_avail,
       current_user, current_timestamp )
  FROM shoelace_data new, shoelace_data old,
       shoelace_data shoelace_data;
```

In step 2, the rule qualification is added to it, so the result set is restricted to rows where `sl_avail` changes:

```
INSERT INTO shoelace_log VALUES (
       new.sl_name, new.sl_avail,
       current_user, current_timestamp )
  FROM shoelace_data new, shoelace_data old,
       shoelace_data shoelace_data
 WHERE new.sl_avail <> old.sl_avail;
```

(This looks even stranger, since `INSERT ... VALUES` doesn't have a `WHERE` clause either, but the planner and executor will have no difficulty with it. They need to support this same functionality anyway for `INSERT ... SELECT`.)

In step 3, the original query tree's qualification is added, restricting the result set further to only the rows that would have been touched by the original query:

```
INSERT INTO shoelace_log VALUES (
       new.sl_name, new.sl_avail,
       current_user, current_timestamp )
  FROM shoelace_data new, shoelace_data old,
       shoelace_data shoelace_data
 WHERE new.sl_avail <> old.sl_avail
   AND shoelace_data.sl_name = 'sl7';
```

Step 4 replaces references to `NEW` by the target list entries from the original query tree or by the matching variable references from the result relation:

```
INSERT INTO shoelace_log VALUES (
       shoelace_data.sl_name, 6,
       current_user, current_timestamp )
  FROM shoelace_data new, shoelace_data old,
       shoelace_data shoelace_data
 WHERE 6 <> old.sl_avail
   AND shoelace_data.sl_name = 'sl7';
```

Step 5 changes `OLD` references into result relation references:

```
INSERT INTO shoelace_log VALUES (
       shoelace_data.sl_name, 6,
       current_user, current_timestamp )
  FROM shoelace_data new, shoelace_data old,
       shoelace_data shoelace_data
 WHERE 6 <> shoelace_data.sl_avail
   AND shoelace_data.sl_name = 'sl7';
```

That's it. Since the rule is `ALSO`, we also output the original query tree. In short, the output from the rule system is a list of two query trees that correspond to these statements:

```
INSERT INTO shoelace_log VALUES (
       shoelace_data.sl_name, 6,
       current_user, current_timestamp )
  FROM shoelace_data
 WHERE 6 <> shoelace_data.sl_avail
   AND shoelace_data.sl_name = 'sl7';

UPDATE shoelace_data SET sl_avail = 6
 WHERE sl_name = 'sl7';
```

These are executed in this order, and that is exactly what the rule was meant to do.

The substitutions and the added qualifications ensure that, if the original query would be, say:

```
UPDATE shoelace_data SET sl_color = 'green'
 WHERE sl_name = 'sl7';
```

no log entry would get written. In that case, the original query tree does not contain a target list entry for `sl_avail`, so `NEW.sl_avail` will get replaced by `shoelace_data.sl_avail`. Thus, the extra command generated by the rule is:

```
INSERT INTO shoelace_log VALUES (
       shoelace_data.sl_name, shoelace_data.sl_avail,
       current_user, current_timestamp )
  FROM shoelace_data
 WHERE shoelace_data.sl_avail <> shoelace_data.sl_avail
   AND shoelace_data.sl_name = 'sl7';
```

and that qualification will never be true.

It will also work if the original query modifies multiple rows. So if someone issued the command:

```
UPDATE shoelace_data SET sl_avail = 0
 WHERE sl_color = 'black';
```

four rows in fact get updated (`sl1`, `sl2`, `sl3`, and `sl4`). But `sl3` already has `sl_avail = 0`. In this case, the original query trees qualification is different and that results in the extra query tree:

```
INSERT INTO shoelace_log
SELECT shoelace_data.sl_name, 0,
       current_user, current_timestamp
  FROM shoelace_data
 WHERE 0 <> shoelace_data.sl_avail
   AND shoelace_data.sl_color = 'black';
```

being generated by the rule. This query tree will surely insert three new log entries. And that's absolutely correct.

Here we can see why it is important that the original query tree is executed last. If the `UPDATE` had been executed first, all the rows would have already been set to zero, so the logging `INSERT` would not find any row where `0 <> shoelace_data.sl_avail`.

43.4.2. Cooperation with Views

A simple way to protect view relations from the mentioned possibility that someone can try to run `INSERT`, `UPDATE`, or `DELETE` on them is to let those query trees get thrown away. So we could create the rules:

```
CREATE RULE shoe_ins_protect AS ON INSERT TO shoe
    DO INSTEAD NOTHING;
CREATE RULE shoe_upd_protect AS ON UPDATE TO shoe
    DO INSTEAD NOTHING;
CREATE RULE shoe_del_protect AS ON DELETE TO shoe
    DO INSTEAD NOTHING;
```

If someone now tries to do any of these operations on the view relation `shoe`, the rule system will apply these rules. Since the rules have no actions and are `INSTEAD`, the resulting list of query trees will be empty and the whole query will become nothing because there is nothing left to be optimized or executed after the rule system is done with it.

A more sophisticated way to use the rule system is to create rules that rewrite the query tree into one that does the right operation on the real tables. To do that on the `shoelace` view, we create the following rules:

```
CREATE RULE shoelace_ins AS ON INSERT TO shoelace
    DO INSTEAD
    INSERT INTO shoelace_data VALUES (
           NEW.sl_name,
           NEW.sl_avail,
```

```
            NEW.sl_color,
            NEW.sl_len,
            NEW.sl_unit
    );

CREATE RULE shoelace_upd AS ON UPDATE TO shoelace
    DO INSTEAD
    UPDATE shoelace_data
       SET sl_name = NEW.sl_name,
           sl_avail = NEW.sl_avail,
           sl_color = NEW.sl_color,
           sl_len = NEW.sl_len,
           sl_unit = NEW.sl_unit
     WHERE sl_name = OLD.sl_name;

CREATE RULE shoelace_del AS ON DELETE TO shoelace
    DO INSTEAD
    DELETE FROM shoelace_data
     WHERE sl_name = OLD.sl_name;
```

If you want to support `RETURNING` queries on the view, you need to make the rules include `RETURNING` clauses that compute the view rows. This is usually pretty trivial for views on a single table, but it's a bit tedious for join views such as `shoelace`. An example for the insert case is:

```
CREATE RULE shoelace_ins AS ON INSERT TO shoelace
    DO INSTEAD
    INSERT INTO shoelace_data VALUES (
           NEW.sl_name,
           NEW.sl_avail,
           NEW.sl_color,
           NEW.sl_len,
           NEW.sl_unit
    )
    RETURNING
           shoelace_data.*,
           (SELECT shoelace_data.sl_len * u.un_fact
            FROM unit u WHERE shoelace_data.sl_unit = u.un_name);
```

Note that this one rule supports both `INSERT` and `INSERT RETURNING` queries on the view — the `RETURNING` clause is simply ignored for `INSERT`.

Now assume that once in a while, a pack of shoelaces arrives at the shop and a big parts list along with it. But you don't want to manually update the `shoelace` view every time. Instead we set up two little tables: one where you can insert the items from the part list, and one with a special trick. The creation commands for these are:

```
CREATE TABLE shoelace_arrive (
    arr_name    text,
    arr_quant   integer
);

CREATE TABLE shoelace_ok (
    ok_name     text,
    ok_quant    integer
);

CREATE RULE shoelace_ok_ins AS ON INSERT TO shoelace_ok
    DO INSTEAD
    UPDATE shoelace
       SET sl_avail = sl_avail + NEW.ok_quant
```

```
    WHERE sl_name = NEW.ok_name;
```

Now you can fill the table `shoelace_arrive` with the data from the parts list:

```
SELECT * FROM shoelace_arrive;

 arr_name | arr_quant
----------+-----------
 sl3      |        10
 sl6      |        20
 sl8      |        20
(3 rows)
```

Take a quick look at the current data:

```
SELECT * FROM shoelace;

 sl_name  | sl_avail | sl_color | sl_len | sl_unit | sl_len_cm
----------+----------+----------+--------+---------+-----------
 sl1      |        5 | black    |     80 | cm      |        80
 sl2      |        6 | black    |    100 | cm      |       100
 sl7      |        6 | brown    |     60 | cm      |        60
 sl3      |        0 | black    |     35 | inch    |      88.9
 sl4      |        8 | black    |     40 | inch    |     101.6
 sl8      |        1 | brown    |     40 | inch    |     101.6
 sl5      |        4 | brown    |      1 | m       |       100
 sl6      |        0 | brown    |    0.9 | m       |        90
(8 rows)
```

Now move the arrived shoelaces in:

```
INSERT INTO shoelace_ok SELECT * FROM shoelace_arrive;
```

and check the results:

```
SELECT * FROM shoelace ORDER BY sl_name;

 sl_name  | sl_avail | sl_color | sl_len | sl_unit | sl_len_cm
----------+----------+----------+--------+---------+-----------
 sl1      |        5 | black    |     80 | cm      |        80
 sl2      |        6 | black    |    100 | cm      |       100
 sl7      |        6 | brown    |     60 | cm      |        60
 sl4      |        8 | black    |     40 | inch    |     101.6
 sl3      |       10 | black    |     35 | inch    |      88.9
 sl8      |       21 | brown    |     40 | inch    |     101.6
 sl5      |        4 | brown    |      1 | m       |       100
 sl6      |       20 | brown    |    0.9 | m       |        90
(8 rows)

SELECT * FROM shoelace_log;

 sl_name | sl_avail | log_who| log_when
---------+----------+--------+----------------------------------
 sl7     |        6 | Al     | Tue Oct 20 19:14:45 1998 MET DST
 sl3     |       10 | Al     | Tue Oct 20 19:25:16 1998 MET DST
 sl6     |       20 | Al     | Tue Oct 20 19:25:16 1998 MET DST
 sl8     |       21 | Al     | Tue Oct 20 19:25:16 1998 MET DST
(4 rows)
```

It's a long way from the one `INSERT ... SELECT` to these results. And the description of the query-tree transformation will be the last in this chapter. First, there is the parser's output:

```
INSERT INTO shoelace_ok
```

```
SELECT shoelace_arrive.arr_name, shoelace_arrive.arr_quant
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok;
```

Now the first rule `shoelace_ok_ins` is applied and turns this into:

```
UPDATE shoelace
   SET sl_avail = shoelace.sl_avail + shoelace_arrive.arr_quant
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok old, shoelace_ok new,
       shoelace shoelace
 WHERE shoelace.sl_name = shoelace_arrive.arr_name;
```

and throws away the original `INSERT` on `shoelace_ok`. This rewritten query is passed to the rule system again, and the second applied rule `shoelace_upd` produces:

```
UPDATE shoelace_data
   SET sl_name = shoelace.sl_name,
       sl_avail = shoelace.sl_avail + shoelace_arrive.arr_quant,
       sl_color = shoelace.sl_color,
       sl_len = shoelace.sl_len,
       sl_unit = shoelace.sl_unit
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok old, shoelace_ok new,
       shoelace shoelace, shoelace old,
       shoelace new, shoelace_data shoelace_data
 WHERE shoelace.sl_name = shoelace_arrive.arr_name
   AND shoelace_data.sl_name = shoelace.sl_name;
```

Again it's an `INSTEAD` rule and the previous query tree is trashed. Note that this query still uses the view `shoelace`. But the rule system isn't finished with this step, so it continues and applies the `_RETURN` rule on it, and we get:

```
UPDATE shoelace_data
   SET sl_name = s.sl_name,
       sl_avail = s.sl_avail + shoelace_arrive.arr_quant,
       sl_color = s.sl_color,
       sl_len = s.sl_len,
       sl_unit = s.sl_unit
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok old, shoelace_ok new,
       shoelace shoelace, shoelace old,
       shoelace new, shoelace_data shoelace_data,
       shoelace old, shoelace new,
       shoelace_data s, unit u
 WHERE s.sl_name = shoelace_arrive.arr_name
   AND shoelace_data.sl_name = s.sl_name;
```

Finally, the rule `log_shoelace` gets applied, producing the extra query tree:

```
INSERT INTO shoelace_log
SELECT s.sl_name,
       s.sl_avail + shoelace_arrive.arr_quant,
       current_user,
       current_timestamp
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok old, shoelace_ok new,
       shoelace shoelace, shoelace old,
       shoelace new, shoelace_data shoelace_data,
       shoelace old, shoelace new,
       shoelace_data s, unit u,
       shoelace_data old, shoelace_data new
       shoelace_log shoelace_log
```

```
 WHERE s.sl_name = shoelace_arrive.arr_name
   AND shoelace_data.sl_name = s.sl_name
   AND (s.sl_avail + shoelace_arrive.arr_quant) <> s.sl_avail;
```

After that the rule system runs out of rules and returns the generated query trees.

So we end up with two final query trees that are equivalent to the SQL statements:

```
INSERT INTO shoelace_log
SELECT s.sl_name,
       s.sl_avail + shoelace_arrive.arr_quant,
       current_user,
       current_timestamp
  FROM shoelace_arrive shoelace_arrive, shoelace_data shoelace_data,
       shoelace_data s
 WHERE s.sl_name = shoelace_arrive.arr_name
   AND shoelace_data.sl_name = s.sl_name
   AND s.sl_avail + shoelace_arrive.arr_quant <> s.sl_avail;

UPDATE shoelace_data
   SET sl_avail = shoelace_data.sl_avail + shoelace_arrive.arr_quant
  FROM shoelace_arrive shoelace_arrive,
       shoelace_data shoelace_data,
       shoelace_data s
 WHERE s.sl_name = shoelace_arrive.sl_name
   AND shoelace_data.sl_name = s.sl_name;
```

The result is that data coming from one relation inserted into another, changed into updates on a third, changed into updating a fourth plus logging that final update in a fifth gets reduced into two queries.

There is a little detail that's a bit ugly. Looking at the two queries, it turns out that the `shoelace_data` relation appears twice in the range table where it could definitely be reduced to one. The planner does not handle it and so the execution plan for the rule systems output of the `INSERT` will be

```
Nested Loop
  ->  Merge Join
        ->  Seq Scan
              ->  Sort
                    ->  Seq Scan on s
        ->  Seq Scan
              ->  Sort
                    ->  Seq Scan on shoelace_arrive
  ->  Seq Scan on shoelace_data
```

while omitting the extra range table entry would result in a

```
Merge Join
  ->  Seq Scan
        ->  Sort
              ->  Seq Scan on s
  ->  Seq Scan
        ->  Sort
              ->  Seq Scan on shoelace_arrive
```

which produces exactly the same entries in the log table. Thus, the rule system caused one extra scan on the table `shoelace_data` that is absolutely not necessary. And the same redundant scan is done once more in the `UPDATE`. But it was a really hard job to make that all possible at all.

Now we make a final demonstration of the Postgres Pro rule system and its power. Say you add some shoelaces with extraordinary colors to your database:

```
INSERT INTO shoelace VALUES ('sl9', 0, 'pink', 35.0, 'inch', 0.0);
INSERT INTO shoelace VALUES ('sl10', 1000, 'magenta', 40.0, 'inch', 0.0);
```

We would like to make a view to check which `shoelace` entries do not fit any shoe in color. The view for this is:

```
CREATE VIEW shoelace_mismatch AS
    SELECT * FROM shoelace WHERE NOT EXISTS
        (SELECT shoename FROM shoe WHERE slcolor = sl_color);
```

Its output is:

```
SELECT * FROM shoelace_mismatch;

 sl_name | sl_avail | sl_color | sl_len | sl_unit | sl_len_cm
---------+----------+----------+--------+---------+-----------
 sl9     |        0 | pink     |     35 | inch    |      88.9
 sl10    |     1000 | magenta  |     40 | inch    |     101.6
```

Now we want to set it up so that mismatching shoelaces that are not in stock are deleted from the database. To make it a little harder for Postgres Pro, we don't delete it directly. Instead we create one more view:

```
CREATE VIEW shoelace_can_delete AS
    SELECT * FROM shoelace_mismatch WHERE sl_avail = 0;
```

and do it this way:

```
DELETE FROM shoelace WHERE EXISTS
    (SELECT * FROM shoelace_can_delete
             WHERE sl_name = shoelace.sl_name);
```

The results are:

```
SELECT * FROM shoelace;

 sl_name | sl_avail | sl_color | sl_len | sl_unit | sl_len_cm
---------+----------+----------+--------+---------+-----------
 sl1     |        5 | black    |     80 | cm      |        80
 sl2     |        6 | black    |    100 | cm      |       100
 sl7     |        6 | brown    |     60 | cm      |        60
 sl4     |        8 | black    |     40 | inch    |     101.6
 sl3     |       10 | black    |     35 | inch    |      88.9
 sl8     |       21 | brown    |     40 | inch    |     101.6
 sl10    |     1000 | magenta  |     40 | inch    |     101.6
 sl5     |        4 | brown    |      1 | m       |       100
 sl6     |       20 | brown    |    0.9 | m       |        90
(9 rows)
```

A `DELETE` on a view, with a subquery qualification that in total uses 4 nesting/joined views, where one of them itself has a subquery qualification containing a view and where calculated view columns are used, gets rewritten into one single query tree that deletes the requested data from a real table.

There are probably only a few situations out in the real world where such a construct is necessary. But it makes you feel comfortable that it works.

43.5. Rules and Privileges

Due to rewriting of queries by the Postgres Pro rule system, other tables/views than those used in the original query get accessed. When update rules are used, this can include write access to tables.

Rewrite rules don't have a separate owner. The owner of a relation (table or view) is automatically the owner of the rewrite rules that are defined for it. The Postgres Pro rule system changes the behavior of the default access control system. Relations that are used due to rules get checked against the privileges of the rule owner, not the user invoking the rule. This means that users only need the required privileges for the tables/views that are explicitly named in their queries.

For example: A user has a list of phone numbers where some of them are private, the others are of interest for the assistant of the office. The user can construct the following:

```
CREATE TABLE phone_data (person text, phone text, private boolean);
CREATE VIEW phone_number AS
    SELECT person, CASE WHEN NOT private THEN phone END AS phone
    FROM phone_data;
GRANT SELECT ON phone_number TO assistant;
```

Nobody except that user (and the database superusers) can access the `phone_data` table. But because of the `GRANT`, the assistant can run a `SELECT` on the `phone_number` view. The rule system will rewrite the `SELECT` from `phone_number` into a `SELECT` from `phone_data`. Since the user is the owner of `phone_number` and therefore the owner of the rule, the read access to `phone_data` is now checked against the user's privileges and the query is permitted. The check for accessing `phone_number` is also performed, but this is done against the invoking user, so nobody but the user and the assistant can use it.

The privileges are checked rule by rule. So the assistant is for now the only one who can see the public phone numbers. But the assistant can set up another view and grant access to that to the public. Then, anyone can see the `phone_number` data through the assistant's view. What the assistant cannot do is to create a view that directly accesses `phone_data`. (Actually the assistant can, but it will not work since every access will be denied during the permission checks.) And as soon as the user notices that the assistant opened their `phone_number` view, the user can revoke the assistant's access. Immediately, any access to the assistant's view would fail.

One might think that this rule-by-rule checking is a security hole, but in fact it isn't. But if it did not work this way, the assistant could set up a table with the same columns as `phone_number` and copy the data to there once per day. Then it's the assistant's own data and the assistant can grant access to everyone they want. A `GRANT` command means, “I trust you”. If someone you trust does the thing above, it's time to think it over and then use `REVOKE`.

Note that while views can be used to hide the contents of certain columns using the technique shown above, they cannot be used to reliably conceal the data in unseen rows unless the `security_barrier` flag has been set. For example, the following view is insecure:

```
CREATE VIEW phone_number AS
    SELECT person, phone FROM phone_data WHERE phone NOT LIKE '412%';
```

This view might seem secure, since the rule system will rewrite any `SELECT` from `phone_number` into a `SELECT` from `phone_data` and add the qualification that only entries where `phone` does not begin with 412 are wanted. But if the user can create their own functions, it is not difficult to convince the planner to execute the user-defined function prior to the `NOT LIKE` expression. For example:

```
CREATE FUNCTION tricky(text, text) RETURNS bool AS $$
BEGIN
    RAISE NOTICE '% => %', $1, $2;
    RETURN true;
END;
$$ LANGUAGE plpgsql COST 0.0000000000000000000001;

SELECT * FROM phone_number WHERE tricky(person, phone);
```

Every person and phone number in the `phone_data` table will be printed as a `NOTICE`, because the planner will choose to execute the inexpensive `tricky` function before the more expensive `NOT LIKE`. Even if the user is prevented from defining new functions, built-in functions can be used in similar attacks. (For example, most casting functions include their input values in the error messages they produce.)

Similar considerations apply to update rules. In the examples of the previous section, the owner of the tables in the example database could grant the privileges `SELECT`, `INSERT`, `UPDATE`, and `DELETE` on the `shoelace` view to someone else, but only `SELECT` on `shoelace_log`. The rule action to write log entries will still be executed successfully, and that other user could see the log entries. But they could not create fake entries, nor could they manipulate or remove existing ones. In this case, there is no possibility

of subverting the rules by convincing the planner to alter the order of operations, because the only rule which references shoelace_log is an unqualified INSERT. This might not be true in more complex scenarios.

When it is necessary for a view to provide row-level security, the security_barrier attribute should be applied to the view. This prevents maliciously-chosen functions and operators from being passed values from rows until after the view has done its work. For example, if the view shown above had been created like this, it would be secure:

```
CREATE VIEW phone_number WITH (security_barrier) AS
    SELECT person, phone FROM phone_data WHERE phone NOT LIKE '412%';
```

Views created with the security_barrier may perform far worse than views created without this option. In general, there is no way to avoid this: the fastest possible plan must be rejected if it may compromise security. For this reason, this option is not enabled by default.

The query planner has more flexibility when dealing with functions that have no side effects. Such functions are referred to as LEAKPROOF, and include many simple, commonly used operators, such as many equality operators. The query planner can safely allow such functions to be evaluated at any point in the query execution process, since invoking them on rows invisible to the user will not leak any information about the unseen rows. Further, functions which do not take arguments or which are not passed any arguments from the security barrier view do not have to be marked as LEAKPROOF to be pushed down, as they never receive data from the view. In contrast, a function that might throw an error depending on the values received as arguments (such as one that throws an error in the event of overflow or division by zero) is not leak-proof, and could provide significant information about the unseen rows if applied before the security view's row filters.

It is important to understand that even a view created with the security_barrier option is intended to be secure only in the limited sense that the contents of the invisible tuples will not be passed to possibly-insecure functions. The user may well have other means of making inferences about the unseen data; for example, they can see the query plan using EXPLAIN, or measure the run time of queries against the view. A malicious attacker might be able to infer something about the amount of unseen data, or even gain some information about the data distribution or most common values (since these things may affect the run time of the plan; or even, since they are also reflected in the optimizer statistics, the choice of plan). If these types of "covert channel" attacks are of concern, it is probably unwise to grant any access to the data at all.

43.6. Rules and Command Status

The Postgres Pro server returns a command status string, such as INSERT 149592 1, for each command it receives. This is simple enough when there are no rules involved, but what happens when the query is rewritten by rules?

Rules affect the command status as follows:

- If there is no unconditional INSTEAD rule for the query, then the originally given query will be executed, and its command status will be returned as usual. (But note that if there were any conditional INSTEAD rules, the negation of their qualifications will have been added to the original query. This might reduce the number of rows it processes, and if so the reported status will be affected.)
- If there is any unconditional INSTEAD rule for the query, then the original query will not be executed at all. In this case, the server will return the command status for the last query that was inserted by an INSTEAD rule (conditional or unconditional) and is of the same command type (INSERT, UPDATE, or DELETE) as the original query. If no query meeting those requirements is added by any rule, then the returned command status shows the original query type and zeroes for the row-count and OID fields.

The programmer can ensure that any desired INSTEAD rule is the one that sets the command status in the second case, by giving it the alphabetically last rule name among the active rules, so that it gets applied last.

43.7. Rules Versus Triggers

Many things that can be done using triggers can also be implemented using the Postgres Pro rule system. One of the things that cannot be implemented by rules are some kinds of constraints, especially foreign keys. It is possible to place a qualified rule that rewrites a command to `NOTHING` if the value of a column does not appear in another table. But then the data is silently thrown away and that's not a good idea. If checks for valid values are required, and in the case of an invalid value an error message should be generated, it must be done by a trigger.

In this chapter, we focused on using rules to update views. All of the update rule examples in this chapter can also be implemented using `INSTEAD OF` triggers on the views. Writing such triggers is often easier than writing rules, particularly if complex logic is required to perform the update.

For the things that can be implemented by both, which is best depends on the usage of the database. A trigger is fired once for each affected row. A rule modifies the query or generates an additional query. So if many rows are affected in one statement, a rule issuing one extra command is likely to be faster than a trigger that is called for every single row and must re-determine what to do many times. However, the trigger approach is conceptually far simpler than the rule approach, and is easier for novices to get right.

Here we show an example of how the choice of rules versus triggers plays out in one situation. There are two tables:

```
CREATE TABLE computer (
    hostname        text,    -- indexed
    manufacturer    text     -- indexed
);

CREATE TABLE software (
    software        text,    -- indexed
    hostname        text     -- indexed
);
```

Both tables have many thousands of rows and the indexes on `hostname` are unique. The rule or trigger should implement a constraint that deletes rows from `software` that reference a deleted computer. The trigger would use this command:

```
DELETE FROM software WHERE hostname = $1;
```

Since the trigger is called for each individual row deleted from `computer`, it can prepare and save the plan for this command and pass the `hostname` value in the parameter. The rule would be written as:

```
CREATE RULE computer_del AS ON DELETE TO computer
    DO DELETE FROM software WHERE hostname = OLD.hostname;
```

Now we look at different types of deletes. In the case of a:

```
DELETE FROM computer WHERE hostname = 'mypc.local.net';
```

the table `computer` is scanned by index (fast), and the command issued by the trigger would also use an index scan (also fast). The extra command from the rule would be:

```
DELETE FROM software WHERE computer.hostname = 'mypc.local.net'
                       AND software.hostname = computer.hostname;
```

Since there are appropriate indexes set up, the planner will create a plan of

```
Nestloop
  ->  Index Scan using comp_hostidx on computer
  ->  Index Scan using soft_hostidx on software
```

So there would be not that much difference in speed between the trigger and the rule implementation.

With the next delete we want to get rid of all the 2000 computers where the `hostname` starts with `old`. There are two possible commands to do that. One is:

```
DELETE FROM computer WHERE hostname >= 'old'
                       AND hostname <  'ole'
```

The command added by the rule will be:

```
DELETE FROM software WHERE computer.hostname >= 'old' AND computer.hostname < 'ole'
                       AND software.hostname = computer.hostname;
```

with the plan

```
Hash Join
  ->  Seq Scan on software
  ->  Hash
    ->  Index Scan using comp_hostidx on computer
```

The other possible command is:

```
DELETE FROM computer WHERE hostname ~ '^old';
```

which results in the following executing plan for the command added by the rule:

```
Nestloop
  ->  Index Scan using comp_hostidx on computer
  ->  Index Scan using soft_hostidx on software
```

This shows, that the planner does not realize that the qualification for `hostname` in `computer` could also be used for an index scan on `software` when there are multiple qualification expressions combined with `AND`, which is what it does in the regular-expression version of the command. The trigger will get invoked once for each of the 2000 old computers that have to be deleted, and that will result in one index scan over `computer` and 2000 index scans over `software`. The rule implementation will do it with two commands that use indexes. And it depends on the overall size of the table `software` whether the rule will still be faster in the sequential scan situation. 2000 command executions from the trigger over the SPI manager take some time, even if all the index blocks will soon be in the cache.

The last command we look at is:

```
DELETE FROM computer WHERE manufacturer = 'bim';
```

Again this could result in many rows to be deleted from `computer`. So the trigger will again run many commands through the executor. The command generated by the rule will be:

```
DELETE FROM software WHERE computer.manufacturer = 'bim'
                       AND software.hostname = computer.hostname;
```

The plan for that command will again be the nested loop over two index scans, only using a different index on `computer`:

```
Nestloop
  ->  Index Scan using comp_manufidx on computer
  ->  Index Scan using soft_hostidx on software
```

In any of these cases, the extra commands from the rule system will be more or less independent from the number of affected rows in a command.

The summary is, rules will only be significantly slower than triggers if their actions result in large and badly qualified joins, a situation where the planner fails.

Chapter 44. Procedural Languages

Postgres Pro allows user-defined functions to be written in other languages besides SQL and C. These other languages are generically called *procedural languages* (PLs). For a function written in a procedural language, the database server has no built-in knowledge about how to interpret the function's source text. Instead, the task is passed to a special handler that knows the details of the language. The handler could either do all the work of parsing, syntax analysis, execution, etc. itself, or it could serve as "glue" between Postgres Pro and an existing implementation of a programming language. The handler itself is a C language function compiled into a shared object and loaded on demand, just like any other C function.

There are currently four procedural languages available in the standard Postgres Pro distribution: PL/pgSQL (Chapter 45), PL/Tcl (Chapter 46), PL/Perl (Chapter 47), and PL/Python (Chapter 48). There are additional procedural languages available that are not included in the core distribution. Appendix J has information about finding them. In addition other languages can be defined by users; the basics of developing a new procedural language are covered in Chapter 56.

44.1. Installing Procedural Languages

A procedural language must be "installed" into each database where it is to be used. But procedural languages installed in the database `template1` are automatically available in all subsequently created databases, since their entries in `template1` will be copied by `CREATE DATABASE`. So the database administrator can decide which languages are available in which databases and can make some languages available by default if desired.

For the languages supplied with the standard distribution, it is only necessary to execute `CREATE EXTENSION` *`language_name`* to install the language into the current database. The manual procedure described below is only recommended for installing languages that have not been packaged as extensions.

Manual Procedural Language Installation

A procedural language is installed in a database in five steps, which must be carried out by a database superuser. In most cases the required SQL commands should be packaged as the installation script of an "extension", so that `CREATE EXTENSION` can be used to execute them.

1. The shared object for the language handler must be compiled and installed into an appropriate library directory. This works in the same way as building and installing modules with regular user-defined C functions does; see Section 40.10.5. Often, the language handler will depend on an external library that provides the actual programming language engine; if so, that must be installed as well.
2. The handler must be declared with the command

   ```
   CREATE FUNCTION handler_function_name()
       RETURNS language_handler
       AS 'path-to-shared-object'
       LANGUAGE C;
   ```

   The special return type of `language_handler` tells the database system that this function does not return one of the defined SQL data types and is not directly usable in SQL statements.
3. (Optional) Optionally, the language handler can provide an "inline" handler function that executes anonymous code blocks (`DO` commands) written in this language. If an inline handler function is provided by the language, declare it with a command like

   ```
   CREATE FUNCTION inline_function_name(internal)
       RETURNS void
       AS 'path-to-shared-object'
       LANGUAGE C;
   ```
4. (Optional) Optionally, the language handler can provide a "validator" function that checks a function definition for correctness without actually executing it. The validator function is called by `CREATE FUNCTION` if it exists. If a validator function is provided by the language, declare it with a command like

```
CREATE FUNCTION validator_function_name(oid)
    RETURNS void
    AS 'path-to-shared-object'
    LANGUAGE C STRICT;
```

5. Finally, the PL must be declared with the command

```
CREATE [TRUSTED] LANGUAGE language_name
    HANDLER handler_function_name
    [INLINE inline_function_name]
    [VALIDATOR validator_function_name] ;
```

The optional key word `TRUSTED` specifies that the language does not grant access to data that the user would not otherwise have. Trusted languages are designed for ordinary database users (those without superuser privilege) and allows them to safely create functions and procedures. Since PL functions are executed inside the database server, the `TRUSTED` flag should only be given for languages that do not allow access to database server internals or the file system. The languages PL/pgSQL, PL/Tcl, and PL/Perl are considered trusted; the languages PL/TclU, PL/PerlU, and PL/PythonU are designed to provide unlimited functionality and should *not* be marked trusted.

Example 44.1 shows how the manual installation procedure would work with the language PL/Perl.

Example 44.1. Manual Installation of PL/Perl

The following command tells the database server where to find the shared object for the PL/Perl language's call handler function:

```
CREATE FUNCTION plperl_call_handler() RETURNS language_handler AS
    '$libdir/plperl' LANGUAGE C;
```

PL/Perl has an inline handler function and a validator function, so we declare those too:

```
CREATE FUNCTION plperl_inline_handler(internal) RETURNS void AS
    '$libdir/plperl' LANGUAGE C STRICT;

CREATE FUNCTION plperl_validator(oid) RETURNS void AS
    '$libdir/plperl' LANGUAGE C STRICT;
```

The command:

```
CREATE TRUSTED LANGUAGE plperl
    HANDLER plperl_call_handler
    INLINE plperl_inline_handler
    VALIDATOR plperl_validator;
```

then defines that the previously declared functions should be invoked for functions and procedures where the language attribute is `plperl`.

In a default Postgres Pro installation, the handler for the PL/pgSQL language is built and installed into the “library” directory; furthermore, the PL/pgSQL language itself is installed in all databases. If Tcl support is configured in, the handlers for PL/Tcl and PL/TclU are built and installed in the library directory, but the language itself is not installed in any database by default. Likewise, the PL/Perl and PL/PerlU handlers are built and installed if Perl support is configured, and the PL/PythonU handler is installed if Python support is configured, but these languages are not installed by default.

Chapter 45. PL/pgSQL — SQL Procedural Language

45.1. Overview

PL/pgSQL is a loadable procedural language for the Postgres Pro database system. The design goals of PL/pgSQL were to create a loadable procedural language that

- can be used to create functions, procedures, and triggers,
- adds control structures to the SQL language,
- can perform complex computations,
- inherits all user-defined types, functions, procedures, and operators,
- can be defined to be trusted by the server,
- is easy to use.

Functions created with PL/pgSQL can be used anywhere that built-in functions could be used. For example, it is possible to create complex conditional computation functions and later use them to define operators or use them in index expressions.

In PostgreSQL 9.0 and later, PL/pgSQL is installed by default. However it is still a loadable module, so especially security-conscious administrators could choose to remove it.

45.1.1. Advantages of Using PL/pgSQL

SQL is the language Postgres Pro and most other relational databases use as query language. It's portable and easy to learn. But every SQL statement must be executed individually by the database server.

That means that your client application must send each query to the database server, wait for it to be processed, receive and process the results, do some computation, then send further queries to the server. All this incurs interprocess communication and will also incur network overhead if your client is on a different machine than the database server.

With PL/pgSQL you can group a block of computation and a series of queries *inside* the database server, thus having the power of a procedural language and the ease of use of SQL, but with considerable savings of client/server communication overhead.

- Extra round trips between client and server are eliminated
- Intermediate results that the client does not need do not have to be marshaled or transferred between server and client
- Multiple rounds of query parsing can be avoided

This can result in a considerable performance increase as compared to an application that does not use stored functions.

Also, with PL/pgSQL you can use all the data types, operators and functions of SQL.

45.1.2. Supported Argument and Result Data Types

Functions written in PL/pgSQL can accept as arguments any scalar or array data type supported by the server, and they can return a result of any of these types. They can also accept or return any composite type (row type) specified by name. It is also possible to declare a PL/pgSQL function as accepting `record`,

which means that any composite type will do as input, or as returning `record`, which means that the result is a row type whose columns are determined by specification in the calling query, as discussed in Section 7.2.1.4.

PL/pgSQL functions can be declared to accept a variable number of arguments by using the `VARIADIC` marker. This works exactly the same way as for SQL functions, as discussed in Section 40.5.6.

PL/pgSQL functions can also be declared to accept and return the polymorphic types described in Section 40.2.5, thus allowing the actual data types handled by the function to vary from call to call. Examples appear in Section 45.3.1.

PL/pgSQL functions can also be declared to return a "set" (or table) of any data type that can be returned as a single instance. Such a function generates its output by executing `RETURN NEXT` for each desired element of the result set, or by using `RETURN QUERY` to output the result of evaluating a query.

Finally, a PL/pgSQL function can be declared to return `void` if it has no useful return value. (Alternatively, it could be written as a procedure in that case.)

PL/pgSQL functions can also be declared with output parameters in place of an explicit specification of the return type. This does not add any fundamental capability to the language, but it is often convenient, especially for returning multiple values. The `RETURNS TABLE` notation can also be used in place of `RETURNS SETOF`.

Specific examples appear in Section 45.3.1 and Section 45.6.1.

45.2. Structure of PL/pgSQL

Functions written in PL/pgSQL are defined to the server by executing CREATE FUNCTION commands. Such a command would normally look like, say,

```
CREATE FUNCTION somefunc(integer, text) RETURNS integer
AS 'function body text'
LANGUAGE plpgsql;
```

The function body is simply a string literal so far as `CREATE FUNCTION` is concerned. It is often helpful to use dollar quoting (see Section 4.1.2.4) to write the function body, rather than the normal single quote syntax. Without dollar quoting, any single quotes or backslashes in the function body must be escaped by doubling them. Almost all the examples in this chapter use dollar-quoted literals for their function bodies.

PL/pgSQL is a block-structured language. The complete text of a function body must be a *block*. A block is defined as:

```
[ <<label>> ]
[ DECLARE
    declarations ]
BEGIN
    statements
END [ label ];
```

Each declaration and each statement within a block is terminated by a semicolon. A block that appears within another block must have a semicolon after `END`, as shown above; however the final `END` that concludes a function body does not require a semicolon.

> **Tip**
>
> A common mistake is to write a semicolon immediately after `BEGIN`. This is incorrect and will result in a syntax error.

A *label* is only needed if you want to identify the block for use in an EXIT statement, or to qualify the names of the variables declared in the block. If a label is given after END, it must match the label at the block's beginning.

All key words are case-insensitive. Identifiers are implicitly converted to lower case unless double-quoted, just as they are in ordinary SQL commands.

Comments work the same way in PL/pgSQL code as in ordinary SQL. A double dash (--) starts a comment that extends to the end of the line. A /* starts a block comment that extends to the matching occurrence of */. Block comments nest.

Any statement in the statement section of a block can be a *subblock*. Subblocks can be used for logical grouping or to localize variables to a small group of statements. Variables declared in a subblock mask any similarly-named variables of outer blocks for the duration of the subblock; but you can access the outer variables anyway if you qualify their names with their block's label. For example:

```
CREATE FUNCTION somefunc() RETURNS integer AS $$
<< outerblock >>
DECLARE
    quantity integer := 30;
BEGIN
    RAISE NOTICE 'Quantity here is %', quantity;  -- Prints 30
    quantity := 50;
    --
    -- Create a subblock
    --
    DECLARE
        quantity integer := 80;
    BEGIN
        RAISE NOTICE 'Quantity here is %', quantity;  -- Prints 80
        RAISE NOTICE 'Outer quantity here is %', outerblock.quantity;  -- Prints 50
    END;

    RAISE NOTICE 'Quantity here is %', quantity;  -- Prints 50

    RETURN quantity;
END;
$$ LANGUAGE plpgsql;
```

> **Note**
>
> There is actually a hidden “outer block” surrounding the body of any PL/pgSQL function. This block provides the declarations of the function's parameters (if any), as well as some special variables such as FOUND (see Section 45.5.5). The outer block is labeled with the function's name, meaning that parameters and special variables can be qualified with the function's name.

It is important not to confuse the use of BEGIN/END for grouping statements in PL/pgSQL with the similarly-named SQL commands for transaction control. PL/pgSQL's BEGIN/END are only for grouping; they do not start or end a transaction. See Section 45.8 for information on managing transactions in PL/pgSQL. Also, a block containing an EXCEPTION clause effectively forms a subtransaction that can be rolled back without affecting the outer transaction. For more about that see Section 45.6.8.

45.3. Declarations

All variables used in a block must be declared in the declarations section of the block. (The only exceptions are that the loop variable of a FOR loop iterating over a range of integer values is automatically declared as an integer variable, and likewise the loop variable of a FOR loop iterating over a cursor's result is automatically declared as a record variable.)

PL/pgSQL variables can have any SQL data type, such as `integer`, `varchar`, and `char`.

Here are some examples of variable declarations:

```
user_id integer;
quantity numeric(5);
url varchar;
myrow tablename%ROWTYPE;
myfield tablename.columnname%TYPE;
arow RECORD;
```

The general syntax of a variable declaration is:

```
name [ CONSTANT ] type [ COLLATE collation_name ] [ NOT NULL ] [ { DEFAULT | := |
 = } expression ];
```

The `DEFAULT` clause, if given, specifies the initial value assigned to the variable when the block is entered. If the `DEFAULT` clause is not given then the variable is initialized to the SQL null value. The `CONSTANT` option prevents the variable from being assigned to after initialization, so that its value will remain constant for the duration of the block. The `COLLATE` option specifies a collation to use for the variable (see Section 45.3.6). If `NOT NULL` is specified, an assignment of a null value results in a run-time error. All variables declared as `NOT NULL` must have a nonnull default value specified. Equal (`=`) can be used instead of PL/SQL-compliant `:=`.

A variable's default value is evaluated and assigned to the variable each time the block is entered (not just once per function call). So, for example, assigning `now()` to a variable of type `timestamp` causes the variable to have the time of the current function call, not the time when the function was precompiled.

Examples:

```
quantity integer DEFAULT 32;
url varchar := 'http://mysite.com';
user_id CONSTANT integer := 10;
```

45.3.1. Declaring Function Parameters

Parameters passed to functions are named with the identifiers `$1`, `$2`, etc. Optionally, aliases can be declared for `$n` parameter names for increased readability. Either the alias or the numeric identifier can then be used to refer to the parameter value.

There are two ways to create an alias. The preferred way is to give a name to the parameter in the `CREATE FUNCTION` command, for example:

```
CREATE FUNCTION sales_tax(subtotal real) RETURNS real AS $$
BEGIN
    RETURN subtotal * 0.06;
END;
$$ LANGUAGE plpgsql;
```

The other way is to explicitly declare an alias, using the declaration syntax

```
name ALIAS FOR $n;
```

The same example in this style looks like:

```
CREATE FUNCTION sales_tax(real) RETURNS real AS $$
DECLARE
    subtotal ALIAS FOR $1;
BEGIN
    RETURN subtotal * 0.06;
END;
$$ LANGUAGE plpgsql;
```

> **Note**
>
> These two examples are not perfectly equivalent. In the first case, `subtotal` could be referenced as `sales_tax.subtotal`, but in the second case it could not. (Had we attached a label to the inner block, `subtotal` could be qualified with that label, instead.)

Some more examples:

```
CREATE FUNCTION instr(varchar, integer) RETURNS integer AS $$
DECLARE
    v_string ALIAS FOR $1;
    index ALIAS FOR $2;
BEGIN
    -- some computations using v_string and index here
END;
$$ LANGUAGE plpgsql;


CREATE FUNCTION concat_selected_fields(in_t sometablename) RETURNS text AS $$
BEGIN
    RETURN in_t.f1 || in_t.f3 || in_t.f5 || in_t.f7;
END;
$$ LANGUAGE plpgsql;
```

When a PL/pgSQL function is declared with output parameters, the output parameters are given *$n* names and optional aliases in just the same way as the normal input parameters. An output parameter is effectively a variable that starts out NULL; it should be assigned to during the execution of the function. The final value of the parameter is what is returned. For instance, the sales-tax example could also be done this way:

```
CREATE FUNCTION sales_tax(subtotal real, OUT tax real) AS $$
BEGIN
    tax := subtotal * 0.06;
END;
$$ LANGUAGE plpgsql;
```

Notice that we omitted `RETURNS real` — we could have included it, but it would be redundant.

To call a function with `OUT` parameters, omit the output parameter(s) in the function call:

```
SELECT sales_tax(100.00);
```

Output parameters are most useful when returning multiple values. A trivial example is:

```
CREATE FUNCTION sum_n_product(x int, y int, OUT sum int, OUT prod int) AS $$
BEGIN
    sum := x + y;
    prod := x * y;
END;
$$ LANGUAGE plpgsql;

SELECT * FROM sum_n_product(2, 4);
 sum | prod
-----+------
   6 |    8
```

As discussed in Section 40.5.4, this effectively creates an anonymous record type for the function's results. If a `RETURNS` clause is given, it must say `RETURNS record`.

This also works with procedures, for example:

```
CREATE PROCEDURE sum_n_product(x int, y int, OUT sum int, OUT prod int) AS $$
BEGIN
    sum := x + y;
    prod := x * y;
END;
$$ LANGUAGE plpgsql;
```

In a call to a procedure, all the parameters must be specified. For output parameters, `NULL` may be specified when calling the procedure from plain SQL:

```
CALL sum_n_product(2, 4, NULL, NULL);
 sum | prod
-----+------
   6 |    8
```

However, when calling a procedure from PL/pgSQL, you should instead write a variable for any output parameter; the variable will receive the result of the call. See Section 45.6.3 for details.

Another way to declare a PL/pgSQL function is with `RETURNS TABLE`, for example:

```
CREATE FUNCTION extended_sales(p_itemno int)
RETURNS TABLE(quantity int, total numeric) AS $$
BEGIN
    RETURN QUERY SELECT s.quantity, s.quantity * s.price FROM sales AS s
                 WHERE s.itemno = p_itemno;
END;
$$ LANGUAGE plpgsql;
```

This is exactly equivalent to declaring one or more `OUT` parameters and specifying `RETURNS SETOF` *sometype*.

When the return type of a PL/pgSQL function is declared as a polymorphic type (see Section 40.2.5), a special parameter `$0` is created. Its data type is the actual return type of the function, as deduced from the actual input types. This allows the function to access its actual return type as shown in Section 45.3.3. `$0` is initialized to null and can be modified by the function, so it can be used to hold the return value if desired, though that is not required. `$0` can also be given an alias. For example, this function works on any data type that has a `+` operator:

```
CREATE FUNCTION add_three_values(v1 anyelement, v2 anyelement, v3 anyelement)
RETURNS anyelement AS $$
DECLARE
    result ALIAS FOR $0;
BEGIN
    result := v1 + v2 + v3;
    RETURN result;
END;
$$ LANGUAGE plpgsql;
```

The same effect can be obtained by declaring one or more output parameters as polymorphic types. In this case the special `$0` parameter is not used; the output parameters themselves serve the same purpose. For example:

```
CREATE FUNCTION add_three_values(v1 anyelement, v2 anyelement, v3 anyelement,
                                 OUT sum anyelement)
AS $$
BEGIN
    sum := v1 + v2 + v3;
END;
$$ LANGUAGE plpgsql;
```

In practice it might be more useful to declare a polymorphic function using the `anycompatible` family of types, so that automatic promotion of the input arguments to a common type will occur. For example:

```
CREATE FUNCTION add_three_values(v1 anycompatible, v2 anycompatible, v3 anycompatible)
RETURNS anycompatible AS $$
BEGIN
    RETURN v1 + v2 + v3;
END;
$$ LANGUAGE plpgsql;
```

With this example, a call such as

```
SELECT add_three_values(1, 2, 4.7);
```

will work, automatically promoting the integer inputs to numeric. The function using `anyelement` would require you to cast the three inputs to the same type manually.

45.3.2. ALIAS

```
newname ALIAS FOR oldname;
```

The `ALIAS` syntax is more general than is suggested in the previous section: you can declare an alias for any variable, not just function parameters. The main practical use for this is to assign a different name for variables with predetermined names, such as `NEW` or `OLD` within a trigger function.

Examples:

```
DECLARE
  prior ALIAS FOR old;
  updated ALIAS FOR new;
```

Since `ALIAS` creates two different ways to name the same object, unrestricted use can be confusing. It's best to use it only for the purpose of overriding predetermined names.

45.3.3. Copying Types

```
variable%TYPE
```

`%TYPE` provides the data type of a variable or table column. You can use this to declare variables that will hold database values. For example, let's say you have a column named `user_id` in your `users` table. To declare a variable with the same data type as `users.user_id` you write:

```
user_id users.user_id%TYPE;
```

By using `%TYPE` you don't need to know the data type of the structure you are referencing, and most importantly, if the data type of the referenced item changes in the future (for instance: you change the type of `user_id` from `integer` to `real`), you might not need to change your function definition.

`%TYPE` is particularly valuable in polymorphic functions, since the data types needed for internal variables can change from one call to the next. Appropriate variables can be created by applying `%TYPE` to the function's arguments or result placeholders.

45.3.4. Row Types

```
name table_name%ROWTYPE;
name composite_type_name;
```

A variable of a composite type is called a *row* variable (or *row-type* variable). Such a variable can hold a whole row of a `SELECT` or `FOR` query result, so long as that query's column set matches the declared type of the variable. The individual fields of the row value are accessed using the usual dot notation, for example `rowvar.field`.

A row variable can be declared to have the same type as the rows of an existing table or view, by using the *table_name*`%ROWTYPE` notation; or it can be declared by giving a composite type's name. (Since every table has an associated composite type of the same name, it actually does not matter in Postgres Pro whether you write `%ROWTYPE` or not. But the form with `%ROWTYPE` is more portable.)

Parameters to a function can be composite types (complete table rows). In that case, the corresponding identifier `$n` will be a row variable, and fields can be selected from it, for example `$1.user_id`.

Here is an example of using composite types. `table1` and `table2` are existing tables having at least the mentioned fields:

```
CREATE FUNCTION merge_fields(t_row table1) RETURNS text AS $$
DECLARE
    t2_row table2%ROWTYPE;
BEGIN
    SELECT * INTO t2_row FROM table2 WHERE ... ;
    RETURN t_row.f1 || t2_row.f3 || t_row.f5 || t2_row.f7;
END;
$$ LANGUAGE plpgsql;

SELECT merge_fields(t.*) FROM table1 t WHERE ... ;
```

45.3.5. Record Types

```
name RECORD;
```

Record variables are similar to row-type variables, but they have no predefined structure. They take on the actual row structure of the row they are assigned during a `SELECT` or `FOR` command. The substructure of a record variable can change each time it is assigned to. A consequence of this is that until a record variable is first assigned to, it has no substructure, and any attempt to access a field in it will draw a run-time error.

Note that `RECORD` is not a true data type, only a placeholder. One should also realize that when a PL/pgSQL function is declared to return type `record`, this is not quite the same concept as a record variable, even though such a function might use a record variable to hold its result. In both cases the actual row structure is unknown when the function is written, but for a function returning `record` the actual structure is determined when the calling query is parsed, whereas a record variable can change its row structure on-the-fly.

45.3.6. Collation of PL/pgSQL Variables

When a PL/pgSQL function has one or more parameters of collatable data types, a collation is identified for each function call depending on the collations assigned to the actual arguments, as described in Section 23.2. If a collation is successfully identified (i.e., there are no conflicts of implicit collations among the arguments) then all the collatable parameters are treated as having that collation implicitly. This will affect the behavior of collation-sensitive operations within the function. For example, consider

```
CREATE FUNCTION less_than(a text, b text) RETURNS boolean AS $$
BEGIN
    RETURN a < b;
END;
$$ LANGUAGE plpgsql;

SELECT less_than(text_field_1, text_field_2) FROM table1;
SELECT less_than(text_field_1, text_field_2 COLLATE "C") FROM table1;
```

The first use of `less_than` will use the common collation of `text_field_1` and `text_field_2` for the comparison, while the second use will use `C` collation.

Furthermore, the identified collation is also assumed as the collation of any local variables that are of collatable types. Thus this function would not work any differently if it were written as

```
CREATE FUNCTION less_than(a text, b text) RETURNS boolean AS $$
DECLARE
    local_a text := a;
    local_b text := b;
```

```
BEGIN
    RETURN local_a < local_b;
END;
$$ LANGUAGE plpgsql;
```

If there are no parameters of collatable data types, or no common collation can be identified for them, then parameters and local variables use the default collation of their data type (which is usually the database's default collation, but could be different for variables of domain types).

A local variable of a collatable data type can have a different collation associated with it by including the `COLLATE` option in its declaration, for example

```
DECLARE
    local_a text COLLATE "en_US";
```

This option overrides the collation that would otherwise be given to the variable according to the rules above.

Also, of course explicit `COLLATE` clauses can be written inside a function if it is desired to force a particular collation to be used in a particular operation. For example,

```
CREATE FUNCTION less_than_c(a text, b text) RETURNS boolean AS $$
BEGIN
    RETURN a < b COLLATE "C";
END;
$$ LANGUAGE plpgsql;
```

This overrides the collations associated with the table columns, parameters, or local variables used in the expression, just as would happen in a plain SQL command.

45.4. Expressions

All expressions used in PL/pgSQL statements are processed using the server's main SQL executor. For example, when you write a PL/pgSQL statement like

```
IF expression THEN ...
```

PL/pgSQL will evaluate the expression by feeding a query like

```
SELECT expression
```

to the main SQL engine. While forming the `SELECT` command, any occurrences of PL/pgSQL variable names are replaced by query parameters, as discussed in detail in Section 45.11.1. This allows the query plan for the `SELECT` to be prepared just once and then reused for subsequent evaluations with different values of the variables. Thus, what really happens on first use of an expression is essentially a `PREPARE` command. For example, if we have declared two integer variables `x` and `y`, and we write

```
IF x < y THEN ...
```

what happens behind the scenes is equivalent to

```
PREPARE statement_name(integer, integer) AS SELECT $1 < $2;
```

and then this prepared statement is `EXECUTE`d for each execution of the `IF` statement, with the current values of the PL/pgSQL variables supplied as parameter values. Normally these details are not important to a PL/pgSQL user, but they are useful to know when trying to diagnose a problem. More information appears in Section 45.11.2.

Since an *expression* is converted to a `SELECT` command, it can contain the same clauses that an ordinary `SELECT` would, except that it cannot include a top-level `UNION`, `INTERSECT`, or `EXCEPT` clause. Thus for example one could test whether a table is non-empty with

```
IF count(*) > 0 FROM my_table THEN ...
```

since the *expression* between IF and THEN is parsed as though it were SELECT count(*) > 0 FROM my_table. The SELECT must produce a single column, and not more than one row. (If it produces no rows, the result is taken as NULL.)

45.5. Basic Statements

In this section and the following ones, we describe all the statement types that are explicitly understood by PL/pgSQL. Anything not recognized as one of these statement types is presumed to be an SQL command and is sent to the main database engine to execute, as described in Section 45.5.2.

45.5.1. Assignment

An assignment of a value to a PL/pgSQL variable is written as:

variable { := | = } *expression*;

As explained previously, the expression in such a statement is evaluated by means of an SQL SELECT command sent to the main database engine. The expression must yield a single value (possibly a row value, if the variable is a row or record variable). The target variable can be a simple variable (optionally qualified with a block name), a field of a row or record target, or an element or slice of an array target. Equal (=) can be used instead of PL/SQL-compliant :=.

If the expression's result data type doesn't match the variable's data type, the value will be coerced as though by an assignment cast (see Section 10.4). If no assignment cast is known for the pair of data types involved, the PL/pgSQL interpreter will attempt to convert the result value textually, that is by applying the result type's output function followed by the variable type's input function. Note that this could result in run-time errors generated by the input function, if the string form of the result value is not acceptable to the input function.

Examples:

```
tax := subtotal * 0.06;
my_record.user_id := 20;
my_array[j] := 20;
my_array[1:3] := array[1,2,3];
complex_array[n].realpart = 12.3;
```

45.5.2. Executing SQL Commands

In general, any SQL command that does not return rows can be executed within a PL/pgSQL function just by writing the command. For example, you could create and fill a table by writing

```
CREATE TABLE mytable (id int primary key, data text);
INSERT INTO mytable VALUES (1,'one'), (2,'two');
```

If the command does return rows (for example SELECT, or INSERT/UPDATE/DELETE with RETURNING), there are two ways to proceed. When the command will return at most one row, or you only care about the first row of output, write the command as usual but add an INTO clause to capture the output, as described in Section 45.5.3. To process all of the output rows, write the command as the data source for a FOR loop, as described in Section 45.6.6.

Usually it is not sufficient just to execute statically-defined SQL commands. Typically you'll want a command to use varying data values, or even to vary in more fundamental ways such as by using different table names at different times. Again, there are two ways to proceed depending on the situation.

PL/pgSQL variable values can be automatically inserted into optimizable SQL commands, which are SELECT, INSERT, UPDATE, DELETE, and certain utility commands that incorporate one of these, such as EXPLAIN and CREATE TABLE ... AS SELECT. In these commands, any PL/pgSQL variable name appearing in the command text is replaced by a query parameter, and then the current value of the variable is provided as the parameter value at run time. This is exactly like the processing described earlier for expressions; for details see Section 45.11.1.

When executing an optimizable SQL command in this way, PL/pgSQL may cache and re-use the execution plan for the command, as discussed in Section 45.11.2.

Non-optimizable SQL commands (also called utility commands) are not capable of accepting query parameters. So automatic substitution of PL/pgSQL variables does not work in such commands. To include non-constant text in a utility command executed from PL/pgSQL, you must build the utility command as a string and then EXECUTE it, as discussed in Section 45.5.4.

EXECUTE must also be used if you want to modify the command in some other way than supplying a data value, for example by changing a table name.

Sometimes it is useful to evaluate an expression or SELECT query but discard the result, for example when calling a function that has side-effects but no useful result value. To do this in PL/pgSQL, use the PERFORM statement:

```
PERFORM query;
```

This executes *query* and discards the result. Write the *query* the same way you would write an SQL SELECT command, but replace the initial keyword SELECT with PERFORM. For WITH queries, use PERFORM and then place the query in parentheses. (In this case, the query can only return one row.) PL/pgSQL variables will be substituted into the query just as described above, and the plan is cached in the same way. Also, the special variable FOUND is set to true if the query produced at least one row, or false if it produced no rows (see Section 45.5.5).

> **Note**
>
> One might expect that writing SELECT directly would accomplish this result, but at present the only accepted way to do it is PERFORM. An SQL command that can return rows, such as SELECT, will be rejected as an error unless it has an INTO clause as discussed in the next section.

An example:

```
PERFORM create_mv('cs_session_page_requests_mv', my_query);
```

45.5.3. Executing a Command with a Single-Row Result

The result of an SQL command yielding a single row (possibly of multiple columns) can be assigned to a record variable, row-type variable, or list of scalar variables. This is done by writing the base SQL command and adding an INTO clause. For example,

```
SELECT select_expressions INTO [STRICT] target FROM ...;
INSERT ... RETURNING expressions INTO [STRICT] target;
UPDATE ... RETURNING expressions INTO [STRICT] target;
DELETE ... RETURNING expressions INTO [STRICT] target;
```

where *target* can be a record variable, a row variable, or a comma-separated list of simple variables and record/row fields. PL/pgSQL variables will be substituted into the rest of the command (that is, everything but the INTO clause) just as described above, and the plan is cached in the same way. This works for SELECT, INSERT/UPDATE/DELETE with RETURNING, and certain utility commands that return row sets, such as EXPLAIN. Except for the INTO clause, the SQL command is the same as it would be written outside PL/pgSQL.

> **Tip**
>
> Note that this interpretation of SELECT with INTO is quite different from Postgres Pro's regular SELECT INTO command, wherein the INTO target is a newly created table. If you want to create a table from a SELECT result inside a PL/pgSQL function, use the syntax CREATE TABLE ... AS SELECT.

If a row variable or a variable list is used as target, the command's result columns must exactly match the structure of the target as to number and data types, or else a run-time error occurs. When a record variable is the target, it automatically configures itself to the row type of the command's result columns.

The INTO clause can appear almost anywhere in the SQL command. Customarily it is written either just before or just after the list of *select_expressions* in a SELECT command, or at the end of the command for other command types. It is recommended that you follow this convention in case the PL/pgSQL parser becomes stricter in future versions.

If STRICT is not specified in the INTO clause, then *target* will be set to the first row returned by the command, or to nulls if the command returned no rows. (Note that "the first row" is not well-defined unless you've used ORDER BY.) Any result rows after the first row are discarded. You can check the special FOUND variable (see Section 45.5.5) to determine whether a row was returned:

```
SELECT * INTO myrec FROM emp WHERE empname = myname;
IF NOT FOUND THEN
    RAISE EXCEPTION 'employee % not found', myname;
END IF;
```

If the STRICT option is specified, the command must return exactly one row or a run-time error will be reported, either NO_DATA_FOUND (no rows) or TOO_MANY_ROWS (more than one row). You can use an exception block if you wish to catch the error, for example:

```
BEGIN
    SELECT * INTO STRICT myrec FROM emp WHERE empname = myname;
    EXCEPTION
        WHEN NO_DATA_FOUND THEN
            RAISE EXCEPTION 'employee % not found', myname;
        WHEN TOO_MANY_ROWS THEN
            RAISE EXCEPTION 'employee % not unique', myname;
END;
```

Successful execution of a command with STRICT always sets FOUND to true.

For INSERT/UPDATE/DELETE with RETURNING, PL/pgSQL reports an error for more than one returned row, even when STRICT is not specified. This is because there is no option such as ORDER BY with which to determine which affected row should be returned.

If print_strict_params is enabled for the function, then when an error is thrown because the requirements of STRICT are not met, the DETAIL part of the error message will include information about the parameters passed to the command. You can change the print_strict_params setting for all functions by setting plpgsql.print_strict_params, though only subsequent function compilations will be affected. You can also enable it on a per-function basis by using a compiler option, for example:

```
CREATE FUNCTION get_userid(username text) RETURNS int
AS $$
#print_strict_params on
DECLARE
userid int;
BEGIN
    SELECT users.userid INTO STRICT userid
        FROM users WHERE users.username = get_userid.username;
    RETURN userid;
END;
$$ LANGUAGE plpgsql;
```

On failure, this function might produce an error message such as

```
ERROR:  query returned no rows
DETAIL:  parameters: username = 'nosuchuser'
CONTEXT:  PL/pgSQL function get_userid(text) line 6 at SQL statement
```

> **Note**
>
> The `STRICT` option matches the behavior of Oracle PL/SQL's `SELECT INTO` and related statements.

45.5.4. Executing Dynamic Commands

Oftentimes you will want to generate dynamic commands inside your PL/pgSQL functions, that is, commands that will involve different tables or different data types each time they are executed. PL/pgSQL's normal attempts to cache plans for commands (as discussed in Section 45.11.2) will not work in such scenarios. To handle this sort of problem, the `EXECUTE` statement is provided:

```
EXECUTE command-string [ INTO [STRICT] target ] [ USING expression [, ... ] ];
```

where *command-string* is an expression yielding a string (of type `text`) containing the command to be executed. The optional *target* is a record variable, a row variable, or a comma-separated list of simple variables and record/row fields, into which the results of the command will be stored. The optional `USING` expressions supply values to be inserted into the command.

No substitution of PL/pgSQL variables is done on the computed command string. Any required variable values must be inserted in the command string as it is constructed; or you can use parameters as described below.

Also, there is no plan caching for commands executed via `EXECUTE`. Instead, the command is always planned each time the statement is run. Thus the command string can be dynamically created within the function to perform actions on different tables and columns.

The `INTO` clause specifies where the results of an SQL command returning rows should be assigned. If a row variable or variable list is provided, it must exactly match the structure of the command's results; if a record variable is provided, it will configure itself to match the result structure automatically. If multiple rows are returned, only the first will be assigned to the `INTO` variable(s). If no rows are returned, NULL is assigned to the `INTO` variable(s). If no `INTO` clause is specified, the command results are discarded.

If the `STRICT` option is given, an error is reported unless the command produces exactly one row.

The command string can use parameter values, which are referenced in the command as `$1`, `$2`, etc. These symbols refer to values supplied in the `USING` clause. This method is often preferable to inserting data values into the command string as text: it avoids run-time overhead of converting the values to text and back, and it is much less prone to SQL-injection attacks since there is no need for quoting or escaping. An example is:

```
EXECUTE 'SELECT count(*) FROM mytable WHERE inserted_by = $1 AND inserted <= $2'
   INTO c
   USING checked_user, checked_date;
```

Note that parameter symbols can only be used for data values — if you want to use dynamically determined table or column names, you must insert them into the command string textually. For example, if the preceding query needed to be done against a dynamically selected table, you could do this:

```
EXECUTE 'SELECT count(*) FROM '
    || quote_ident(tabname)
    || ' WHERE inserted_by = $1 AND inserted <= $2'
   INTO c
   USING checked_user, checked_date;
```

A cleaner approach is to use `format()`'s `%I` specification to insert table or column names with automatic quoting:

```
EXECUTE format('SELECT count(*) FROM %I '
   'WHERE inserted_by = $1 AND inserted <= $2', tabname)
   INTO c
```

```
    USING checked_user, checked_date;
```

(This example relies on the SQL rule that string literals separated by a newline are implicitly concatenated.)

Another restriction on parameter symbols is that they only work in optimizable SQL commands (SELECT, INSERT, UPDATE, DELETE, and certain commands containing one of these). In other statement types (generically called utility statements), you must insert values textually even if they are just data values.

An EXECUTE with a simple constant command string and some USING parameters, as in the first example above, is functionally equivalent to just writing the command directly in PL/pgSQL and allowing replacement of PL/pgSQL variables to happen automatically. The important difference is that EXECUTE will replan the command on each execution, generating a plan that is specific to the current parameter values; whereas PL/pgSQL may otherwise create a generic plan and cache it for re-use. In situations where the best plan depends strongly on the parameter values, it can be helpful to use EXECUTE to positively ensure that a generic plan is not selected.

SELECT INTO is not currently supported within EXECUTE; instead, execute a plain SELECT command and specify INTO as part of the EXECUTE itself.

> **Note**
>
> The PL/pgSQL EXECUTE statement is not related to the EXECUTE SQL statement supported by the Postgres Pro server. The server's EXECUTE statement cannot be used directly within PL/pgSQL functions (and is not needed).

Example 45.1. Quoting Values in Dynamic Queries

When working with dynamic commands you will often have to handle escaping of single quotes. The recommended method for quoting fixed text in your function body is dollar quoting. (If you have legacy code that does not use dollar quoting, please refer to the overview in Section 45.12.1, which can save you some effort when translating said code to a more reasonable scheme.)

Dynamic values require careful handling since they might contain quote characters. An example using format() (this assumes that you are dollar quoting the function body so quote marks need not be doubled):

```
EXECUTE format('UPDATE tbl SET %I = $1 '
    'WHERE key = $2', colname) USING newvalue, keyvalue;
```

It is also possible to call the quoting functions directly:

```
EXECUTE 'UPDATE tbl SET '
        || quote_ident(colname)
        || ' = '
        || quote_literal(newvalue)
        || ' WHERE key = '
        || quote_literal(keyvalue);
```

This example demonstrates the use of the quote_ident and quote_literal functions (see Section 9.4). For safety, expressions containing column or table identifiers should be passed through quote_ident before insertion in a dynamic query. Expressions containing values that should be literal strings in the constructed command should be passed through quote_literal. These functions take the appropriate steps to return the input text enclosed in double or single quotes respectively, with any embedded special characters properly escaped.

Because quote_literal is labeled STRICT, it will always return null when called with a null argument. In the above example, if newvalue or keyvalue were null, the entire dynamic query string would become

null, leading to an error from EXECUTE. You can avoid this problem by using the quote_nullable function, which works the same as quote_literal except that when called with a null argument it returns the string NULL. For example,

```
EXECUTE 'UPDATE tbl SET '
        || quote_ident(colname)
        || ' = '
        || quote_nullable(newvalue)
        || ' WHERE key = '
        || quote_nullable(keyvalue);
```

If you are dealing with values that might be null, you should usually use quote_nullable in place of quote_literal.

As always, care must be taken to ensure that null values in a query do not deliver unintended results. For example the WHERE clause

```
'WHERE key = ' || quote_nullable(keyvalue)
```

will never succeed if keyvalue is null, because the result of using the equality operator = with a null operand is always null. If you wish null to work like an ordinary key value, you would need to rewrite the above as

```
'WHERE key IS NOT DISTINCT FROM ' || quote_nullable(keyvalue)
```

(At present, IS NOT DISTINCT FROM is handled much less efficiently than =, so don't do this unless you must. See Section 9.2 for more information on nulls and IS DISTINCT.)

Note that dollar quoting is only useful for quoting fixed text. It would be a very bad idea to try to write this example as:

```
EXECUTE 'UPDATE tbl SET '
        || quote_ident(colname)
        || ' = $$'
        || newvalue
        || '$$ WHERE key = '
        || quote_literal(keyvalue);
```

because it would break if the contents of newvalue happened to contain $$. The same objection would apply to any other dollar-quoting delimiter you might pick. So, to safely quote text that is not known in advance, you *must* use quote_literal, quote_nullable, or quote_ident, as appropriate.

Dynamic SQL statements can also be safely constructed using the format function (see Section 9.4.1). For example:

```
EXECUTE format('UPDATE tbl SET %I = %L '
   'WHERE key = %L', colname, newvalue, keyvalue);
```

%I is equivalent to quote_ident, and %L is equivalent to quote_nullable. The format function can be used in conjunction with the USING clause:

```
EXECUTE format('UPDATE tbl SET %I = $1 WHERE key = $2', colname)
   USING newvalue, keyvalue;
```

This form is better because the variables are handled in their native data type format, rather than unconditionally converting them to text and quoting them via %L. It is also more efficient.

A much larger example of a dynamic command and EXECUTE can be seen in Example 45.10, which builds and executes a CREATE FUNCTION command to define a new function.

45.5.5. Obtaining the Result Status

There are several ways to determine the effect of a command. The first method is to use the GET DIAGNOSTICS command, which has the form:

```
GET [ CURRENT ] DIAGNOSTICS variable { = | := } item [ , ... ];
```

This command allows retrieval of system status indicators. `CURRENT` is a noise word (but see also `GET STACKED DIAGNOSTICS` in Section 45.6.8.1). Each *item* is a key word identifying a status value to be assigned to the specified *variable* (which should be of the right data type to receive it). The currently available status items are shown in Table 45.1. Colon-equal (`:=`) can be used instead of the SQL-standard `=` token. An example:

```
GET DIAGNOSTICS integer_var = ROW_COUNT;
```

Table 45.1. Available Diagnostics Items

Name	Type	Description
`ROW_COUNT`	`bigint`	the number of rows processed by the most recent SQL command
`PG_CONTEXT`	`text`	line(s) of text describing the current call stack (see Section 45.6.9)

The second method to determine the effects of a command is to check the special variable named `FOUND`, which is of type `boolean`. `FOUND` starts out false within each PL/pgSQL function call. It is set by each of the following types of statements:

- A `SELECT INTO` statement sets `FOUND` true if a row is assigned, false if no row is returned.
- A `PERFORM` statement sets `FOUND` true if it produces (and discards) one or more rows, false if no row is produced.
- `UPDATE`, `INSERT`, and `DELETE` statements set `FOUND` true if at least one row is affected, false if no row is affected.
- A `FETCH` statement sets `FOUND` true if it returns a row, false if no row is returned.
- A `MOVE` statement sets `FOUND` true if it successfully repositions the cursor, false otherwise.
- A `FOR` or `FOREACH` statement sets `FOUND` true if it iterates one or more times, else false. `FOUND` is set this way when the loop exits; inside the execution of the loop, `FOUND` is not modified by the loop statement, although it might be changed by the execution of other statements within the loop body.
- `RETURN QUERY` and `RETURN QUERY EXECUTE` statements set `FOUND` true if the query returns at least one row, false if no row is returned.

Other PL/pgSQL statements do not change the state of `FOUND`. Note in particular that `EXECUTE` changes the output of `GET DIAGNOSTICS`, but does not change `FOUND`.

`FOUND` is a local variable within each PL/pgSQL function; any changes to it affect only the current function.

45.5.6. Doing Nothing At All

Sometimes a placeholder statement that does nothing is useful. For example, it can indicate that one arm of an if/then/else chain is deliberately empty. For this purpose, use the `NULL` statement:

```
NULL;
```

For example, the following two fragments of code are equivalent:

```
BEGIN
    y := x / 0;
EXCEPTION
    WHEN division_by_zero THEN
        NULL;  -- ignore the error
END;
```

```
BEGIN
    y := x / 0;
EXCEPTION
    WHEN division_by_zero THEN  -- ignore the error
END;
```

Which is preferable is a matter of taste.

> **Note**
>
> In Oracle's PL/SQL, empty statement lists are not allowed, and so `NULL` statements are *required* for situations such as this. PL/pgSQL allows you to just write nothing, instead.

45.6. Control Structures

Control structures are probably the most useful (and important) part of PL/pgSQL. With PL/pgSQL's control structures, you can manipulate Postgres Pro data in a very flexible and powerful way.

45.6.1. Returning from a Function

There are two commands available that allow you to return data from a function: `RETURN` and `RETURN NEXT`.

45.6.1.1. `RETURN`

```
RETURN expression;
```

`RETURN` with an expression terminates the function and returns the value of *`expression`* to the caller. This form is used for PL/pgSQL functions that do not return a set.

In a function that returns a scalar type, the expression's result will automatically be cast into the function's return type as described for assignments. But to return a composite (row) value, you must write an expression delivering exactly the requested column set. This may require use of explicit casting.

If you declared the function with output parameters, write just `RETURN` with no expression. The current values of the output parameter variables will be returned.

If you declared the function to return `void`, a `RETURN` statement can be used to exit the function early; but do not write an expression following `RETURN`.

The return value of a function cannot be left undefined. If control reaches the end of the top-level block of the function without hitting a `RETURN` statement, a run-time error will occur. This restriction does not apply to functions with output parameters and functions returning `void`, however. In those cases a `RETURN` statement is automatically executed if the top-level block finishes.

Some examples:

```
-- functions returning a scalar type
RETURN 1 + 2;
RETURN scalar_var;

-- functions returning a composite type
RETURN composite_type_var;
RETURN (1, 2, 'three'::text);  -- must cast columns to correct types
```

45.6.1.2. `RETURN NEXT` and `RETURN QUERY`

```
RETURN NEXT expression;
```

```
RETURN QUERY query;
RETURN QUERY EXECUTE command-string [ USING expression [, ... ] ];
```

When a PL/pgSQL function is declared to return `SETOF sometype`, the procedure to follow is slightly different. In that case, the individual items to return are specified by a sequence of `RETURN NEXT` or `RETURN QUERY` commands, and then a final `RETURN` command with no argument is used to indicate that the function has finished executing. `RETURN NEXT` can be used with both scalar and composite data types; with a composite result type, an entire “table” of results will be returned. `RETURN QUERY` appends the results of executing a query to the function's result set. `RETURN NEXT` and `RETURN QUERY` can be freely intermixed in a single set-returning function, in which case their results will be concatenated.

`RETURN NEXT` and `RETURN QUERY` do not actually return from the function — they simply append zero or more rows to the function's result set. Execution then continues with the next statement in the PL/pgSQL function. As successive `RETURN NEXT` or `RETURN QUERY` commands are executed, the result set is built up. A final `RETURN`, which should have no argument, causes control to exit the function (or you can just let control reach the end of the function).

`RETURN QUERY` has a variant `RETURN QUERY EXECUTE`, which specifies the query to be executed dynamically. Parameter expressions can be inserted into the computed query string via `USING`, in just the same way as in the `EXECUTE` command.

If you declared the function with output parameters, write just `RETURN NEXT` with no expression. On each execution, the current values of the output parameter variable(s) will be saved for eventual return as a row of the result. Note that you must declare the function as returning `SETOF record` when there are multiple output parameters, or `SETOF sometype` when there is just one output parameter of type *sometype*, in order to create a set-returning function with output parameters.

Here is an example of a function using `RETURN NEXT`:

```
CREATE TABLE foo (fooid INT, foosubid INT, fooname TEXT);
INSERT INTO foo VALUES (1, 2, 'three');
INSERT INTO foo VALUES (4, 5, 'six');

CREATE OR REPLACE FUNCTION get_all_foo() RETURNS SETOF foo AS
$BODY$
DECLARE
    r foo%rowtype;
BEGIN
    FOR r IN
        SELECT * FROM foo WHERE fooid > 0
    LOOP
        -- can do some processing here
        RETURN NEXT r; -- return current row of SELECT
    END LOOP;
    RETURN;
END;
$BODY$
LANGUAGE plpgsql;

SELECT * FROM get_all_foo();
```

Here is an example of a function using `RETURN QUERY`:

```
CREATE FUNCTION get_available_flightid(date) RETURNS SETOF integer AS
$BODY$
BEGIN
    RETURN QUERY SELECT flightid
                   FROM flight
                  WHERE flightdate >= $1
                    AND flightdate < ($1 + 1);
```

```
    -- Since execution is not finished, we can check whether rows were returned
    -- and raise exception if not.
    IF NOT FOUND THEN
        RAISE EXCEPTION 'No flight at %.', $1;
    END IF;

    RETURN;
 END;
$BODY$
LANGUAGE plpgsql;

-- Returns available flights or raises exception if there are no
-- available flights.
SELECT * FROM get_available_flightid(CURRENT_DATE);
```

> **Note**
>
> The current implementation of `RETURN NEXT` and `RETURN QUERY` stores the entire result set before returning from the function, as discussed above. That means that if a PL/pgSQL function produces a very large result set, performance might be poor: data will be written to disk to avoid memory exhaustion, but the function itself will not return until the entire result set has been generated. A future version of PL/pgSQL might allow users to define set-returning functions that do not have this limitation. Currently, the point at which data begins being written to disk is controlled by the work_mem configuration variable. Administrators who have sufficient memory to store larger result sets in memory should consider increasing this parameter.

45.6.2. Returning from a Procedure

A procedure does not have a return value. A procedure can therefore end without a `RETURN` statement. If you wish to use a `RETURN` statement to exit the code early, write just `RETURN` with no expression.

If the procedure has output parameters, the final values of the output parameter variables will be returned to the caller.

45.6.3. Calling a Procedure

A PL/pgSQL function, procedure, or `DO` block can call a procedure using `CALL`. Output parameters are handled differently from the way that `CALL` works in plain SQL. Each `OUT` or `INOUT` parameter of the procedure must correspond to a variable in the `CALL` statement, and whatever the procedure returns is assigned back to that variable after it returns. For example:

```
CREATE PROCEDURE triple(INOUT x int)
LANGUAGE plpgsql
AS $$
BEGIN
    x := x * 3;
END;
$$;

DO $$
DECLARE myvar int := 5;
BEGIN
  CALL triple(myvar);
  RAISE NOTICE 'myvar = %', myvar;  -- prints 15
END;
$$;
```

The variable corresponding to an output parameter can be a simple variable or a field of a composite-type variable. Currently, it cannot be an element of an array.

45.6.4. Conditionals

`IF` and `CASE` statements let you execute alternative commands based on certain conditions. PL/pgSQL has three forms of `IF`:

- `IF ... THEN ... END IF`
- `IF ... THEN ... ELSE ... END IF`
- `IF ... THEN ... ELSIF ... THEN ... ELSE ... END IF`

and two forms of `CASE`:

- `CASE ... WHEN ... THEN ... ELSE ... END CASE`
- `CASE WHEN ... THEN ... ELSE ... END CASE`

45.6.4.1. IF-THEN

```
IF boolean-expression THEN
    statements
END IF;
```

`IF-THEN` statements are the simplest form of `IF`. The statements between `THEN` and `END IF` will be executed if the condition is true. Otherwise, they are skipped.

Example:

```
IF v_user_id <> 0 THEN
    UPDATE users SET email = v_email WHERE user_id = v_user_id;
END IF;
```

45.6.4.2. IF-THEN-ELSE

```
IF boolean-expression THEN
    statements
ELSE
    statements
END IF;
```

`IF-THEN-ELSE` statements add to `IF-THEN` by letting you specify an alternative set of statements that should be executed if the condition is not true. (Note this includes the case where the condition evaluates to NULL.)

Examples:

```
IF parentid IS NULL OR parentid = ''
THEN
    RETURN fullname;
ELSE
    RETURN hp_true_filename(parentid) || '/' || fullname;
END IF;
```

```
IF v_count > 0 THEN
    INSERT INTO users_count (count) VALUES (v_count);
    RETURN 't';
ELSE
    RETURN 'f';
END IF;
```

45.6.4.3. IF-THEN-ELSIF

```
IF boolean-expression THEN
```

```
    statements
[ ELSIF boolean-expression THEN
    statements
[ ELSIF boolean-expression THEN
    statements
    ...
]
]
[ ELSE
    statements ]
END IF;
```

Sometimes there are more than just two alternatives. `IF-THEN-ELSIF` provides a convenient method of checking several alternatives in turn. The `IF` conditions are tested successively until the first one that is true is found. Then the associated statement(s) are executed, after which control passes to the next statement after `END IF`. (Any subsequent `IF` conditions are *not* tested.) If none of the `IF` conditions is true, then the `ELSE` block (if any) is executed.

Here is an example:

```
IF number = 0 THEN
    result := 'zero';
ELSIF number > 0 THEN
    result := 'positive';
ELSIF number < 0 THEN
    result := 'negative';
ELSE
    -- hmm, the only other possibility is that number is null
    result := 'NULL';
END IF;
```

The key word `ELSIF` can also be spelled `ELSEIF`.

An alternative way of accomplishing the same task is to nest `IF-THEN-ELSE` statements, as in the following example:

```
IF demo_row.sex = 'm' THEN
    pretty_sex := 'man';
ELSE
    IF demo_row.sex = 'f' THEN
        pretty_sex := 'woman';
    END IF;
END IF;
```

However, this method requires writing a matching `END IF` for each `IF`, so it is much more cumbersome than using `ELSIF` when there are many alternatives.

45.6.4.4. Simple `CASE`

```
CASE search-expression
    WHEN expression [, expression [ ... ]] THEN
      statements
  [ WHEN expression [, expression [ ... ]] THEN
      statements
    ... ]
  [ ELSE
      statements ]
END CASE;
```

The simple form of `CASE` provides conditional execution based on equality of operands. The *search-expression* is evaluated (once) and successively compared to each *expression* in the `WHEN` clauses. If

a match is found, then the corresponding *statements* are executed, and then control passes to the next statement after END CASE. (Subsequent WHEN expressions are not evaluated.) If no match is found, the ELSE *statements* are executed; but if ELSE is not present, then a CASE_NOT_FOUND exception is raised.

Here is a simple example:

```
CASE x
    WHEN 1, 2 THEN
        msg := 'one or two';
    ELSE
        msg := 'other value than one or two';
END CASE;
```

45.6.4.5. Searched CASE

```
CASE
    WHEN boolean-expression THEN
      statements
  [ WHEN boolean-expression THEN
      statements
    ... ]
  [ ELSE
      statements ]
END CASE;
```

The searched form of CASE provides conditional execution based on truth of Boolean expressions. Each WHEN clause's *boolean-expression* is evaluated in turn, until one is found that yields true. Then the corresponding *statements* are executed, and then control passes to the next statement after END CASE. (Subsequent WHEN expressions are not evaluated.) If no true result is found, the ELSE *statements* are executed; but if ELSE is not present, then a CASE_NOT_FOUND exception is raised.

Here is an example:

```
CASE
    WHEN x BETWEEN 0 AND 10 THEN
        msg := 'value is between zero and ten';
    WHEN x BETWEEN 11 AND 20 THEN
        msg := 'value is between eleven and twenty';
END CASE;
```

This form of CASE is entirely equivalent to IF-THEN-ELSIF, except for the rule that reaching an omitted ELSE clause results in an error rather than doing nothing.

45.6.5. Simple Loops

With the LOOP, EXIT, CONTINUE, WHILE, FOR, and FOREACH statements, you can arrange for your PL/pgSQL function to repeat a series of commands.

45.6.5.1. LOOP

```
[ <<label>> ]
LOOP
    statements
END LOOP [ label ];
```

LOOP defines an unconditional loop that is repeated indefinitely until terminated by an EXIT or RETURN statement. The optional *label* can be used by EXIT and CONTINUE statements within nested loops to specify which loop those statements refer to.

45.6.5.2. EXIT

```
EXIT [ label ] [ WHEN boolean-expression ];
```

If no *label* is given, the innermost loop is terminated and the statement following `END LOOP` is executed next. If *label* is given, it must be the label of the current or some outer level of nested loop or block. Then the named loop or block is terminated and control continues with the statement after the loop's/block's corresponding `END`.

If `WHEN` is specified, the loop exit occurs only if *boolean-expression* is true. Otherwise, control passes to the statement after `EXIT`.

`EXIT` can be used with all types of loops; it is not limited to use with unconditional loops.

When used with a `BEGIN` block, `EXIT` passes control to the next statement after the end of the block. Note that a label must be used for this purpose; an unlabeled `EXIT` is never considered to match a `BEGIN` block. (This is a change from pre-8.4 releases of PostgreSQL, which would allow an unlabeled `EXIT` to match a `BEGIN` block.)

Examples:

```
LOOP
    -- some computations
    IF count > 0 THEN
        EXIT;  -- exit loop
    END IF;
END LOOP;

LOOP
    -- some computations
    EXIT WHEN count > 0;  -- same result as previous example
END LOOP;

<<ablock>>
BEGIN
    -- some computations
    IF stocks > 100000 THEN
        EXIT ablock;  -- causes exit from the BEGIN block
    END IF;
    -- computations here will be skipped when stocks > 100000
END;
```

45.6.5.3. CONTINUE

```
CONTINUE [ label ] [ WHEN boolean-expression ];
```

If no *label* is given, the next iteration of the innermost loop is begun. That is, all statements remaining in the loop body are skipped, and control returns to the loop control expression (if any) to determine whether another loop iteration is needed. If *label* is present, it specifies the label of the loop whose execution will be continued.

If `WHEN` is specified, the next iteration of the loop is begun only if *boolean-expression* is true. Otherwise, control passes to the statement after `CONTINUE`.

`CONTINUE` can be used with all types of loops; it is not limited to use with unconditional loops.

Examples:

```
LOOP
    -- some computations
    EXIT WHEN count > 100;
    CONTINUE WHEN count < 50;
```

```
    -- some computations for count IN [50 .. 100]
END LOOP;
```

45.6.5.4. WHILE

```
[ <<label>> ]
WHILE boolean-expression LOOP
    statements
END LOOP [ label ];
```

The WHILE statement repeats a sequence of statements so long as the *boolean-expression* evaluates to true. The expression is checked just before each entry to the loop body.

For example:

```
WHILE amount_owed > 0 AND gift_certificate_balance > 0 LOOP
    -- some computations here
END LOOP;

WHILE NOT done LOOP
    -- some computations here
END LOOP;
```

45.6.5.5. FOR (Integer Variant)

```
[ <<label>> ]
FOR name IN [ REVERSE ] expression .. expression [ BY expression ] LOOP
    statements
END LOOP [ label ];
```

This form of FOR creates a loop that iterates over a range of integer values. The variable *name* is automatically defined as type integer and exists only inside the loop (any existing definition of the variable name is ignored within the loop). The two expressions giving the lower and upper bound of the range are evaluated once when entering the loop. If the BY clause isn't specified the iteration step is 1, otherwise it's the value specified in the BY clause, which again is evaluated once on loop entry. If REVERSE is specified then the step value is subtracted, rather than added, after each iteration.

Some examples of integer FOR loops:

```
FOR i IN 1..10 LOOP
    -- i will take on the values 1,2,3,4,5,6,7,8,9,10 within the loop
END LOOP;

FOR i IN REVERSE 10..1 LOOP
    -- i will take on the values 10,9,8,7,6,5,4,3,2,1 within the loop
END LOOP;

FOR i IN REVERSE 10..1 BY 2 LOOP
    -- i will take on the values 10,8,6,4,2 within the loop
END LOOP;
```

If the lower bound is greater than the upper bound (or less than, in the REVERSE case), the loop body is not executed at all. No error is raised.

If a *label* is attached to the FOR loop then the integer loop variable can be referenced with a qualified name, using that *label*.

45.6.6. Looping through Query Results

Using a different type of FOR loop, you can iterate through the results of a query and manipulate that data accordingly. The syntax is:

```
[ <<label>> ]
FOR target IN query LOOP
    statements
END LOOP [ label ];
```

The *target* is a record variable, row variable, or comma-separated list of scalar variables. The *target* is successively assigned each row resulting from the *query* and the loop body is executed for each row. Here is an example:

```
CREATE FUNCTION refresh_mviews() RETURNS integer AS $$
DECLARE
    mviews RECORD;
BEGIN
    RAISE NOTICE 'Refreshing all materialized views...';

    FOR mviews IN
       SELECT n.nspname AS mv_schema,
              c.relname AS mv_name,
              pg_catalog.pg_get_userbyid(c.relowner) AS owner
         FROM pg_catalog.pg_class c
    LEFT JOIN pg_catalog.pg_namespace n ON (n.oid = c.relnamespace)
        WHERE c.relkind = 'm'
     ORDER BY 1
    LOOP

        -- Now "mviews" has one record with information about the materialized view

        RAISE NOTICE 'Refreshing materialized view %.% (owner: %)...',
                     quote_ident(mviews.mv_schema),
                     quote_ident(mviews.mv_name),
                     quote_ident(mviews.owner);
        EXECUTE format('REFRESH MATERIALIZED VIEW %I.%I', mviews.mv_schema,
 mviews.mv_name);
    END LOOP;

    RAISE NOTICE 'Done refreshing materialized views.';
    RETURN 1;
END;
$$ LANGUAGE plpgsql;
```

If the loop is terminated by an `EXIT` statement, the last assigned row value is still accessible after the loop.

The *query* used in this type of `FOR` statement can be any SQL command that returns rows to the caller: `SELECT` is the most common case, but you can also use `INSERT`, `UPDATE`, or `DELETE` with a `RETURNING` clause. Some utility commands such as `EXPLAIN` will work too.

PL/pgSQL variables are replaced by query parameters, and the query plan is cached for possible re-use, as discussed in detail in Section 45.11.1 and Section 45.11.2.

The `FOR-IN-EXECUTE` statement is another way to iterate over rows:

```
[ <<label>> ]
FOR target IN EXECUTE text_expression [ USING expression [, ... ] ] LOOP
    statements
END LOOP [ label ];
```

This is like the previous form, except that the source query is specified as a string expression, which is evaluated and replanned on each entry to the `FOR` loop. This allows the programmer to choose the speed of a preplanned query or the flexibility of a dynamic query, just as with a plain `EXECUTE` statement. As with `EXECUTE`, parameter values can be inserted into the dynamic command via `USING`.

Another way to specify the query whose results should be iterated through is to declare it as a cursor. This is described in Section 45.7.4.

45.6.7. Looping through Arrays

The FOREACH loop is much like a FOR loop, but instead of iterating through the rows returned by an SQL query, it iterates through the elements of an array value. (In general, FOREACH is meant for looping through components of a composite-valued expression; variants for looping through composites besides arrays may be added in future.) The FOREACH statement to loop over an array is:

```
[ <<label>> ]
FOREACH target [ SLICE number ] IN ARRAY expression LOOP
    statements
END LOOP [ label ];
```

Without SLICE, or if SLICE 0 is specified, the loop iterates through individual elements of the array produced by evaluating the *expression*. The *target* variable is assigned each element value in sequence, and the loop body is executed for each element. Here is an example of looping through the elements of an integer array:

```
CREATE FUNCTION sum(int[]) RETURNS int8 AS $$
DECLARE
  s int8 := 0;
  x int;
BEGIN
  FOREACH x IN ARRAY $1
  LOOP
    s := s + x;
  END LOOP;
  RETURN s;
END;
$$ LANGUAGE plpgsql;
```

The elements are visited in storage order, regardless of the number of array dimensions. Although the *target* is usually just a single variable, it can be a list of variables when looping through an array of composite values (records). In that case, for each array element, the variables are assigned from successive columns of the composite value.

With a positive SLICE value, FOREACH iterates through slices of the array rather than single elements. The SLICE value must be an integer constant not larger than the number of dimensions of the array. The *target* variable must be an array, and it receives successive slices of the array value, where each slice is of the number of dimensions specified by SLICE. Here is an example of iterating through one-dimensional slices:

```
CREATE FUNCTION scan_rows(int[]) RETURNS void AS $$
DECLARE
  x int[];
BEGIN
  FOREACH x SLICE 1 IN ARRAY $1
  LOOP
    RAISE NOTICE 'row = %', x;
  END LOOP;
END;
$$ LANGUAGE plpgsql;

SELECT scan_rows(ARRAY[[1,2,3],[4,5,6],[7,8,9],[10,11,12]]);

NOTICE:  row = {1,2,3}
NOTICE:  row = {4,5,6}
NOTICE:  row = {7,8,9}
```

```
NOTICE:  row = {10,11,12}
```

45.6.8. Trapping Errors

By default, any error occurring in a PL/pgSQL function aborts execution of the function and the surrounding transaction. You can trap errors and recover from them by using a BEGIN block with an EXCEPTION clause. The syntax is an extension of the normal syntax for a BEGIN block:

```
[ <<label>> ]
[ DECLARE
    declarations ]
BEGIN
    statements
EXCEPTION
    WHEN condition [ OR condition ... ] THEN
        handler_statements
    [ WHEN condition [ OR condition ... ] THEN
          handler_statements
      ... ]
END;
```

If no error occurs, this form of block simply executes all the *statements*, and then control passes to the next statement after END. But if an error occurs within the *statements*, further processing of the *statements* is abandoned, and control passes to the EXCEPTION list. The list is searched for the first *condition* matching the error that occurred. If a match is found, the corresponding *handler_statements* are executed, and then control passes to the next statement after END. If no match is found, the error propagates out as though the EXCEPTION clause were not there at all: the error can be caught by an enclosing block with EXCEPTION, or if there is none it aborts processing of the function.

The *condition* names can be any of those shown in Appendix A. A category name matches any error within its category. The special condition name OTHERS matches every error type except QUERY_CANCELED and ASSERT_FAILURE. (It is possible, but often unwise, to trap those two error types by name.) Condition names are not case-sensitive. Also, an error condition can be specified by SQLSTATE code; for example these are equivalent:

```
WHEN division_by_zero THEN ...
WHEN SQLSTATE '22012' THEN ...
```

If a new error occurs within the selected *handler_statements*, it cannot be caught by this EXCEPTION clause, but is propagated out. A surrounding EXCEPTION clause could catch it.

When an error is caught by an EXCEPTION clause, the local variables of the PL/pgSQL function remain as they were when the error occurred, but all changes to persistent database state within the block are rolled back. As an example, consider this fragment:

```
INSERT INTO mytab(firstname, lastname) VALUES('Tom', 'Jones');
BEGIN
    UPDATE mytab SET firstname = 'Joe' WHERE lastname = 'Jones';
    x := x + 1;
    y := x / 0;
EXCEPTION
    WHEN division_by_zero THEN
        RAISE NOTICE 'caught division_by_zero';
        RETURN x;
END;
```

When control reaches the assignment to y, it will fail with a division_by_zero error. This will be caught by the EXCEPTION clause. The value returned in the RETURN statement will be the incremented value of x, but the effects of the UPDATE command will have been rolled back. The INSERT command preceding the block is not rolled back, however, so the end result is that the database contains Tom Jones not Joe Jones.

> **Tip**
>
> A block containing an `EXCEPTION` clause is significantly more expensive to enter and exit than a block without one. Therefore, don't use `EXCEPTION` without need.

Example 45.2. Exceptions with `UPDATE/INSERT`

This example uses exception handling to perform either `UPDATE` or `INSERT`, as appropriate. It is recommended that applications use `INSERT` with `ON CONFLICT DO UPDATE` rather than actually using this pattern. This example serves primarily to illustrate use of PL/pgSQL control flow structures:

```
CREATE TABLE db (a INT PRIMARY KEY, b TEXT);

CREATE FUNCTION merge_db(key INT, data TEXT) RETURNS VOID AS
$$
BEGIN
    LOOP
        -- first try to update the key
        UPDATE db SET b = data WHERE a = key;
        IF found THEN
            RETURN;
        END IF;
        -- not there, so try to insert the key
        -- if someone else inserts the same key concurrently,
        -- we could get a unique-key failure
        BEGIN
            INSERT INTO db(a,b) VALUES (key, data);
            RETURN;
        EXCEPTION WHEN unique_violation THEN
            -- Do nothing, and loop to try the UPDATE again.
        END;
    END LOOP;
END;
$$
LANGUAGE plpgsql;

SELECT merge_db(1, 'david');
SELECT merge_db(1, 'dennis');
```

This coding assumes the `unique_violation` error is caused by the `INSERT`, and not by, say, an `INSERT` in a trigger function on the table. It might also misbehave if there is more than one unique index on the table, since it will retry the operation regardless of which index caused the error. More safety could be had by using the features discussed next to check that the trapped error was the one expected.

45.6.8.1. Obtaining Information about an Error

Exception handlers frequently need to identify the specific error that occurred. There are two ways to get information about the current exception in PL/pgSQL: special variables and the `GET STACKED DIAGNOSTICS` command.

Within an exception handler, the special variable `SQLSTATE` contains the error code that corresponds to the exception that was raised (refer to Table A.1 for a list of possible error codes). The special variable `SQLERRM` contains the error message associated with the exception. These variables are undefined outside exception handlers.

Within an exception handler, one may also retrieve information about the current exception by using the `GET STACKED DIAGNOSTICS` command, which has the form:

```
GET STACKED DIAGNOSTICS variable { = | := } item [ , ... ];
```

Each *item* is a key word identifying a status value to be assigned to the specified *variable* (which should be of the right data type to receive it). The currently available status items are shown in Table 45.2.

Table 45.2. Error Diagnostics Items

Name	Type	Description
RETURNED_SQLSTATE	text	the SQLSTATE error code of the exception
COLUMN_NAME	text	the name of the column related to exception
CONSTRAINT_NAME	text	the name of the constraint related to exception
PG_DATATYPE_NAME	text	the name of the data type related to exception
MESSAGE_TEXT	text	the text of the exception's primary message
TABLE_NAME	text	the name of the table related to exception
SCHEMA_NAME	text	the name of the schema related to exception
PG_EXCEPTION_DETAIL	text	the text of the exception's detail message, if any
PG_EXCEPTION_HINT	text	the text of the exception's hint message, if any
PG_EXCEPTION_CONTEXT	text	line(s) of text describing the call stack at the time of the exception (see Section 45.6.9)

If the exception did not set a value for an item, an empty string will be returned.

Here is an example:

```
DECLARE
  text_var1 text;
  text_var2 text;
  text_var3 text;
BEGIN
  -- some processing which might cause an exception
  ...
EXCEPTION WHEN OTHERS THEN
  GET STACKED DIAGNOSTICS text_var1 = MESSAGE_TEXT,
                          text_var2 = PG_EXCEPTION_DETAIL,
                          text_var3 = PG_EXCEPTION_HINT;
END;
```

45.6.9. Obtaining Execution Location Information

The `GET DIAGNOSTICS` command, previously described in Section 45.5.5, retrieves information about current execution state (whereas the `GET STACKED DIAGNOSTICS` command discussed above reports information about the execution state as of a previous error). Its `PG_CONTEXT` status item is useful for identifying the current execution location. `PG_CONTEXT` returns a text string with line(s) of text describing the call stack. The first line refers to the current function and currently executing `GET DIAGNOSTICS` command. The second and any subsequent lines refer to calling functions further up the call stack. For example:

```
CREATE OR REPLACE FUNCTION outer_func() RETURNS integer AS $$
BEGIN
  RETURN inner_func();
END;
$$ LANGUAGE plpgsql;

CREATE OR REPLACE FUNCTION inner_func() RETURNS integer AS $$
DECLARE
  stack text;
BEGIN
  GET DIAGNOSTICS stack = PG_CONTEXT;
  RAISE NOTICE E'--- Call Stack ---\n%', stack;
  RETURN 1;
END;
$$ LANGUAGE plpgsql;

SELECT outer_func();

NOTICE:  --- Call Stack ---
PL/pgSQL function inner_func() line 5 at GET DIAGNOSTICS
PL/pgSQL function outer_func() line 3 at RETURN
CONTEXT:  PL/pgSQL function outer_func() line 3 at RETURN
 outer_func
 ------------
           1
(1 row)
```

`GET STACKED DIAGNOSTICS ... PG_EXCEPTION_CONTEXT` returns the same sort of stack trace, but describing the location at which an error was detected, rather than the current location.

45.7. Cursors

Rather than executing a whole query at once, it is possible to set up a *cursor* that encapsulates the query, and then read the query result a few rows at a time. One reason for doing this is to avoid memory overrun when the result contains a large number of rows. (However, PL/pgSQL users do not normally need to worry about that, since `FOR` loops automatically use a cursor internally to avoid memory problems.) A more interesting usage is to return a reference to a cursor that a function has created, allowing the caller to read the rows. This provides an efficient way to return large row sets from functions.

45.7.1. Declaring Cursor Variables

All access to cursors in PL/pgSQL goes through cursor variables, which are always of the special data type `refcursor`. One way to create a cursor variable is just to declare it as a variable of type `refcursor`. Another way is to use the cursor declaration syntax, which in general is:

name [[NO] SCROLL] CURSOR [(*arguments*)] FOR *query*;

(`FOR` can be replaced by `IS` for Oracle compatibility.) If `SCROLL` is specified, the cursor will be capable of scrolling backward; if `NO SCROLL` is specified, backward fetches will be rejected; if neither specification appears, it is query-dependent whether backward fetches will be allowed. *arguments*, if specified, is a comma-separated list of pairs *name datatype* that define names to be replaced by parameter values in the given query. The actual values to substitute for these names will be specified later, when the cursor is opened.

Some examples:

```
DECLARE
    curs1 refcursor;
    curs2 CURSOR FOR SELECT * FROM tenk1;
```

```
    curs3 CURSOR (key integer) FOR SELECT * FROM tenk1 WHERE unique1 = key;
```

All three of these variables have the data type `refcursor`, but the first can be used with any query, while the second has a fully specified query already *bound* to it, and the last has a parameterized query bound to it. (`key` will be replaced by an integer parameter value when the cursor is opened.) The variable `curs1` is said to be *unbound* since it is not bound to any particular query.

The `SCROLL` option cannot be used when the cursor's query uses `FOR UPDATE/SHARE`. Also, it is best to use `NO SCROLL` with a query that involves volatile functions. The implementation of `SCROLL` assumes that re-reading the query's output will give consistent results, which a volatile function might not do.

45.7.2. Opening Cursors

Before a cursor can be used to retrieve rows, it must be *opened*. (This is the equivalent action to the SQL command `DECLARE CURSOR`.) PL/pgSQL has three forms of the `OPEN` statement, two of which use unbound cursor variables while the third uses a bound cursor variable.

> **Note**
>
> Bound cursor variables can also be used without explicitly opening the cursor, via the `FOR` statement described in Section 45.7.4.

45.7.2.1. `OPEN FOR` *query*

```
OPEN unbound_cursorvar [ [ NO ] SCROLL ] FOR query;
```

The cursor variable is opened and given the specified query to execute. The cursor cannot be open already, and it must have been declared as an unbound cursor variable (that is, as a simple `refcursor` variable). The query must be a `SELECT`, or something else that returns rows (such as `EXPLAIN`). The query is treated in the same way as other SQL commands in PL/pgSQL: PL/pgSQL variable names are substituted, and the query plan is cached for possible reuse. When a PL/pgSQL variable is substituted into the cursor query, the value that is substituted is the one it has at the time of the `OPEN`; subsequent changes to the variable will not affect the cursor's behavior. The `SCROLL` and `NO SCROLL` options have the same meanings as for a bound cursor.

An example:

```
OPEN curs1 FOR SELECT * FROM foo WHERE key = mykey;
```

45.7.2.2. `OPEN FOR EXECUTE`

```
OPEN unbound_cursorvar [ [ NO ] SCROLL ] FOR EXECUTE query_string
                                        [ USING expression [, ... ] ];
```

The cursor variable is opened and given the specified query to execute. The cursor cannot be open already, and it must have been declared as an unbound cursor variable (that is, as a simple `refcursor` variable). The query is specified as a string expression, in the same way as in the `EXECUTE` command. As usual, this gives flexibility so the query plan can vary from one run to the next (see Section 45.11.2), and it also means that variable substitution is not done on the command string. As with `EXECUTE`, parameter values can be inserted into the dynamic command via `format()` and `USING`. The `SCROLL` and `NO SCROLL` options have the same meanings as for a bound cursor.

An example:

```
OPEN curs1 FOR EXECUTE format('SELECT * FROM %I WHERE col1 = $1',tabname) USING
 keyvalue;
```

In this example, the table name is inserted into the query via `format()`. The comparison value for `col1` is inserted via a `USING` parameter, so it needs no quoting.

45.7.2.3. Opening a Bound Cursor

```
OPEN bound_cursorvar [ ( [ argument_name := ] argument_value [, ...] ) ];
```

This form of OPEN is used to open a cursor variable whose query was bound to it when it was declared. The cursor cannot be open already. A list of actual argument value expressions must appear if and only if the cursor was declared to take arguments. These values will be substituted in the query.

The query plan for a bound cursor is always considered cacheable; there is no equivalent of EXECUTE in this case. Notice that SCROLL and NO SCROLL cannot be specified in OPEN, as the cursor's scrolling behavior was already determined.

Argument values can be passed using either *positional* or *named* notation. In positional notation, all arguments are specified in order. In named notation, each argument's name is specified using := to separate it from the argument expression. Similar to calling functions, described in Section 4.3, it is also allowed to mix positional and named notation.

Examples (these use the cursor declaration examples above):

```
OPEN curs2;
OPEN curs3(42);
OPEN curs3(key := 42);
```

Because variable substitution is done on a bound cursor's query, there are really two ways to pass values into the cursor: either with an explicit argument to OPEN, or implicitly by referencing a PL/pgSQL variable in the query. However, only variables declared before the bound cursor was declared will be substituted into it. In either case the value to be passed is determined at the time of the OPEN. For example, another way to get the same effect as the curs3 example above is

```
DECLARE
    key integer;
    curs4 CURSOR FOR SELECT * FROM tenk1 WHERE unique1 = key;
BEGIN
    key := 42;
    OPEN curs4;
```

45.7.3. Using Cursors

Once a cursor has been opened, it can be manipulated with the statements described here.

These manipulations need not occur in the same function that opened the cursor to begin with. You can return a refcursor value out of a function and let the caller operate on the cursor. (Internally, a refcursor value is simply the string name of a so-called portal containing the active query for the cursor. This name can be passed around, assigned to other refcursor variables, and so on, without disturbing the portal.)

All portals are implicitly closed at transaction end. Therefore a refcursor value is usable to reference an open cursor only until the end of the transaction.

45.7.3.1. FETCH

```
FETCH [ direction { FROM | IN } ] cursor INTO target;
```

FETCH retrieves the next row (in the indicated direction) from the cursor into a target, which might be a row variable, a record variable, or a comma-separated list of simple variables, just like SELECT INTO. If there is no suitable row, the target is set to NULL(s). As with SELECT INTO, the special variable FOUND can be checked to see whether a row was obtained or not. If no row is obtained, the cursor is positioned after the last row or before the first row, depending on the movement direction.

The *direction* clause can be any of the variants allowed in the SQL FETCH command except the ones that can fetch more than one row; namely, it can be NEXT, PRIOR, FIRST, LAST, ABSOLUTE *count*, RELATIVE

count, FORWARD, or BACKWARD. Omitting *direction* is the same as specifying NEXT. In the forms using a *count*, the *count* can be any integer-valued expression (unlike the SQL FETCH command, which only allows an integer constant). *direction* values that require moving backward are likely to fail unless the cursor was declared or opened with the SCROLL option.

cursor must be the name of a refcursor variable that references an open cursor portal.

Examples:

```
FETCH curs1 INTO rowvar;
FETCH curs2 INTO foo, bar, baz;
FETCH LAST FROM curs3 INTO x, y;
FETCH RELATIVE -2 FROM curs4 INTO x;
```

45.7.3.2. MOVE

```
MOVE [ direction { FROM | IN } ] cursor;
```

MOVE repositions a cursor without retrieving any data. MOVE works like the FETCH command, except it only repositions the cursor and does not return the row moved to. The *direction* clause can be any of the variants allowed in the SQL FETCH command, including those that can fetch more than one row; the cursor is positioned to the last such row. (However, the case in which the *direction* clause is simply a *count* expression with no key word is deprecated in PL/pgSQL. That syntax is ambiguous with the case where the *direction* clause is omitted altogether, and hence it may fail if the *count* is not a constant.) As with SELECT INTO, the special variable FOUND can be checked to see whether there was a row to move to. If there is no such row, the cursor is positioned after the last row or before the first row, depending on the movement direction.

Examples:

```
MOVE curs1;
MOVE LAST FROM curs3;
MOVE RELATIVE -2 FROM curs4;
MOVE FORWARD 2 FROM curs4;
```

45.7.3.3. UPDATE/DELETE WHERE CURRENT OF

```
UPDATE table SET ... WHERE CURRENT OF cursor;
DELETE FROM table WHERE CURRENT OF cursor;
```

When a cursor is positioned on a table row, that row can be updated or deleted using the cursor to identify the row. There are restrictions on what the cursor's query can be (in particular, no grouping) and it's best to use FOR UPDATE in the cursor. For more information see the DECLARE reference page.

An example:

```
UPDATE foo SET dataval = myval WHERE CURRENT OF curs1;
```

45.7.3.4. CLOSE

```
CLOSE cursor;
```

CLOSE closes the portal underlying an open cursor. This can be used to release resources earlier than end of transaction, or to free up the cursor variable to be opened again.

An example:

```
CLOSE curs1;
```

45.7.3.5. Returning Cursors

PL/pgSQL functions can return cursors to the caller. This is useful to return multiple rows or columns, especially with very large result sets. To do this, the function opens the cursor and returns the cursor

name to the caller (or simply opens the cursor using a portal name specified by or otherwise known to the caller). The caller can then fetch rows from the cursor. The cursor can be closed by the caller, or it will be closed automatically when the transaction closes.

The portal name used for a cursor can be specified by the programmer or automatically generated. To specify a portal name, simply assign a string to the `refcursor` variable before opening it. The string value of the `refcursor` variable will be used by `OPEN` as the name of the underlying portal. However, if the `refcursor` variable is null, `OPEN` automatically generates a name that does not conflict with any existing portal, and assigns it to the `refcursor` variable.

> **Note**
>
> A bound cursor variable is initialized to the string value representing its name, so that the portal name is the same as the cursor variable name, unless the programmer overrides it by assignment before opening the cursor. But an unbound cursor variable defaults to the null value initially, so it will receive an automatically-generated unique name, unless overridden.

The following example shows one way a cursor name can be supplied by the caller:

```
CREATE TABLE test (col text);
INSERT INTO test VALUES ('123');

CREATE FUNCTION reffunc(refcursor) RETURNS refcursor AS '
BEGIN
    OPEN $1 FOR SELECT col FROM test;
    RETURN $1;
END;
' LANGUAGE plpgsql;

BEGIN;
SELECT reffunc('funccursor');
FETCH ALL IN funccursor;
COMMIT;
```

The following example uses automatic cursor name generation:

```
CREATE FUNCTION reffunc2() RETURNS refcursor AS '
DECLARE
    ref refcursor;
BEGIN
    OPEN ref FOR SELECT col FROM test;
    RETURN ref;
END;
' LANGUAGE plpgsql;

-- need to be in a transaction to use cursors.
BEGIN;
SELECT reffunc2();

      reffunc2
--------------------
 <unnamed cursor 1>
(1 row)

FETCH ALL IN "<unnamed cursor 1>";
COMMIT;
```

The following example shows one way to return multiple cursors from a single function:

```
CREATE FUNCTION myfunc(refcursor, refcursor) RETURNS SETOF refcursor AS $$
BEGIN
    OPEN $1 FOR SELECT * FROM table_1;
    RETURN NEXT $1;
    OPEN $2 FOR SELECT * FROM table_2;
    RETURN NEXT $2;
END;
$$ LANGUAGE plpgsql;

-- need to be in a transaction to use cursors.
BEGIN;

SELECT * FROM myfunc('a', 'b');

FETCH ALL FROM a;
FETCH ALL FROM b;
COMMIT;
```

45.7.4. Looping through a Cursor's Result

There is a variant of the `FOR` statement that allows iterating through the rows returned by a cursor. The syntax is:

```
[ <<label>> ]
FOR recordvar IN bound_cursorvar [ ( [ argument_name := ] argument_value [, ...] ) ]
 LOOP
    statements
END LOOP [ label ];
```

The cursor variable must have been bound to some query when it was declared, and it *cannot* be open already. The `FOR` statement automatically opens the cursor, and it closes the cursor again when the loop exits. A list of actual argument value expressions must appear if and only if the cursor was declared to take arguments. These values will be substituted in the query, in just the same way as during an `OPEN` (see Section 45.7.2.3).

The variable *recordvar* is automatically defined as type `record` and exists only inside the loop (any existing definition of the variable name is ignored within the loop). Each row returned by the cursor is successively assigned to this record variable and the loop body is executed.

45.8. Transaction Management

In procedures invoked by the `CALL` command as well as in anonymous code blocks (`DO` command), it is possible to end transactions using the commands `COMMIT` and `ROLLBACK`. A new transaction is started automatically after a transaction is ended using these commands, so there is no separate `START TRANSACTION` command. (Note that `BEGIN` and `END` have different meanings in PL/pgSQL.)

Here is a simple example:

```
CREATE PROCEDURE transaction_test1()
LANGUAGE plpgsql
AS $$
BEGIN
    FOR i IN 0..9 LOOP
        INSERT INTO test1 (a) VALUES (i);
        IF i % 2 = 0 THEN
            COMMIT;
        ELSE
            ROLLBACK;
        END IF;
    END LOOP;
```

```
END;
$$;

CALL transaction_test1();
```

A new transaction starts out with default transaction characteristics such as transaction isolation level. In cases where transactions are committed in a loop, it might be desirable to start new transactions automatically with the same characteristics as the previous one. The commands `COMMIT AND CHAIN` and `ROLLBACK AND CHAIN` accomplish this.

Transaction control is only possible in `CALL` or `DO` invocations from the top level or nested `CALL` or `DO` invocations without any other intervening command. For example, if the call stack is `CALL proc1()` → `CALL proc2()` → `CALL proc3()`, then the second and third procedures can perform transaction control actions. But if the call stack is `CALL proc1()` → `SELECT func2()` → `CALL proc3()`, then the last procedure cannot do transaction control, because of the `SELECT` in between.

Special considerations apply to cursor loops. Consider this example:

```
CREATE PROCEDURE transaction_test2()
LANGUAGE plpgsql
AS $$
DECLARE
    r RECORD;
BEGIN
    FOR r IN SELECT * FROM test2 ORDER BY x LOOP
        INSERT INTO test1 (a) VALUES (r.x);
        COMMIT;
    END LOOP;
END;
$$;

CALL transaction_test2();
```

Normally, cursors are automatically closed at transaction commit. However, a cursor created as part of a loop like this is automatically converted to a holdable cursor by the first `COMMIT` or `ROLLBACK`. That means that the cursor is fully evaluated at the first `COMMIT` or `ROLLBACK` rather than row by row. The cursor is still removed automatically after the loop, so this is mostly invisible to the user.

Transaction commands are not allowed in cursor loops driven by commands that are not read-only (for example `UPDATE ... RETURNING`).

A transaction cannot be ended inside a block with exception handlers.

45.9. Errors and Messages

45.9.1. Reporting Errors and Messages

Use the `RAISE` statement to report messages and raise errors.

```
RAISE [ level ] 'format' [, expression [, ... ]] [ USING option = expression
 [, ... ] ];
RAISE [ level ] condition_name [ USING option = expression [, ... ] ];
RAISE [ level ] SQLSTATE 'sqlstate' [ USING option = expression [, ... ] ];
RAISE [ level ] USING option = expression [, ... ];
RAISE ;
```

The *level* option specifies the error severity. Allowed levels are `DEBUG`, `LOG`, `INFO`, `NOTICE`, `WARNING`, and `EXCEPTION`, with `EXCEPTION` being the default. `EXCEPTION` raises an error (which normally aborts the current transaction); the other levels only generate messages of different priority levels. Whether messages of a particular priority are reported to the client, written to the server log, or both is controlled

by the log_min_messages and client_min_messages configuration variables. See Chapter 19 for more information.

After *level* if any, you can specify a *format* string (which must be a simple string literal, not an expression). The format string specifies the error message text to be reported. The format string can be followed by optional argument expressions to be inserted into the message. Inside the format string, % is replaced by the string representation of the next optional argument's value. Write %% to emit a literal %. The number of arguments must match the number of % placeholders in the format string, or an error is raised during the compilation of the function.

In this example, the value of v_job_id will replace the % in the string:

```
RAISE NOTICE 'Calling cs_create_job(%)', v_job_id;
```

You can attach additional information to the error report by writing USING followed by *option* = *expression* items. Each *expression* can be any string-valued expression. The allowed *option* key words are:

MESSAGE

Sets the error message text. This option can't be used in the form of RAISE that includes a format string before USING.

DETAIL

Supplies an error detail message.

HINT

Supplies a hint message.

ERRCODE

Specifies the error code (SQLSTATE) to report, either by condition name, as shown in Appendix A, or directly as a five-character SQLSTATE code.

COLUMN
CONSTRAINT
DATATYPE
TABLE
SCHEMA

Supplies the name of a related object.

This example will abort the transaction with the given error message and hint:

```
RAISE EXCEPTION 'Nonexistent ID --> %', user_id
      USING HINT = 'Please check your user ID';
```

These two examples show equivalent ways of setting the SQLSTATE:

```
RAISE 'Duplicate user ID: %', user_id USING ERRCODE = 'unique_violation';
RAISE 'Duplicate user ID: %', user_id USING ERRCODE = '23505';
```

There is a second RAISE syntax in which the main argument is the condition name or SQLSTATE to be reported, for example:

```
RAISE division_by_zero;
RAISE SQLSTATE '22012';
```

In this syntax, USING can be used to supply a custom error message, detail, or hint. Another way to do the earlier example is

```
RAISE unique_violation USING MESSAGE = 'Duplicate user ID: ' || user_id;
```

Still another variant is to write RAISE USING or RAISE *level* USING and put everything else into the USING list.

The last variant of RAISE has no parameters at all. This form can only be used inside a BEGIN block's EXCEPTION clause; it causes the error currently being handled to be re-thrown.

> **Note**
>
> Before PostgreSQL 9.1, RAISE without parameters was interpreted as re-throwing the error from the block containing the active exception handler. Thus an EXCEPTION clause nested within that handler could not catch it, even if the RAISE was within the nested EXCEPTION clause's block. This was deemed surprising as well as being incompatible with Oracle's PL/SQL.

If no condition name nor SQLSTATE is specified in a RAISE EXCEPTION command, the default is to use raise_exception (P0001). If no message text is specified, the default is to use the condition name or SQLSTATE as message text.

> **Note**
>
> When specifying an error code by SQLSTATE code, you are not limited to the predefined error codes, but can select any error code consisting of five digits and/or upper-case ASCII letters, other than 00000. It is recommended that you avoid throwing error codes that end in three zeroes, because these are category codes and can only be trapped by trapping the whole category.

45.9.2. Checking Assertions

The ASSERT statement is a convenient shorthand for inserting debugging checks into PL/pgSQL functions.

```
ASSERT condition [ , message ];
```

The *condition* is a Boolean expression that is expected to always evaluate to true; if it does, the ASSERT statement does nothing further. If the result is false or null, then an ASSERT_FAILURE exception is raised. (If an error occurs while evaluating the *condition*, it is reported as a normal error.)

If the optional *message* is provided, it is an expression whose result (if not null) replaces the default error message text “assertion failed”, should the *condition* fail. The *message* expression is not evaluated in the normal case where the assertion succeeds.

Testing of assertions can be enabled or disabled via the configuration parameter plpgsql.check_asserts, which takes a Boolean value; the default is on. If this parameter is off then ASSERT statements do nothing.

Note that ASSERT is meant for detecting program bugs, not for reporting ordinary error conditions. Use the RAISE statement, described above, for that.

45.10. Trigger Functions

PL/pgSQL can be used to define trigger functions on data changes or database events. A trigger function is created with the CREATE FUNCTION command, declaring it as a function with no arguments and a return type of trigger (for data change triggers) or event_trigger (for database event triggers). Special local variables named TG_*something* are automatically defined to describe the condition that triggered the call.

45.10.1. Triggers on Data Changes

A data change trigger is declared as a function with no arguments and a return type of trigger. Note that the function must be declared with no arguments even if it expects to receive some arguments specified in CREATE TRIGGER — such arguments are passed via TG_ARGV, as described below.

When a PL/pgSQL function is called as a trigger, several special variables are created automatically in the top-level block. They are:

`NEW`

Data type `RECORD`; variable holding the new database row for `INSERT`/`UPDATE` operations in row-level triggers. This variable is null in statement-level triggers and for `DELETE` operations.

`OLD`

Data type `RECORD`; variable holding the old database row for `UPDATE`/`DELETE` operations in row-level triggers. This variable is null in statement-level triggers and for `INSERT` operations.

`TG_NAME`

Data type `name`; variable that contains the name of the trigger actually fired.

`TG_WHEN`

Data type `text`; a string of `BEFORE`, `AFTER`, or `INSTEAD OF`, depending on the trigger's definition.

`TG_LEVEL`

Data type `text`; a string of either `ROW` or `STATEMENT` depending on the trigger's definition.

`TG_OP`

Data type `text`; a string of `INSERT`, `UPDATE`, `DELETE`, or `TRUNCATE` telling for which operation the trigger was fired.

`TG_RELID`

Data type `oid`; the object ID of the table that caused the trigger invocation.

`TG_RELNAME`

Data type `name`; the name of the table that caused the trigger invocation. This is now deprecated, and could disappear in a future release. Use `TG_TABLE_NAME` instead.

`TG_TABLE_NAME`

Data type `name`; the name of the table that caused the trigger invocation.

`TG_TABLE_SCHEMA`

Data type `name`; the name of the schema of the table that caused the trigger invocation.

`TG_NARGS`

Data type `integer`; the number of arguments given to the trigger function in the `CREATE TRIGGER` statement.

`TG_ARGV[]`

Data type array of `text`; the arguments from the `CREATE TRIGGER` statement. The index counts from 0. Invalid indexes (less than 0 or greater than or equal to `tg_nargs`) result in a null value.

A trigger function must return either `NULL` or a record/row value having exactly the structure of the table the trigger was fired for.

Row-level triggers fired `BEFORE` can return null to signal the trigger manager to skip the rest of the operation for this row (i.e., subsequent triggers are not fired, and the `INSERT`/`UPDATE`/`DELETE` does not occur for this row). If a nonnull value is returned then the operation proceeds with that row value. Returning a row value different from the original value of `NEW` alters the row that will be inserted or

updated. Thus, if the trigger function wants the triggering action to succeed normally without altering the row value, NEW (or a value equal thereto) has to be returned. To alter the row to be stored, it is possible to replace single values directly in NEW and return the modified NEW, or to build a complete new record/row to return. In the case of a before-trigger on DELETE, the returned value has no direct effect, but it has to be nonnull to allow the trigger action to proceed. Note that NEW is null in DELETE triggers, so returning that is usually not sensible. The usual idiom in DELETE triggers is to return OLD.

INSTEAD OF triggers (which are always row-level triggers, and may only be used on views) can return null to signal that they did not perform any updates, and that the rest of the operation for this row should be skipped (i.e., subsequent triggers are not fired, and the row is not counted in the rows-affected status for the surrounding INSERT/UPDATE/DELETE). Otherwise a nonnull value should be returned, to signal that the trigger performed the requested operation. For INSERT and UPDATE operations, the return value should be NEW, which the trigger function may modify to support INSERT RETURNING and UPDATE RETURNING (this will also affect the row value passed to any subsequent triggers, or passed to a special EXCLUDED alias reference within an INSERT statement with an ON CONFLICT DO UPDATE clause). For DELETE operations, the return value should be OLD.

The return value of a row-level trigger fired AFTER or a statement-level trigger fired BEFORE or AFTER is always ignored; it might as well be null. However, any of these types of triggers might still abort the entire operation by raising an error.

Example 45.3 shows an example of a trigger function in PL/pgSQL.

Example 45.3. A PL/pgSQL Trigger Function

This example trigger ensures that any time a row is inserted or updated in the table, the current user name and time are stamped into the row. And it checks that an employee's name is given and that the salary is a positive value.

```
CREATE TABLE emp (
    empname text,
    salary integer,
    last_date timestamp,
    last_user text
);

CREATE FUNCTION emp_stamp() RETURNS trigger AS $emp_stamp$
    BEGIN
        -- Check that empname and salary are given
        IF NEW.empname IS NULL THEN
            RAISE EXCEPTION 'empname cannot be null';
        END IF;
        IF NEW.salary IS NULL THEN
            RAISE EXCEPTION '% cannot have null salary', NEW.empname;
        END IF;

        -- Who works for us when they must pay for it?
        IF NEW.salary < 0 THEN
            RAISE EXCEPTION '% cannot have a negative salary', NEW.empname;
        END IF;

        -- Remember who changed the payroll when
        NEW.last_date := current_timestamp;
        NEW.last_user := current_user;
        RETURN NEW;
    END;
$emp_stamp$ LANGUAGE plpgsql;

CREATE TRIGGER emp_stamp BEFORE INSERT OR UPDATE ON emp
```

```
    FOR EACH ROW EXECUTE FUNCTION emp_stamp();
```

Another way to log changes to a table involves creating a new table that holds a row for each insert, update, or delete that occurs. This approach can be thought of as auditing changes to a table. Example 45.4 shows an example of an audit trigger function in PL/pgSQL.

Example 45.4. A PL/pgSQL Trigger Function for Auditing

This example trigger ensures that any insert, update or delete of a row in the `emp` table is recorded (i.e., audited) in the `emp_audit` table. The current time and user name are stamped into the row, together with the type of operation performed on it.

```
CREATE TABLE emp (
    empname           text NOT NULL,
    salary            integer
);

CREATE TABLE emp_audit(
    operation         char(1)   NOT NULL,
    stamp             timestamp NOT NULL,
    userid            text      NOT NULL,
    empname           text      NOT NULL,
    salary integer
);

CREATE OR REPLACE FUNCTION process_emp_audit() RETURNS TRIGGER AS $emp_audit$
    BEGIN
        --
        -- Create a row in emp_audit to reflect the operation performed on emp,
        -- making use of the special variable TG_OP to work out the operation.
        --
        IF (TG_OP = 'DELETE') THEN
            INSERT INTO emp_audit SELECT 'D', now(), current_user, OLD.*;
        ELSIF (TG_OP = 'UPDATE') THEN
            INSERT INTO emp_audit SELECT 'U', now(), current_user, NEW.*;
        ELSIF (TG_OP = 'INSERT') THEN
            INSERT INTO emp_audit SELECT 'I', now(), current_user, NEW.*;
        END IF;
        RETURN NULL; -- result is ignored since this is an AFTER trigger
    END;
$emp_audit$ LANGUAGE plpgsql;

CREATE TRIGGER emp_audit
AFTER INSERT OR UPDATE OR DELETE ON emp
    FOR EACH ROW EXECUTE FUNCTION process_emp_audit();
```

A variation of the previous example uses a view joining the main table to the audit table, to show when each entry was last modified. This approach still records the full audit trail of changes to the table, but also presents a simplified view of the audit trail, showing just the last modified timestamp derived from the audit trail for each entry. Example 45.5 shows an example of an audit trigger on a view in PL/pgSQL.

Example 45.5. A PL/pgSQL View Trigger Function for Auditing

This example uses a trigger on the view to make it updatable, and ensure that any insert, update or delete of a row in the view is recorded (i.e., audited) in the `emp_audit` table. The current time and user name are recorded, together with the type of operation performed, and the view displays the last modified time of each row.

```
CREATE TABLE emp (
    empname           text PRIMARY KEY,
```

```
    salary            integer
);

CREATE TABLE emp_audit(
    operation         char(1)   NOT NULL,
    userid            text      NOT NULL,
    empname           text      NOT NULL,
    salary            integer,
    stamp             timestamp NOT NULL
);

CREATE VIEW emp_view AS
    SELECT e.empname,
           e.salary,
           max(ea.stamp) AS last_updated
      FROM emp e
      LEFT JOIN emp_audit ea ON ea.empname = e.empname
     GROUP BY 1, 2;

CREATE OR REPLACE FUNCTION update_emp_view() RETURNS TRIGGER AS $$
    BEGIN
        --
        -- Perform the required operation on emp, and create a row in emp_audit
        -- to reflect the change made to emp.
        --
        IF (TG_OP = 'DELETE') THEN
            DELETE FROM emp WHERE empname = OLD.empname;
            IF NOT FOUND THEN RETURN NULL; END IF;

            OLD.last_updated = now();
            INSERT INTO emp_audit VALUES('D', current_user, OLD.*);
            RETURN OLD;
        ELSIF (TG_OP = 'UPDATE') THEN
            UPDATE emp SET salary = NEW.salary WHERE empname = OLD.empname;
            IF NOT FOUND THEN RETURN NULL; END IF;

            NEW.last_updated = now();
            INSERT INTO emp_audit VALUES('U', current_user, NEW.*);
            RETURN NEW;
        ELSIF (TG_OP = 'INSERT') THEN
            INSERT INTO emp VALUES(NEW.empname, NEW.salary);

            NEW.last_updated = now();
            INSERT INTO emp_audit VALUES('I', current_user, NEW.*);
            RETURN NEW;
        END IF;
    END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER emp_audit
INSTEAD OF INSERT OR UPDATE OR DELETE ON emp_view
    FOR EACH ROW EXECUTE FUNCTION update_emp_view();
```

One use of triggers is to maintain a summary table of another table. The resulting summary can be used in place of the original table for certain queries — often with vastly reduced run times. This technique is commonly used in Data Warehousing, where the tables of measured or observed data (called fact tables) might be extremely large. Example 45.6 shows an example of a trigger function in PL/pgSQL that maintains a summary table for a fact table in a data warehouse.

Example 45.6. A PL/pgSQL Trigger Function for Maintaining a Summary Table

The schema detailed here is partly based on the *Grocery Store* example from *The Data Warehouse Toolkit* by Ralph Kimball.

```
--
-- Main tables - time dimension and sales fact.
--
CREATE TABLE time_dimension (
    time_key                    integer NOT NULL,
    day_of_week                 integer NOT NULL,
    day_of_month                integer NOT NULL,
    month                       integer NOT NULL,
    quarter                     integer NOT NULL,
    year                        integer NOT NULL
);
CREATE UNIQUE INDEX time_dimension_key ON time_dimension(time_key);

CREATE TABLE sales_fact (
    time_key                    integer NOT NULL,
    product_key                 integer NOT NULL,
    store_key                   integer NOT NULL,
    amount_sold                 numeric(12,2) NOT NULL,
    units_sold                  integer NOT NULL,
    amount_cost                 numeric(12,2) NOT NULL
);
CREATE INDEX sales_fact_time ON sales_fact(time_key);

--
-- Summary table - sales by time.
--
CREATE TABLE sales_summary_bytime (
    time_key                    integer NOT NULL,
    amount_sold                 numeric(15,2) NOT NULL,
    units_sold                  numeric(12) NOT NULL,
    amount_cost                 numeric(15,2) NOT NULL
);
CREATE UNIQUE INDEX sales_summary_bytime_key ON sales_summary_bytime(time_key);

--
-- Function and trigger to amend summarized column(s) on UPDATE, INSERT, DELETE.
--
CREATE OR REPLACE FUNCTION maint_sales_summary_bytime() RETURNS TRIGGER
AS $maint_sales_summary_bytime$
    DECLARE
        delta_time_key          integer;
        delta_amount_sold       numeric(15,2);
        delta_units_sold        numeric(12);
        delta_amount_cost       numeric(15,2);
    BEGIN

        -- Work out the increment/decrement amount(s).
        IF (TG_OP = 'DELETE') THEN

            delta_time_key = OLD.time_key;
            delta_amount_sold = -1 * OLD.amount_sold;
            delta_units_sold = -1 * OLD.units_sold;
            delta_amount_cost = -1 * OLD.amount_cost;
```

```
ELSIF (TG_OP = 'UPDATE') THEN

    -- forbid updates that change the time_key -
    -- (probably not too onerous, as DELETE + INSERT is how most
    -- changes will be made).
    IF ( OLD.time_key != NEW.time_key) THEN
        RAISE EXCEPTION 'Update of time_key : % -> % not allowed',
                                              OLD.time_key, NEW.time_key;
    END IF;

    delta_time_key = OLD.time_key;
    delta_amount_sold = NEW.amount_sold - OLD.amount_sold;
    delta_units_sold = NEW.units_sold - OLD.units_sold;
    delta_amount_cost = NEW.amount_cost - OLD.amount_cost;

ELSIF (TG_OP = 'INSERT') THEN

    delta_time_key = NEW.time_key;
    delta_amount_sold = NEW.amount_sold;
    delta_units_sold = NEW.units_sold;
    delta_amount_cost = NEW.amount_cost;

END IF;


-- Insert or update the summary row with the new values.
<<insert_update>>
LOOP
    UPDATE sales_summary_bytime
        SET amount_sold = amount_sold + delta_amount_sold,
            units_sold = units_sold + delta_units_sold,
            amount_cost = amount_cost + delta_amount_cost
        WHERE time_key = delta_time_key;

    EXIT insert_update WHEN found;

    BEGIN
        INSERT INTO sales_summary_bytime (
                    time_key,
                    amount_sold,
                    units_sold,
                    amount_cost)
            VALUES (
                    delta_time_key,
                    delta_amount_sold,
                    delta_units_sold,
                    delta_amount_cost
                   );

        EXIT insert_update;

    EXCEPTION
        WHEN UNIQUE_VIOLATION THEN
            -- do nothing
    END;
END LOOP insert_update;

RETURN NULL;
```

```
    END;
$maint_sales_summary_bytime$ LANGUAGE plpgsql;

CREATE TRIGGER maint_sales_summary_bytime
AFTER INSERT OR UPDATE OR DELETE ON sales_fact
    FOR EACH ROW EXECUTE FUNCTION maint_sales_summary_bytime();

INSERT INTO sales_fact VALUES(1,1,1,10,3,15);
INSERT INTO sales_fact VALUES(1,2,1,20,5,35);
INSERT INTO sales_fact VALUES(2,2,1,40,15,135);
INSERT INTO sales_fact VALUES(2,3,1,10,1,13);
SELECT * FROM sales_summary_bytime;
DELETE FROM sales_fact WHERE product_key = 1;
SELECT * FROM sales_summary_bytime;
UPDATE sales_fact SET units_sold = units_sold * 2;
SELECT * FROM sales_summary_bytime;
```

`AFTER` triggers can also make use of *transition tables* to inspect the entire set of rows changed by the triggering statement. The `CREATE TRIGGER` command assigns names to one or both transition tables, and then the function can refer to those names as though they were read-only temporary tables. Example 45.7 shows an example.

Example 45.7. Auditing with Transition Tables

This example produces the same results as Example 45.4, but instead of using a trigger that fires for every row, it uses a trigger that fires once per statement, after collecting the relevant information in a transition table. This can be significantly faster than the row-trigger approach when the invoking statement has modified many rows. Notice that we must make a separate trigger declaration for each kind of event, since the `REFERENCING` clauses must be different for each case. But this does not stop us from using a single trigger function if we choose. (In practice, it might be better to use three separate functions and avoid the run-time tests on `TG_OP`.)

```
CREATE TABLE emp (
    empname           text NOT NULL,
    salary            integer
);

CREATE TABLE emp_audit(
    operation         char(1)   NOT NULL,
    stamp             timestamp NOT NULL,
    userid            text      NOT NULL,
    empname           text      NOT NULL,
    salary integer
);

CREATE OR REPLACE FUNCTION process_emp_audit() RETURNS TRIGGER AS $emp_audit$
    BEGIN
        --
        -- Create rows in emp_audit to reflect the operations performed on emp,
        -- making use of the special variable TG_OP to work out the operation.
        --
        IF (TG_OP = 'DELETE') THEN
            INSERT INTO emp_audit
                SELECT 'D', now(), current_user, o.* FROM old_table o;
        ELSIF (TG_OP = 'UPDATE') THEN
            INSERT INTO emp_audit
                SELECT 'U', now(), current_user, n.* FROM new_table n;
        ELSIF (TG_OP = 'INSERT') THEN
```

```
            INSERT INTO emp_audit
                SELECT 'I', now(), current_user, n.* FROM new_table n;
        END IF;
        RETURN NULL; -- result is ignored since this is an AFTER trigger
    END;
$emp_audit$ LANGUAGE plpgsql;

CREATE TRIGGER emp_audit_ins
    AFTER INSERT ON emp
    REFERENCING NEW TABLE AS new_table
    FOR EACH STATEMENT EXECUTE FUNCTION process_emp_audit();
CREATE TRIGGER emp_audit_upd
    AFTER UPDATE ON emp
    REFERENCING OLD TABLE AS old_table NEW TABLE AS new_table
    FOR EACH STATEMENT EXECUTE FUNCTION process_emp_audit();
CREATE TRIGGER emp_audit_del
    AFTER DELETE ON emp
    REFERENCING OLD TABLE AS old_table
    FOR EACH STATEMENT EXECUTE FUNCTION process_emp_audit();
```

45.10.2. Triggers on Events

PL/pgSQL can be used to define event triggers. Postgres Pro requires that a function that is to be called as an event trigger must be declared as a function with no arguments and a return type of `event_trigger`.

When a PL/pgSQL function is called as an event trigger, several special variables are created automatically in the top-level block. They are:

`TG_EVENT`

Data type `text`; a string representing the event the trigger is fired for.

`TG_TAG`

Data type `text`; variable that contains the command tag for which the trigger is fired.

Example 45.8 shows an example of an event trigger function in PL/pgSQL.

Example 45.8. A PL/pgSQL Event Trigger Function

This example trigger simply raises a `NOTICE` message each time a supported command is executed.

```
CREATE OR REPLACE FUNCTION snitch() RETURNS event_trigger AS $$
BEGIN
    RAISE NOTICE 'snitch: % %', tg_event, tg_tag;
END;
$$ LANGUAGE plpgsql;

CREATE EVENT TRIGGER snitch ON ddl_command_start EXECUTE FUNCTION snitch();
```

45.11. PL/pgSQL under the Hood

This section discusses some implementation details that are frequently important for PL/pgSQL users to know.

45.11.1. Variable Substitution

SQL statements and expressions within a PL/pgSQL function can refer to variables and parameters of the function. Behind the scenes, PL/pgSQL substitutes query parameters for such references. Query parameters will only be substituted in places where they are syntactically permissible. As an extreme case, consider this example of poor programming style:

```
INSERT INTO foo (foo) VALUES (foo(foo));
```

The first occurrence of `foo` must syntactically be a table name, so it will not be substituted, even if the function has a variable named `foo`. The second occurrence must be the name of a column of that table, so it will not be substituted either. Likewise the third occurrence must be a function name, so it also will not be substituted for. Only the last occurrence is a candidate to be a reference to a variable of the PL/pgSQL function.

Another way to understand this is that variable substitution can only insert data values into an SQL command; it cannot dynamically change which database objects are referenced by the command. (If you want to do that, you must build a command string dynamically, as explained in Section 45.5.4.)

Since the names of variables are syntactically no different from the names of table columns, there can be ambiguity in statements that also refer to tables: is a given name meant to refer to a table column, or a variable? Let's change the previous example to

```
INSERT INTO dest (col) SELECT foo + bar FROM src;
```

Here, `dest` and `src` must be table names, and `col` must be a column of `dest`, but `foo` and `bar` might reasonably be either variables of the function or columns of `src`.

By default, PL/pgSQL will report an error if a name in an SQL statement could refer to either a variable or a table column. You can fix such a problem by renaming the variable or column, or by qualifying the ambiguous reference, or by telling PL/pgSQL which interpretation to prefer.

The simplest solution is to rename the variable or column. A common coding rule is to use a different naming convention for PL/pgSQL variables than you use for column names. For example, if you consistently name function variables `v_`*`something`* while none of your column names start with `v_`, no conflicts will occur.

Alternatively you can qualify ambiguous references to make them clear. In the above example, `src.foo` would be an unambiguous reference to the table column. To create an unambiguous reference to a variable, declare it in a labeled block and use the block's label (see Section 45.2). For example,

```
<<block>>
DECLARE
    foo int;
BEGIN
    foo := ...;
    INSERT INTO dest (col) SELECT block.foo + bar FROM src;
```

Here `block.foo` means the variable even if there is a column `foo` in `src`. Function parameters, as well as special variables such as `FOUND`, can be qualified by the function's name, because they are implicitly declared in an outer block labeled with the function's name.

Sometimes it is impractical to fix all the ambiguous references in a large body of PL/pgSQL code. In such cases you can specify that PL/pgSQL should resolve ambiguous references as the variable (which is compatible with PL/pgSQL's behavior before PostgreSQL 9.0), or as the table column (which is compatible with some other systems such as Oracle).

To change this behavior on a system-wide basis, set the configuration parameter `plpgsql.variable_conflict` to one of `error`, `use_variable`, or `use_column` (where `error` is the factory default). This parameter affects subsequent compilations of statements in PL/pgSQL functions, but not statements already compiled in the current session. Because changing this setting can cause unexpected changes in the behavior of PL/pgSQL functions, it can only be changed by a superuser.

You can also set the behavior on a function-by-function basis, by inserting one of these special commands at the start of the function text:

```
#variable_conflict error
#variable_conflict use_variable
#variable_conflict use_column
```

These commands affect only the function they are written in, and override the setting of `plpgsql.variable_conflict`. An example is

```
CREATE FUNCTION stamp_user(id int, comment text) RETURNS void AS $$
    #variable_conflict use_variable
    DECLARE
        curtime timestamp := now();
    BEGIN
        UPDATE users SET last_modified = curtime, comment = comment
          WHERE users.id = id;
    END;
$$ LANGUAGE plpgsql;
```

In the `UPDATE` command, `curtime`, `comment`, and `id` will refer to the function's variable and parameters whether or not `users` has columns of those names. Notice that we had to qualify the reference to `users.id` in the `WHERE` clause to make it refer to the table column. But we did not have to qualify the reference to `comment` as a target in the `UPDATE` list, because syntactically that must be a column of `users`. We could write the same function without depending on the `variable_conflict` setting in this way:

```
CREATE FUNCTION stamp_user(id int, comment text) RETURNS void AS $$
    <<fn>>
    DECLARE
        curtime timestamp := now();
    BEGIN
        UPDATE users SET last_modified = fn.curtime, comment = stamp_user.comment
          WHERE users.id = stamp_user.id;
    END;
$$ LANGUAGE plpgsql;
```

Variable substitution does not happen in a command string given to `EXECUTE` or one of its variants. If you need to insert a varying value into such a command, do so as part of constructing the string value, or use `USING`, as illustrated in Section 45.5.4.

Variable substitution currently works only in `SELECT`, `INSERT`, `UPDATE`, `DELETE`, and commands containing one of these (such as `EXPLAIN` and `CREATE TABLE ... AS SELECT`), because the main SQL engine allows query parameters only in these commands. To use a non-constant name or value in other statement types (generically called utility statements), you must construct the utility statement as a string and `EXECUTE` it.

45.11.2. Plan Caching

The PL/pgSQL interpreter parses the function's source text and produces an internal binary instruction tree the first time the function is called (within each session). The instruction tree fully translates the PL/pgSQL statement structure, but individual SQL expressions and SQL commands used in the function are not translated immediately.

As each expression and SQL command is first executed in the function, the PL/pgSQL interpreter parses and analyzes the command to create a prepared statement, using the SPI manager's `SPI_prepare` function. Subsequent visits to that expression or command reuse the prepared statement. Thus, a function with conditional code paths that are seldom visited will never incur the overhead of analyzing those commands that are never executed within the current session. A disadvantage is that errors in a specific expression or command cannot be detected until that part of the function is reached in execution. (Trivial syntax errors will be detected during the initial parsing pass, but anything deeper will not be detected until execution.)

PL/pgSQL (or more precisely, the SPI manager) can furthermore attempt to cache the execution plan associated with any particular prepared statement. If a cached plan is not used, then a fresh execution plan is generated on each visit to the statement, and the current parameter values (that is, PL/pgSQL variable values) can be used to optimize the selected plan. If the statement has no parameters, or is executed many times, the SPI manager will consider creating a *generic* plan that is not dependent on specific parameter values, and caching that for re-use. Typically this will happen only if the execution plan is not very sensitive to the values of the PL/pgSQL variables referenced in it. If it is, generating a plan each time is a net win. See PREPARE for more information about the behavior of prepared statements.

Because PL/pgSQL saves prepared statements and sometimes execution plans in this way, SQL commands that appear directly in a PL/pgSQL function must refer to the same tables and columns on every execution; that is, you cannot use a parameter as the name of a table or column in an SQL command. To get around this restriction, you can construct dynamic commands using the PL/pgSQL `EXECUTE` statement — at the price of performing new parse analysis and constructing a new execution plan on every execution.

The mutable nature of record variables presents another problem in this connection. When fields of a record variable are used in expressions or statements, the data types of the fields must not change from one call of the function to the next, since each expression will be analyzed using the data type that is present when the expression is first reached. `EXECUTE` can be used to get around this problem when necessary.

If the same function is used as a trigger for more than one table, PL/pgSQL prepares and caches statements independently for each such table — that is, there is a cache for each trigger function and table combination, not just for each function. This alleviates some of the problems with varying data types; for instance, a trigger function will be able to work successfully with a column named `key` even if it happens to have different types in different tables.

Likewise, functions having polymorphic argument types have a separate statement cache for each combination of actual argument types they have been invoked for, so that data type differences do not cause unexpected failures.

Statement caching can sometimes have surprising effects on the interpretation of time-sensitive values. For example there is a difference between what these two functions do:

```
CREATE FUNCTION logfunc1(logtxt text) RETURNS void AS $$
    BEGIN
        INSERT INTO logtable VALUES (logtxt, 'now');
    END;
$$ LANGUAGE plpgsql;
```

and:

```
CREATE FUNCTION logfunc2(logtxt text) RETURNS void AS $$
    DECLARE
        curtime timestamp;
    BEGIN
        curtime := 'now';
        INSERT INTO logtable VALUES (logtxt, curtime);
    END;
$$ LANGUAGE plpgsql;
```

In the case of `logfunc1`, the Postgres Pro main parser knows when analyzing the `INSERT` that the string `'now'` should be interpreted as `timestamp`, because the target column of `logtable` is of that type. Thus, `'now'` will be converted to a `timestamp` constant when the `INSERT` is analyzed, and then used in all invocations of `logfunc1` during the lifetime of the session. Needless to say, this isn't what the programmer wanted. A better idea is to use the `now()` or `current_timestamp` function.

In the case of `logfunc2`, the Postgres Pro main parser does not know what type `'now'` should become and therefore it returns a data value of type `text` containing the string `now`. During the ensuing assignment to the local variable `curtime`, the PL/pgSQL interpreter casts this string to the `timestamp` type by calling the `textout` and `timestamp_in` functions for the conversion. So, the computed time stamp is updated on each execution as the programmer expects. Even though this happens to work as expected, it's not terribly efficient, so use of the `now()` function would still be a better idea.

45.12. Tips for Developing in PL/pgSQL

One good way to develop in PL/pgSQL is to use the text editor of your choice to create your functions, and in another window, use psql to load and test those functions. If you are doing it this way, it is a good

idea to write the function using `CREATE OR REPLACE FUNCTION`. That way you can just reload the file to update the function definition. For example:

```
CREATE OR REPLACE FUNCTION testfunc(integer) RETURNS integer AS $$
          ....
$$ LANGUAGE plpgsql;
```

While running psql, you can load or reload such a function definition file with:

```
\i filename.sql
```

and then immediately issue SQL commands to test the function.

Another good way to develop in PL/pgSQL is with a GUI database access tool that facilitates development in a procedural language. One example of such a tool is pgAdmin, although others exist. These tools often provide convenient features such as escaping single quotes and making it easier to recreate and debug functions.

45.12.1. Handling of Quotation Marks

The code of a PL/pgSQL function is specified in `CREATE FUNCTION` as a string literal. If you write the string literal in the ordinary way with surrounding single quotes, then any single quotes inside the function body must be doubled; likewise any backslashes must be doubled (assuming escape string syntax is used). Doubling quotes is at best tedious, and in more complicated cases the code can become downright incomprehensible, because you can easily find yourself needing half a dozen or more adjacent quote marks. It's recommended that you instead write the function body as a “dollar-quoted” string literal (see Section 4.1.2.4). In the dollar-quoting approach, you never double any quote marks, but instead take care to choose a different dollar-quoting delimiter for each level of nesting you need. For example, you might write the `CREATE FUNCTION` command as:

```
CREATE OR REPLACE FUNCTION testfunc(integer) RETURNS integer AS $PROC$
          ....
$PROC$ LANGUAGE plpgsql;
```

Within this, you might use quote marks for simple literal strings in SQL commands and `$$` to delimit fragments of SQL commands that you are assembling as strings. If you need to quote text that includes `$$`, you could use `$Q$`, and so on.

The following chart shows what you have to do when writing quote marks without dollar quoting. It might be useful when translating pre-dollar quoting code into something more comprehensible.

1 quotation mark

To begin and end the function body, for example:

```
CREATE FUNCTION foo() RETURNS integer AS '
          ....
' LANGUAGE plpgsql;
```

Anywhere within a single-quoted function body, quote marks *must* appear in pairs.

2 quotation marks

For string literals inside the function body, for example:

```
a_output := ''Blah'';
SELECT * FROM users WHERE f_name=''foobar'';
```

In the dollar-quoting approach, you'd just write:

```
a_output := 'Blah';
SELECT * FROM users WHERE f_name='foobar';
```

which is exactly what the PL/pgSQL parser would see in either case.

4 quotation marks

When you need a single quotation mark in a string constant inside the function body, for example:

```
a_output := a_output || '' AND name LIKE ''''foobar'''' AND xyz''
```

The value actually appended to `a_output` would be: `AND name LIKE 'foobar' AND xyz`.

In the dollar-quoting approach, you'd write:

```
a_output := a_output || $$ AND name LIKE 'foobar' AND xyz$$
```

being careful that any dollar-quote delimiters around this are not just `$$`.

6 quotation marks

When a single quotation mark in a string inside the function body is adjacent to the end of that string constant, for example:

```
a_output := a_output || '' AND name LIKE ''''foobar''''''
```

The value appended to `a_output` would then be: `AND name LIKE 'foobar'`.

In the dollar-quoting approach, this becomes:

```
a_output := a_output || $$ AND name LIKE 'foobar'$$
```

10 quotation marks

When you want two single quotation marks in a string constant (which accounts for 8 quotation marks) and this is adjacent to the end of that string constant (2 more). You will probably only need that if you are writing a function that generates other functions, as in Example 45.10. For example:

```
a_output := a_output || '' if v_'' ||
    referrer_keys.kind || '' like ''''''''''
    || referrer_keys.key_string || ''''''''''
    then return ''''''  || referrer_keys.referrer_type
    || ''''''; end if;'';
```

The value of `a_output` would then be:

```
if v_... like ''...'' then return ''...''; end if;
```

In the dollar-quoting approach, this becomes:

```
a_output := a_output || $$ if v_$$ || referrer_keys.kind || $$ like '$$
    || referrer_keys.key_string || $$'
    then return '$$  || referrer_keys.referrer_type
    || $$'; end if;$$;
```

where we assume we only need to put single quote marks into `a_output`, because it will be re-quoted before use.

45.12.2. Additional Compile-Time and Run-Time Checks

To aid the user in finding instances of simple but common problems before they cause harm, PL/pgSQL provides additional *checks*. When enabled, depending on the configuration, they can be used to emit either a `WARNING` or an `ERROR` during the compilation of a function. A function which has received a `WARNING` can be executed without producing further messages, so you are advised to test in a separate development environment.

Setting `plpgsql.extra_warnings`, or `plpgsql.extra_errors`, as appropriate, to `"all"` is encouraged in development and/or testing environments.

These additional checks are enabled through the configuration variables `plpgsql.extra_warnings` for warnings and `plpgsql.extra_errors` for errors. Both can be set either to a comma-separated list of checks, `"none"` or `"all"`. The default is `"none"`. Currently the list of available checks includes:

`shadowed_variables`

Checks if a declaration shadows a previously defined variable.

`strict_multi_assignment`

Some PL/PgSQL commands allow assigning values to more than one variable at a time, such as `SELECT INTO`. Typically, the number of target variables and the number of source variables should

match, though PL/PgSQL will use `NULL` for missing values and extra variables are ignored. Enabling this check will cause PL/PgSQL to throw a `WARNING` or `ERROR` whenever the number of target variables and the number of source variables are different.

`too_many_rows`

Enabling this check will cause PL/PgSQL to check if a given query returns more than one row when an `INTO` clause is used. As an `INTO` statement will only ever use one row, having a query return multiple rows is generally either inefficient and/or nondeterministic and therefore is likely an error.

The following example shows the effect of `plpgsql.extra_warnings` set to `shadowed_variables`:

```
SET plpgsql.extra_warnings TO 'shadowed_variables';

CREATE FUNCTION foo(f1 int) RETURNS int AS $$
DECLARE
f1 int;
BEGIN
RETURN f1;
END;
$$ LANGUAGE plpgsql;
WARNING:  variable "f1" shadows a previously defined variable
LINE 3: f1 int;
        ^
CREATE FUNCTION
```

The below example shows the effects of setting `plpgsql.extra_warnings` to `strict_multi_assignment`:

```
SET plpgsql.extra_warnings TO 'strict_multi_assignment';

CREATE OR REPLACE FUNCTION public.foo()
 RETURNS void
 LANGUAGE plpgsql
AS $$
DECLARE
  x int;
  y int;
BEGIN
  SELECT 1 INTO x, y;
  SELECT 1, 2 INTO x, y;
  SELECT 1, 2, 3 INTO x, y;
END;
$$;

SELECT foo();
WARNING:  number of source and target fields in assignment does not match
DETAIL:  strict_multi_assignment check of extra_warnings is active.
HINT:  Make sure the query returns the exact list of columns.
WARNING:  number of source and target fields in assignment does not match
DETAIL:  strict_multi_assignment check of extra_warnings is active.
HINT:  Make sure the query returns the exact list of columns.

 foo
-----


(1 row)
```

45.13. Porting from Oracle PL/SQL

This section explains differences between Postgres Pro's PL/pgSQL language and Oracle's PL/SQL language, to help developers who port applications from Oracle® to Postgres Pro.

PL/pgSQL is similar to PL/SQL in many aspects. It is a block-structured, imperative language, and all variables have to be declared. Assignments, loops, and conditionals are similar. The main differences you should keep in mind when porting from PL/SQL to PL/pgSQL are:

- If a name used in an SQL command could be either a column name of a table used in the command or a reference to a variable of the function, PL/SQL treats it as a column name. By default, PL/pgSQL will throw an error complaining that the name is ambiguous. You can specify `plpgsql.variable_conflict = use_column` to change this behavior to match PL/SQL, as explained in Section 45.11.1. It's often best to avoid such ambiguities in the first place, but if you have to port a large amount of code that depends on this behavior, setting `variable_conflict` may be the best solution.
- In Postgres Pro the function body must be written as a string literal. Therefore you need to use dollar quoting or escape single quotes in the function body. (See Section 45.12.1.)
- Data type names often need translation. For example, in Oracle string values are commonly declared as being of type `varchar2`, which is a non-SQL-standard type. In Postgres Pro, use type `varchar` or `text` instead. Similarly, replace type `number` with `numeric`, or use some other numeric data type if there's a more appropriate one.
- Instead of packages, use schemas to organize your functions into groups.
- Since there are no packages, there are no package-level variables either. This is somewhat annoying. You can keep per-session state in temporary tables instead.
- Integer `FOR` loops with `REVERSE` work differently: PL/SQL counts down from the second number to the first, while PL/pgSQL counts down from the first number to the second, requiring the loop bounds to be swapped when porting. This incompatibility is unfortunate but is unlikely to be changed. (See Section 45.6.5.5.)
- `FOR` loops over queries (other than cursors) also work differently: the target variable(s) must have been declared, whereas PL/SQL always declares them implicitly. An advantage of this is that the variable values are still accessible after the loop exits.
- There are various notational differences for the use of cursor variables.

45.13.1. Porting Examples

Example 45.9 shows how to port a simple function from PL/SQL to PL/pgSQL.

Example 45.9. Porting a Simple Function from PL/SQL to PL/pgSQL

Here is an Oracle PL/SQL function:

```
CREATE OR REPLACE FUNCTION cs_fmt_browser_version(v_name varchar2,
                                                  v_version varchar2)
RETURN varchar2 IS
BEGIN
    IF v_version IS NULL THEN
        RETURN v_name;
    END IF;
    RETURN v_name || '/' || v_version;
END;
/
show errors;
```

Let's go through this function and see the differences compared to PL/pgSQL:

- The type name `varchar2` has to be changed to `varchar` or `text`. In the examples in this section, we'll use `varchar`, but `text` is often a better choice if you do not need specific string length limits.
- The `RETURN` key word in the function prototype (not the function body) becomes `RETURNS` in Postgres Pro. Also, `IS` becomes `AS`, and you need to add a `LANGUAGE` clause because PL/pgSQL is not the only possible function language.

- In Postgres Pro, the function body is considered to be a string literal, so you need to use quote marks or dollar quotes around it. This substitutes for the terminating `/` in the Oracle approach.
- The `show errors` command does not exist in Postgres Pro, and is not needed since errors are reported automatically.

This is how this function would look when ported to Postgres Pro:

```
CREATE OR REPLACE FUNCTION cs_fmt_browser_version(v_name varchar,
                                                  v_version varchar)
RETURNS varchar AS $$
BEGIN
    IF v_version IS NULL THEN
        RETURN v_name;
    END IF;
    RETURN v_name || '/' || v_version;
END;
$$ LANGUAGE plpgsql;
```

Example 45.10 shows how to port a function that creates another function and how to handle the ensuing quoting problems.

Example 45.10. Porting a Function that Creates Another Function from PL/SQL to PL/pgSQL

The following procedure grabs rows from a `SELECT` statement and builds a large function with the results in `IF` statements, for the sake of efficiency.

This is the Oracle version:

```
CREATE OR REPLACE PROCEDURE cs_update_referrer_type_proc IS
    CURSOR referrer_keys IS
        SELECT * FROM cs_referrer_keys
        ORDER BY try_order;
    func_cmd VARCHAR(4000);
BEGIN
    func_cmd := 'CREATE OR REPLACE FUNCTION cs_find_referrer_type(v_host IN VARCHAR2,
                 v_domain IN VARCHAR2, v_url IN VARCHAR2) RETURN VARCHAR2 IS BEGIN';

    FOR referrer_key IN referrer_keys LOOP
        func_cmd := func_cmd ||
          ' IF v_' || referrer_key.kind
          || ' LIKE ''' || referrer_key.key_string
          || ''' THEN RETURN ''' || referrer_key.referrer_type
          || '''; END IF;';
    END LOOP;

    func_cmd := func_cmd || ' RETURN NULL; END;';

    EXECUTE IMMEDIATE func_cmd;
END;
/
show errors;
```

Here is how this function would end up in Postgres Pro:

```
CREATE OR REPLACE PROCEDURE cs_update_referrer_type_proc() AS $func$
DECLARE
    referrer_keys CURSOR IS
        SELECT * FROM cs_referrer_keys
        ORDER BY try_order;
    func_body text;
    func_cmd text;
```

```
BEGIN
    func_body := 'BEGIN';

    FOR referrer_key IN referrer_keys LOOP
        func_body := func_body ||
          ' IF v_' || referrer_key.kind
          || ' LIKE ' || quote_literal(referrer_key.key_string)
          || ' THEN RETURN ' || quote_literal(referrer_key.referrer_type)
          || '; END IF;' ;
    END LOOP;

    func_body := func_body || ' RETURN NULL; END;';

    func_cmd :=
      'CREATE OR REPLACE FUNCTION cs_find_referrer_type(v_host varchar,
                                                        v_domain varchar,
                                                        v_url varchar)
        RETURNS varchar AS '
      || quote_literal(func_body)
      || ' LANGUAGE plpgsql;' ;

    EXECUTE func_cmd;
END;
$func$ LANGUAGE plpgsql;
```

Notice how the body of the function is built separately and passed through `quote_literal` to double any quote marks in it. This technique is needed because we cannot safely use dollar quoting for defining the new function: we do not know for sure what strings will be interpolated from the `referrer_key.key_string` field. (We are assuming here that `referrer_key.kind` can be trusted to always be `host`, `domain`, or `url`, but `referrer_key.key_string` might be anything, in particular it might contain dollar signs.) This function is actually an improvement on the Oracle original, because it will not generate broken code when `referrer_key.key_string` or `referrer_key.referrer_type` contain quote marks.

Example 45.11 shows how to port a function with `OUT` parameters and string manipulation. Postgres Pro does not have a built-in `instr` function, but you can create one using a combination of other functions. In Section 45.13.3 there is a PL/pgSQL implementation of `instr` that you can use to make your porting easier.

Example 45.11. Porting a Procedure With String Manipulation and `OUT` Parameters from PL/SQL to PL/pgSQL

The following Oracle PL/SQL procedure is used to parse a URL and return several elements (host, path, and query).

This is the Oracle version:

```
CREATE OR REPLACE PROCEDURE cs_parse_url(
    v_url IN VARCHAR2,
    v_host OUT VARCHAR2,  -- This will be passed back
    v_path OUT VARCHAR2,  -- This one too
    v_query OUT VARCHAR2) -- And this one
IS
    a_pos1 INTEGER;
    a_pos2 INTEGER;
BEGIN
    v_host := NULL;
    v_path := NULL;
    v_query := NULL;
    a_pos1 := instr(v_url, '//');
```

```
    IF a_pos1 = 0 THEN
        RETURN;
    END IF;
    a_pos2 := instr(v_url, '/', a_pos1 + 2);
    IF a_pos2 = 0 THEN
        v_host := substr(v_url, a_pos1 + 2);
        v_path := '/';
        RETURN;
    END IF;

    v_host := substr(v_url, a_pos1 + 2, a_pos2 - a_pos1 - 2);
    a_pos1 := instr(v_url, '?', a_pos2 + 1);

    IF a_pos1 = 0 THEN
        v_path := substr(v_url, a_pos2);
        RETURN;
    END IF;

    v_path := substr(v_url, a_pos2, a_pos1 - a_pos2);
    v_query := substr(v_url, a_pos1 + 1);
END;
/
show errors;
```

Here is a possible translation into PL/pgSQL:

```
CREATE OR REPLACE FUNCTION cs_parse_url(
    v_url IN VARCHAR,
    v_host OUT VARCHAR,  -- This will be passed back
    v_path OUT VARCHAR,  -- This one too
    v_query OUT VARCHAR) -- And this one
AS $$
DECLARE
    a_pos1 INTEGER;
    a_pos2 INTEGER;
BEGIN
    v_host := NULL;
    v_path := NULL;
    v_query := NULL;
    a_pos1 := instr(v_url, '//');

    IF a_pos1 = 0 THEN
        RETURN;
    END IF;
    a_pos2 := instr(v_url, '/', a_pos1 + 2);
    IF a_pos2 = 0 THEN
        v_host := substr(v_url, a_pos1 + 2);
        v_path := '/';
        RETURN;
    END IF;

    v_host := substr(v_url, a_pos1 + 2, a_pos2 - a_pos1 - 2);
    a_pos1 := instr(v_url, '?', a_pos2 + 1);

    IF a_pos1 = 0 THEN
        v_path := substr(v_url, a_pos2);
        RETURN;
    END IF;
```

```
    v_path := substr(v_url, a_pos2, a_pos1 - a_pos2);
    v_query := substr(v_url, a_pos1 + 1);
END;
$$ LANGUAGE plpgsql;
```

This function could be used like this:

```
SELECT * FROM cs_parse_url('http://foobar.com/query.cgi?baz');
```

Example 45.12 shows how to port a procedure that uses numerous features that are specific to Oracle.

Example 45.12. Porting a Procedure from PL/SQL to PL/pgSQL

The Oracle version:

```
CREATE OR REPLACE PROCEDURE cs_create_job(v_job_id IN INTEGER) IS
    a_running_job_count INTEGER;
BEGIN
    LOCK TABLE cs_jobs IN EXCLUSIVE MODE;

    SELECT count(*) INTO a_running_job_count FROM cs_jobs WHERE end_stamp IS NULL;

    IF a_running_job_count > 0 THEN
        COMMIT; -- free lock
        raise_application_error(-20000,
                'Unable to create a new job: a job is currently running.');
    END IF;

    DELETE FROM cs_active_job;
    INSERT INTO cs_active_job(job_id) VALUES (v_job_id);

    BEGIN
        INSERT INTO cs_jobs (job_id, start_stamp) VALUES (v_job_id, now());
    EXCEPTION
        WHEN dup_val_on_index THEN NULL; -- don't worry if it already exists
    END;
    COMMIT;
END;
/
show errors
```

This is how we could port this procedure to PL/pgSQL:

```
CREATE OR REPLACE PROCEDURE cs_create_job(v_job_id integer) AS $$
DECLARE
    a_running_job_count integer;
BEGIN
    LOCK TABLE cs_jobs IN EXCLUSIVE MODE;

    SELECT count(*) INTO a_running_job_count FROM cs_jobs WHERE end_stamp IS NULL;

    IF a_running_job_count > 0 THEN
        COMMIT; -- free lock
        RAISE EXCEPTION 'Unable to create a new job: a job is currently running'; -- 1
    END IF;

    DELETE FROM cs_active_job;
    INSERT INTO cs_active_job(job_id) VALUES (v_job_id);

    BEGIN
        INSERT INTO cs_jobs (job_id, start_stamp) VALUES (v_job_id, now());
```

```
    EXCEPTION
        WHEN unique_violation THEN -- 2
            -- don't worry if it already exists
    END;
    COMMIT;
END;
$$ LANGUAGE plpgsql;
```

1 The syntax of `RAISE` is considerably different from Oracle's statement, although the basic case `RAISE` *`exception_name`* works similarly.

2 The exception names supported by PL/pgSQL are different from Oracle's. The set of built-in exception names is much larger (see Appendix A). There is not currently a way to declare user-defined exception names, although you can throw user-chosen SQLSTATE values instead.

45.13.2. Other Things to Watch For

This section explains a few other things to watch for when porting Oracle PL/SQL functions to Postgres Pro.

45.13.2.1. Implicit Rollback after Exceptions

In PL/pgSQL, when an exception is caught by an `EXCEPTION` clause, all database changes since the block's `BEGIN` are automatically rolled back. That is, the behavior is equivalent to what you'd get in Oracle with:

```
BEGIN
    SAVEPOINT s1;
    ... code here ...
EXCEPTION
    WHEN ... THEN
        ROLLBACK TO s1;
        ... code here ...
    WHEN ... THEN
        ROLLBACK TO s1;
        ... code here ...
END;
```

If you are translating an Oracle procedure that uses `SAVEPOINT` and `ROLLBACK TO` in this style, your task is easy: just omit the `SAVEPOINT` and `ROLLBACK TO`. If you have a procedure that uses `SAVEPOINT` and `ROLLBACK TO` in a different way then some actual thought will be required.

45.13.2.2. `EXECUTE`

The PL/pgSQL version of `EXECUTE` works similarly to the PL/SQL version, but you have to remember to use `quote_literal` and `quote_ident` as described in Section 45.5.4. Constructs of the type `EXECUTE 'SELECT * FROM $1';` will not work reliably unless you use these functions.

45.13.2.3. Optimizing PL/pgSQL Functions

Postgres Pro gives you two function creation modifiers to optimize execution: “volatility” (whether the function always returns the same result when given the same arguments) and “strictness” (whether the function returns null if any argument is null). Consult the CREATE FUNCTION reference page for details.

When making use of these optimization attributes, your `CREATE FUNCTION` statement might look something like this:

```
CREATE FUNCTION foo(...) RETURNS integer AS $$
...
$$ LANGUAGE plpgsql STRICT IMMUTABLE;
```

45.13.3. Appendix

This section contains the code for a set of Oracle-compatible `instr` functions that you can use to simplify your porting efforts.

```
--
-- instr functions that mimic Oracle's counterpart
-- Syntax: instr(string1, string2 [, n [, m]])
-- where [] denotes optional parameters.
--
-- Search string1, beginning at the nth character, for the mth occurrence
-- of string2.  If n is negative, search backwards, starting at the abs(n)'th
-- character from the end of string1.
-- If n is not passed, assume 1 (search starts at first character).
-- If m is not passed, assume 1 (find first occurrence).
-- Returns starting index of string2 in string1, or 0 if string2 is not found.
--

CREATE FUNCTION instr(varchar, varchar) RETURNS integer AS $$
BEGIN
    RETURN instr($1, $2, 1);
END;
$$ LANGUAGE plpgsql STRICT IMMUTABLE;


CREATE FUNCTION instr(string varchar, string_to_search_for varchar,
                      beg_index integer)
RETURNS integer AS $$
DECLARE
    pos integer NOT NULL DEFAULT 0;
    temp_str varchar;
    beg integer;
    length integer;
    ss_length integer;
BEGIN
    IF beg_index > 0 THEN
        temp_str := substring(string FROM beg_index);
        pos := position(string_to_search_for IN temp_str);

        IF pos = 0 THEN
            RETURN 0;
        ELSE
            RETURN pos + beg_index - 1;
        END IF;
    ELSIF beg_index < 0 THEN
        ss_length := char_length(string_to_search_for);
        length := char_length(string);
        beg := length + 1 + beg_index;

        WHILE beg > 0 LOOP
            temp_str := substring(string FROM beg FOR ss_length);
            IF string_to_search_for = temp_str THEN
                RETURN beg;
            END IF;

            beg := beg - 1;
        END LOOP;

        RETURN 0;
    ELSE
        RETURN 0;
    END IF;
```

```
END;
$$ LANGUAGE plpgsql STRICT IMMUTABLE;


CREATE FUNCTION instr(string varchar, string_to_search_for varchar,
                      beg_index integer, occur_index integer)
RETURNS integer AS $$
DECLARE
    pos integer NOT NULL DEFAULT 0;
    occur_number integer NOT NULL DEFAULT 0;
    temp_str varchar;
    beg integer;
    i integer;
    length integer;
    ss_length integer;
BEGIN
    IF occur_index <= 0 THEN
        RAISE 'argument ''%'' is out of range', occur_index
          USING ERRCODE = '22003';
    END IF;

    IF beg_index > 0 THEN
        beg := beg_index - 1;
        FOR i IN 1..occur_index LOOP
            temp_str := substring(string FROM beg + 1);
            pos := position(string_to_search_for IN temp_str);
            IF pos = 0 THEN
                RETURN 0;
            END IF;
            beg := beg + pos;
        END LOOP;

        RETURN beg;
    ELSIF beg_index < 0 THEN
        ss_length := char_length(string_to_search_for);
        length := char_length(string);
        beg := length + 1 + beg_index;

        WHILE beg > 0 LOOP
            temp_str := substring(string FROM beg FOR ss_length);
            IF string_to_search_for = temp_str THEN
                occur_number := occur_number + 1;
                IF occur_number = occur_index THEN
                    RETURN beg;
                END IF;
            END IF;

            beg := beg - 1;
        END LOOP;

        RETURN 0;
    ELSE
        RETURN 0;
    END IF;
END;
$$ LANGUAGE plpgsql STRICT IMMUTABLE;
```

Chapter 46. PL/Tcl — Tcl Procedural Language

PL/Tcl is a loadable procedural language for the Postgres Pro database system that enables the *Tcl language* to be used to write Postgres Pro functions and procedures.

46.1. Overview

PL/Tcl offers most of the capabilities a function writer has in the C language, with a few restrictions, and with the addition of the powerful string processing libraries that are available for Tcl.

One compelling *good* restriction is that everything is executed from within the safety of the context of a Tcl interpreter. In addition to the limited command set of safe Tcl, only a few commands are available to access the database via SPI and to raise messages via `elog()`. PL/Tcl provides no way to access internals of the database server or to gain OS-level access under the permissions of the Postgres Pro server process, as a C function can do. Thus, unprivileged database users can be trusted to use this language; it does not give them unlimited authority.

The other notable implementation restriction is that Tcl functions cannot be used to create input/output functions for new data types.

Sometimes it is desirable to write Tcl functions that are not restricted to safe Tcl. For example, one might want a Tcl function that sends email. To handle these cases, there is a variant of PL/Tcl called `PL/TclU` (for untrusted Tcl). This is exactly the same language except that a full Tcl interpreter is used. *If PL/TclU is used, it must be installed as an untrusted procedural language* so that only database superusers can create functions in it. The writer of a PL/TclU function must take care that the function cannot be used to do anything unwanted, since it will be able to do anything that could be done by a user logged in as the database administrator.

The shared object code for the PL/Tcl and PL/TclU call handlers is automatically built and installed in the Postgres Pro library directory if Tcl support is specified in the configuration step of the installation procedure. To install PL/Tcl and/or PL/TclU in a particular database, use the `CREATE EXTENSION` command, for example `CREATE EXTENSION pltcl` or `CREATE EXTENSION pltclu`.

46.2. PL/Tcl Functions and Arguments

To create a function in the PL/Tcl language, use the standard CREATE FUNCTION syntax:

```
CREATE FUNCTION funcname (argument-types) RETURNS return-type AS $$
    # PL/Tcl function body
$$ LANGUAGE pltcl;
```

PL/TclU is the same, except that the language has to be specified as `pltclu`.

The body of the function is simply a piece of Tcl script. When the function is called, the argument values are passed to the Tcl script as variables named `1` ... *n*. The result is returned from the Tcl code in the usual way, with a `return` statement. In a procedure, the return value from the Tcl code is ignored.

For example, a function returning the greater of two integer values could be defined as:

```
CREATE FUNCTION tcl_max(integer, integer) RETURNS integer AS $$
    if {$1 > $2} {return $1}
    return $2
$$ LANGUAGE pltcl STRICT;
```

Note the clause `STRICT`, which saves us from having to think about null input values: if a null value is passed, the function will not be called at all, but will just return a null result automatically.

In a nonstrict function, if the actual value of an argument is null, the corresponding `$`*n* variable will be set to an empty string. To detect whether a particular argument is null, use the function `argisnull`.

For example, suppose that we wanted `tcl_max` with one null and one nonnull argument to return the nonnull argument, rather than null:

```
CREATE FUNCTION tcl_max(integer, integer) RETURNS integer AS $$
    if {[argisnull 1]} {
        if {[argisnull 2]} { return_null }
        return $2
    }
    if {[argisnull 2]} { return $1 }
    if {$1 > $2} {return $1}
    return $2
$$ LANGUAGE pltcl;
```

As shown above, to return a null value from a PL/Tcl function, execute `return_null`. This can be done whether the function is strict or not.

Composite-type arguments are passed to the function as Tcl arrays. The element names of the array are the attribute names of the composite type. If an attribute in the passed row has the null value, it will not appear in the array. Here is an example:

```
CREATE TABLE employee (
    name text,
    salary integer,
    age integer
);

CREATE FUNCTION overpaid(employee) RETURNS boolean AS $$
    if {200000.0 < $1(salary)} {
        return "t"
    }
    if {$1(age) < 30 && 100000.0 < $1(salary)} {
        return "t"
    }
    return "f"
$$ LANGUAGE pltcl;
```

PL/Tcl functions can return composite-type results, too. To do this, the Tcl code must return a list of column name/value pairs matching the expected result type. Any column names omitted from the list are returned as nulls, and an error is raised if there are unexpected column names. Here is an example:

```
CREATE FUNCTION square_cube(in int, out squared int, out cubed int) AS $$
    return [list squared [expr {$1 * $1}] cubed [expr {$1 * $1 * $1}]]
$$ LANGUAGE pltcl;
```

Output arguments of procedures are returned in the same way, for example:

```
CREATE PROCEDURE tcl_triple(INOUT a integer, INOUT b integer) AS $$
    return [list a [expr {$1 * 3}] b [expr {$2 * 3}]]
$$ LANGUAGE pltcl;

CALL tcl_triple(5, 10);
```

Tip

The result list can be made from an array representation of the desired tuple with the `array get` Tcl command. For example:

```
CREATE FUNCTION raise_pay(employee, delta int) RETURNS employee AS $$
    set 1(salary) [expr {$1(salary) + $2}]
    return [array get 1]
$$ LANGUAGE pltcl;
```

PL/Tcl functions can return sets. To do this, the Tcl code should call `return_next` once per row to be returned, passing either the appropriate value when returning a scalar type, or a list of column name/value pairs when returning a composite type. Here is an example returning a scalar type:

```
CREATE FUNCTION sequence(int, int) RETURNS SETOF int AS $$
    for {set i $1} {$i < $2} {incr i} {
        return_next $i
    }
$$ LANGUAGE pltcl;
```

and here is one returning a composite type:

```
CREATE FUNCTION table_of_squares(int, int) RETURNS TABLE (x int, x2 int) AS $$
    for {set i $1} {$i < $2} {incr i} {
        return_next [list x $i x2 [expr {$i * $i}]]
    }
$$ LANGUAGE pltcl;
```

46.3. Data Values in PL/Tcl

The argument values supplied to a PL/Tcl function's code are simply the input arguments converted to text form (just as if they had been displayed by a `SELECT` statement). Conversely, the `return` and `return_next` commands will accept any string that is acceptable input format for the function's declared result type, or for the specified column of a composite result type.

46.4. Global Data in PL/Tcl

Sometimes it is useful to have some global data that is held between two calls to a function or is shared between different functions. This is easily done in PL/Tcl, but there are some restrictions that must be understood.

For security reasons, PL/Tcl executes functions called by any one SQL role in a separate Tcl interpreter for that role. This prevents accidental or malicious interference by one user with the behavior of another user's PL/Tcl functions. Each such interpreter will have its own values for any “global” Tcl variables. Thus, two PL/Tcl functions will share the same global variables if and only if they are executed by the same SQL role. In an application wherein a single session executes code under multiple SQL roles (via `SECURITY DEFINER` functions, use of `SET ROLE`, etc) you may need to take explicit steps to ensure that PL/Tcl functions can share data. To do that, make sure that functions that should communicate are owned by the same user, and mark them `SECURITY DEFINER`. You must of course take care that such functions can't be used to do anything unintended.

All PL/TclU functions used in a session execute in the same Tcl interpreter, which of course is distinct from the interpreter(s) used for PL/Tcl functions. So global data is automatically shared between PL/TclU functions. This is not considered a security risk because all PL/TclU functions execute at the same trust level, namely that of a database superuser.

To help protect PL/Tcl functions from unintentionally interfering with each other, a global array is made available to each function via the `upvar` command. The global name of this variable is the function's internal name, and the local name is `GD`. It is recommended that `GD` be used for persistent private data of a function. Use regular Tcl global variables only for values that you specifically intend to be shared among multiple functions. (Note that the `GD` arrays are only global within a particular interpreter, so they do not bypass the security restrictions mentioned above.)

An example of using `GD` appears in the `spi_execp` example below.

46.5. Database Access from PL/Tcl

In this section, we follow the usual Tcl convention of using question marks, rather than brackets, to indicate an optional element in a syntax synopsis. The following commands are available to access the database from the body of a PL/Tcl function:

`spi_exec ?-count n? ?-array name? command ?loop-body?`

Executes an SQL command given as a string. An error in the command causes an error to be raised. Otherwise, the return value of `spi_exec` is the number of rows processed (selected, inserted, updated, or deleted) by the command, or zero if the command is a utility statement. In addition, if the command is a `SELECT` statement, the values of the selected columns are placed in Tcl variables as described below.

The optional `-count` value tells `spi_exec` to stop once *n* rows have been retrieved, much as if the query included a `LIMIT` clause. If *n* is zero, the query is run to completion, the same as when `-count` is omitted.

If the command is a `SELECT` statement, the values of the result columns are placed into Tcl variables named after the columns. If the `-array` option is given, the column values are instead stored into elements of the named associative array, with the column names used as array indexes. In addition, the current row number within the result (counting from zero) is stored into the array element named "`.tupno`", unless that name is in use as a column name in the result.

If the command is a `SELECT` statement and no *loop-body* script is given, then only the first row of results are stored into Tcl variables or array elements; remaining rows, if any, are ignored. No storing occurs if the query returns no rows. (This case can be detected by checking the result of `spi_exec`.) For example:

```
spi_exec "SELECT count(*) AS cnt FROM pg_proc"
```

will set the Tcl variable `$cnt` to the number of rows in the `pg_proc` system catalog.

If the optional *loop-body* argument is given, it is a piece of Tcl script that is executed once for each row in the query result. (*loop-body* is ignored if the given command is not a `SELECT`.) The values of the current row's columns are stored into Tcl variables or array elements before each iteration. For example:

```
spi_exec -array C "SELECT * FROM pg_class" {
    elog DEBUG "have table $C(relname)"
}
```

will print a log message for every row of `pg_class`. This feature works similarly to other Tcl looping constructs; in particular `continue` and `break` work in the usual way inside the loop body.

If a column of a query result is null, the target variable for it is "unset" rather than being set.

`spi_prepare query typelist`

Prepares and saves a query plan for later execution. The saved plan will be retained for the life of the current session.

The query can use parameters, that is, placeholders for values to be supplied whenever the plan is actually executed. In the query string, refer to parameters by the symbols `$1` ... `$n`. If the query uses parameters, the names of the parameter types must be given as a Tcl list. (Write an empty list for *typelist* if no parameters are used.)

The return value from `spi_prepare` is a query ID to be used in subsequent calls to `spi_execp`. See `spi_execp` for an example.

`spi_execp ?-count n? ?-array name? ?-nulls string? queryid ?value-list? ?loop-body?`

Executes a query previously prepared with `spi_prepare`. *queryid* is the ID returned by `spi_prepare`. If the query references parameters, a *value-list* must be supplied. This is a Tcl list of actual values for the parameters. The list must be the same length as the parameter type list previously given to `spi_prepare`. Omit *value-list* if the query has no parameters.

The optional value for `-nulls` is a string of spaces and `'n'` characters telling `spi_execp` which of the parameters are null values. If given, it must have exactly the same length as the *value-list*. If it is not given, all the parameter values are nonnull.

Except for the way in which the query and its parameters are specified, `spi_execp` works just like `spi_exec`. The `-count`, `-array`, and *`loop-body`* options are the same, and so is the result value.

Here's an example of a PL/Tcl function using a prepared plan:

```
CREATE FUNCTION t1_count(integer, integer) RETURNS integer AS $$
    if {![ info exists GD(plan) ]} {
        # prepare the saved plan on the first call
        set GD(plan) [ spi_prepare \
                "SELECT count(*) AS cnt FROM t1 WHERE num >= \$1 AND num <= \$2" \
                [ list int4 int4 ] ]
    }
    spi_execp -count 1 $GD(plan) [ list $1 $2 ]
    return $cnt
$$ LANGUAGE pltcl;
```

We need backslashes inside the query string given to `spi_prepare` to ensure that the `$n` markers will be passed through to `spi_prepare` as-is, and not replaced by Tcl variable substitution.

`subtransaction` *`command`*

The Tcl script contained in *`command`* is executed within an SQL subtransaction. If the script returns an error, that entire subtransaction is rolled back before returning the error out to the surrounding Tcl code. See Section 46.9 for more details and an example.

`quote` *`string`*

Doubles all occurrences of single quote and backslash characters in the given string. This can be used to safely quote strings that are to be inserted into SQL commands given to `spi_exec` or `spi_prepare`. For example, think about an SQL command string like:

```
"SELECT '$val' AS ret"
```

where the Tcl variable `val` actually contains `doesn't`. This would result in the final command string:

```
SELECT 'doesn't' AS ret
```

which would cause a parse error during `spi_exec` or `spi_prepare`. To work properly, the submitted command should contain:

```
SELECT 'doesn''t' AS ret
```

which can be formed in PL/Tcl using:

```
"SELECT '[ quote $val ]' AS ret"
```

One advantage of `spi_execp` is that you don't have to quote parameter values like this, since the parameters are never parsed as part of an SQL command string.

`elog` *`level msg`*

Emits a log or error message. Possible levels are `DEBUG`, `LOG`, `INFO`, `NOTICE`, `WARNING`, `ERROR`, and `FATAL`. `ERROR` raises an error condition; if this is not trapped by the surrounding Tcl code, the error propagates out to the calling query, causing the current transaction or subtransaction to be aborted. This is effectively the same as the Tcl `error` command. `FATAL` aborts the transaction and causes the current session to shut down. (There is probably no good reason to use this error level in PL/Tcl functions, but it's provided for completeness.) The other levels only generate messages of different priority levels. Whether messages of a particular priority are reported to the client, written to the server log, or both is controlled by the log_min_messages and client_min_messages configuration variables. See Chapter 19 and Section 46.8 for more information.

46.6. Trigger Functions in PL/Tcl

Trigger functions can be written in PL/Tcl. Postgres Pro requires that a function that is to be called as a trigger must be declared as a function with no arguments and a return type of `trigger`.

The information from the trigger manager is passed to the function body in the following variables:

`$TG_name`

The name of the trigger from the `CREATE TRIGGER` statement.

`$TG_relid`

The object ID of the table that caused the trigger function to be invoked.

`$TG_table_name`

The name of the table that caused the trigger function to be invoked.

`$TG_table_schema`

The schema of the table that caused the trigger function to be invoked.

`$TG_relatts`

A Tcl list of the table column names, prefixed with an empty list element. So looking up a column name in the list with Tcl's `lsearch` command returns the element's number starting with 1 for the first column, the same way the columns are customarily numbered in Postgres Pro. (Empty list elements also appear in the positions of columns that have been dropped, so that the attribute numbering is correct for columns to their right.)

`$TG_when`

The string `BEFORE`, `AFTER`, or `INSTEAD OF`, depending on the type of trigger event.

`$TG_level`

The string `ROW` or `STATEMENT` depending on the type of trigger event.

`$TG_op`

The string `INSERT`, `UPDATE`, `DELETE`, or `TRUNCATE` depending on the type of trigger event.

`$NEW`

An associative array containing the values of the new table row for `INSERT` or `UPDATE` actions, or empty for `DELETE`. The array is indexed by column name. Columns that are null will not appear in the array. This is not set for statement-level triggers.

`$OLD`

An associative array containing the values of the old table row for `UPDATE` or `DELETE` actions, or empty for `INSERT`. The array is indexed by column name. Columns that are null will not appear in the array. This is not set for statement-level triggers.

`$args`

A Tcl list of the arguments to the function as given in the `CREATE TRIGGER` statement. These arguments are also accessible as `$1` ... `$n` in the function body.

The return value from a trigger function can be one of the strings `OK` or `SKIP`, or a list of column name/value pairs. If the return value is `OK`, the operation (`INSERT`/`UPDATE`/`DELETE`) that fired the trigger will proceed normally. `SKIP` tells the trigger manager to silently suppress the operation for this row. If a list is returned, it tells PL/Tcl to return a modified row to the trigger manager; the contents of the modified row are specified by the column names and values in the list. Any columns not mentioned in the list are set to null. Returning a modified row is only meaningful for row-level `BEFORE INSERT` or `UPDATE` triggers, for which the modified row will be inserted instead of the one given in `$NEW`; or for row-level `INSTEAD OF INSERT` or `UPDATE` triggers where the returned row is used as the source data for `INSERT RETURNING` or `UPDATE RETURNING` clauses. In row-level `BEFORE DELETE` or `INSTEAD OF DELETE` triggers, returning

a modified row has the same effect as returning `OK`, that is the operation proceeds. The trigger return value is ignored for all other types of triggers.

> **Tip**
>
> The result list can be made from an array representation of the modified tuple with the `array get` Tcl command.

Here's a little example trigger function that forces an integer value in a table to keep track of the number of updates that are performed on the row. For new rows inserted, the value is initialized to 0 and then incremented on every update operation.

```
CREATE FUNCTION trigfunc_modcount() RETURNS trigger AS $$
    switch $TG_op {
        INSERT {
            set NEW($1) 0
        }
        UPDATE {
            set NEW($1) $OLD($1)
            incr NEW($1)
        }
        default {
            return OK
        }
    }
    return [array get NEW]
$$ LANGUAGE pltcl;

CREATE TABLE mytab (num integer, description text, modcnt integer);

CREATE TRIGGER trig_mytab_modcount BEFORE INSERT OR UPDATE ON mytab
    FOR EACH ROW EXECUTE FUNCTION trigfunc_modcount('modcnt');
```

Notice that the trigger function itself does not know the column name; that's supplied from the trigger arguments. This lets the trigger function be reused with different tables.

46.7. Event Trigger Functions in PL/Tcl

Event trigger functions can be written in PL/Tcl. Postgres Pro requires that a function that is to be called as an event trigger must be declared as a function with no arguments and a return type of `event_trigger`.

The information from the trigger manager is passed to the function body in the following variables:

`$TG_event`

The name of the event the trigger is fired for.

`$TG_tag`

The command tag for which the trigger is fired.

The return value of the trigger function is ignored.

Here's a little example event trigger function that simply raises a `NOTICE` message each time a supported command is executed:

```
CREATE OR REPLACE FUNCTION tclsnitch() RETURNS event_trigger AS $$
  elog NOTICE "tclsnitch: $TG_event $TG_tag"
$$ LANGUAGE pltcl;
```

```
CREATE EVENT TRIGGER tcl_a_snitch ON ddl_command_start EXECUTE FUNCTION tclsnitch();
```

46.8. Error Handling in PL/Tcl

Tcl code within or called from a PL/Tcl function can raise an error, either by executing some invalid operation or by generating an error using the Tcl `error` command or PL/Tcl's `elog` command. Such errors can be caught within Tcl using the Tcl `catch` command. If an error is not caught but is allowed to propagate out to the top level of execution of the PL/Tcl function, it is reported as an SQL error in the function's calling query.

Conversely, SQL errors that occur within PL/Tcl's `spi_exec`, `spi_prepare`, and `spi_execp` commands are reported as Tcl errors, so they are catchable by Tcl's `catch` command. (Each of these PL/Tcl commands runs its SQL operation in a subtransaction, which is rolled back on error, so that any partially-completed operation is automatically cleaned up.) Again, if an error propagates out to the top level without being caught, it turns back into an SQL error.

Tcl provides an `errorCode` variable that can represent additional information about an error in a form that is easy for Tcl programs to interpret. The contents are in Tcl list format, and the first word identifies the subsystem or library reporting the error; beyond that the contents are left to the individual subsystem or library. For database errors reported by PL/Tcl commands, the first word is `POSTGRES`, the second word is the Postgres Pro version number, and additional words are field name/value pairs providing detailed information about the error. Fields `SQLSTATE`, `condition`, and `message` are always supplied (the first two represent the error code and condition name as shown in Appendix A). Fields that may be present include `detail`, `hint`, `context`, `schema`, `table`, `column`, `datatype`, `constraint`, `statement`, `cursor_position`, `filename`, `lineno`, and `funcname`.

A convenient way to work with PL/Tcl's `errorCode` information is to load it into an array, so that the field names become array subscripts. Code for doing that might look like

```
if {[catch { spi_exec $sql_command }]} {
    if {[lindex $::errorCode 0] == "POSTGRES"} {
        array set errorArray $::errorCode
        if {$errorArray(condition) == "undefined_table"} {
            # deal with missing table
        } else {
            # deal with some other type of SQL error
        }
    }
}
```

(The double colons explicitly specify that `errorCode` is a global variable.)

46.9. Explicit Subtransactions in PL/Tcl

Recovering from errors caused by database access as described in Section 46.8 can lead to an undesirable situation where some operations succeed before one of them fails, and after recovering from that error the data is left in an inconsistent state. PL/Tcl offers a solution to this problem in the form of explicit subtransactions.

Consider a function that implements a transfer between two accounts:

```
CREATE FUNCTION transfer_funds() RETURNS void AS $$
    if [catch {
        spi_exec "UPDATE accounts SET balance = balance - 100 WHERE account_name =
 'joe'"
        spi_exec "UPDATE accounts SET balance = balance + 100 WHERE account_name =
 'mary'"
    } errormsg] {
        set result [format "error transferring funds: %s" $errormsg]
```

```
    } else {
        set result "funds transferred successfully"
    }
    spi_exec "INSERT INTO operations (result) VALUES ('[quote $result]')"
$$ LANGUAGE pltcl;
```

If the second `UPDATE` statement results in an exception being raised, this function will log the failure, but the result of the first `UPDATE` will nevertheless be committed. In other words, the funds will be withdrawn from Joe's account, but will not be transferred to Mary's account. This happens because each `spi_exec` is a separate subtransaction, and only one of those subtransactions got rolled back.

To handle such cases, you can wrap multiple database operations in an explicit subtransaction, which will succeed or roll back as a whole. PL/Tcl provides a `subtransaction` command to manage this. We can rewrite our function as:

```
CREATE FUNCTION transfer_funds2() RETURNS void AS $$
    if [catch {
        subtransaction {
            spi_exec "UPDATE accounts SET balance = balance - 100 WHERE account_name =
 'joe'"
            spi_exec "UPDATE accounts SET balance = balance + 100 WHERE account_name =
 'mary'"
        }
    } errormsg] {
        set result [format "error transferring funds: %s" $errormsg]
    } else {
        set result "funds transferred successfully"
    }
    spi_exec "INSERT INTO operations (result) VALUES ('[quote $result]')"
$$ LANGUAGE pltcl;
```

Note that use of `catch` is still required for this purpose. Otherwise the error would propagate to the top level of the function, preventing the desired insertion into the `operations` table. The `subtransaction` command does not trap errors, it only assures that all database operations executed inside its scope will be rolled back together when an error is reported.

A rollback of an explicit subtransaction occurs on any error reported by the contained Tcl code, not only errors originating from database access. Thus a regular Tcl exception raised inside a `subtransaction` command will also cause the subtransaction to be rolled back. However, non-error exits out of the contained Tcl code (for instance, due to `return`) do not cause a rollback.

46.10. Transaction Management

In a procedure called from the top level or an anonymous code block (`DO` command) called from the top level it is possible to control transactions. To commit the current transaction, call the `commit` command. To roll back the current transaction, call the `rollback` command. (Note that it is not possible to run the SQL commands `COMMIT` or `ROLLBACK` via `spi_exec` or similar. It has to be done using these functions.) After a transaction is ended, a new transaction is automatically started, so there is no separate command for that.

Here is an example:

```
CREATE PROCEDURE transaction_test1()
LANGUAGE pltcl
AS $$
for {set i 0} {$i < 10} {incr i} {
    spi_exec "INSERT INTO test1 (a) VALUES ($i)"
    if {$i % 2 == 0} {
        commit
    } else {
```

```
        rollback
    }
}
$$;

CALL transaction_test1();
```

Transactions cannot be ended when an explicit subtransaction is active.

46.11. PL/Tcl Configuration

This section lists configuration parameters that affect PL/Tcl.

`pltcl.start_proc` (`string`)

This parameter, if set to a nonempty string, specifies the name (possibly schema-qualified) of a parameterless PL/Tcl function that is to be executed whenever a new Tcl interpreter is created for PL/Tcl. Such a function can perform per-session initialization, such as loading additional Tcl code. A new Tcl interpreter is created when a PL/Tcl function is first executed in a database session, or when an additional interpreter has to be created because a PL/Tcl function is called by a new SQL role.

The referenced function must be written in the `pltcl` language, and must not be marked `SECURITY DEFINER`. (These restrictions ensure that it runs in the interpreter it's supposed to initialize.) The current user must have permission to call it, too.

If the function fails with an error it will abort the function call that caused the new interpreter to be created and propagate out to the calling query, causing the current transaction or subtransaction to be aborted. Any actions already done within Tcl won't be undone; however, that interpreter won't be used again. If the language is used again the initialization will be attempted again within a fresh Tcl interpreter.

Only superusers can change this setting. Although this setting can be changed within a session, such changes will not affect Tcl interpreters that have already been created.

`pltclu.start_proc` (`string`)

This parameter is exactly like `pltcl.start_proc`, except that it applies to PL/TclU. The referenced function must be written in the `pltclu` language.

46.12. Tcl Procedure Names

In Postgres Pro, the same function name can be used for different function definitions as long as the number of arguments or their types differ. Tcl, however, requires all procedure names to be distinct. PL/Tcl deals with this by making the internal Tcl procedure names contain the object ID of the function from the system table `pg_proc` as part of their name. Thus, Postgres Pro functions with the same name and different argument types will be different Tcl procedures, too. This is not normally a concern for a PL/Tcl programmer, but it might be visible when debugging.

Chapter 47. PL/Perl — Perl Procedural Language

PL/Perl is a loadable procedural language that enables you to write Postgres Pro functions and procedures in the *Perl programming language*.

The main advantage to using PL/Perl is that this allows use, within stored functions and procedures, of the manyfold “string munging” operators and functions available for Perl. Parsing complex strings might be easier using Perl than it is with the string functions and control structures provided in PL/pgSQL.

To install PL/Perl in a particular database, use `CREATE EXTENSION plperl`.

> **Tip**
>
> If a language is installed into `template1`, all subsequently created databases will have the language installed automatically.

> **Note**
>
> Users of source packages must specially enable the build of PL/Perl during the installation process. Users of binary packages might find PL/Perl in a separate subpackage.

47.1. PL/Perl Functions and Arguments

To create a function in the PL/Perl language, use the standard CREATE FUNCTION syntax:

```
CREATE FUNCTION funcname (argument-types)
RETURNS return-type
-- function attributes can go here
AS $$
    # PL/Perl function body goes here
$$ LANGUAGE plperl;
```

The body of the function is ordinary Perl code. In fact, the PL/Perl glue code wraps it inside a Perl subroutine. A PL/Perl function is called in a scalar context, so it can't return a list. You can return non-scalar values (arrays, records, and sets) by returning a reference, as discussed below.

In a PL/Perl procedure, any return value from the Perl code is ignored.

PL/Perl also supports anonymous code blocks called with the DO statement:

```
DO $$
    # PL/Perl code
$$ LANGUAGE plperl;
```

An anonymous code block receives no arguments, and whatever value it might return is discarded. Otherwise it behaves just like a function.

> **Note**
>
> The use of named nested subroutines is dangerous in Perl, especially if they refer to lexical variables in the enclosing scope. Because a PL/Perl function is wrapped in a subroutine, any named subroutine you place inside one will be nested. In general, it is far safer to create anonymous subroutines which you call via a coderef. For more information, see the entries for `Variable "%s"`

`will not stay shared` and `Variable "%s" is not available` in the perldiag man page, or search the Internet for “perl nested named subroutine”.

The syntax of the `CREATE FUNCTION` command requires the function body to be written as a string constant. It is usually most convenient to use dollar quoting (see Section 4.1.2.4) for the string constant. If you choose to use escape string syntax `E''`, you must double any single quote marks (`'`) and backslashes (`\`) used in the body of the function (see Section 4.1.2.1).

Arguments and results are handled as in any other Perl subroutine: arguments are passed in `@_`, and a result value is returned with `return` or as the last expression evaluated in the function.

For example, a function returning the greater of two integer values could be defined as:

```
CREATE FUNCTION perl_max (integer, integer) RETURNS integer AS $$
    if ($_[0] > $_[1]) { return $_[0]; }
    return $_[1];
$$ LANGUAGE plperl;
```

Note

Arguments will be converted from the database's encoding to UTF-8 for use inside PL/Perl, and then converted from UTF-8 back to the database encoding upon return.

If an SQL null value is passed to a function, the argument value will appear as “undefined” in Perl. The above function definition will not behave very nicely with null inputs (in fact, it will act as though they are zeroes). We could add `STRICT` to the function definition to make Postgres Pro do something more reasonable: if a null value is passed, the function will not be called at all, but will just return a null result automatically. Alternatively, we could check for undefined inputs in the function body. For example, suppose that we wanted `perl_max` with one null and one nonnull argument to return the nonnull argument, rather than a null value:

```
CREATE FUNCTION perl_max (integer, integer) RETURNS integer AS $$
    my ($x, $y) = @_;
    if (not defined $x) {
        return undef if not defined $y;
        return $y;
    }
    return $x if not defined $y;
    return $x if $x > $y;
    return $y;
$$ LANGUAGE plperl;
```

As shown above, to return an SQL null value from a PL/Perl function, return an undefined value. This can be done whether the function is strict or not.

Anything in a function argument that is not a reference is a string, which is in the standard Postgres Pro external text representation for the relevant data type. In the case of ordinary numeric or text types, Perl will just do the right thing and the programmer will normally not have to worry about it. However, in other cases the argument will need to be converted into a form that is more usable in Perl. For example, the `decode_bytea` function can be used to convert an argument of type `bytea` into unescaped binary.

Similarly, values passed back to Postgres Pro must be in the external text representation format. For example, the `encode_bytea` function can be used to escape binary data for a return value of type `bytea`.

One case that is particularly important is boolean values. As just stated, the default behavior for `bool` values is that they are passed to Perl as text, thus either `'t'` or `'f'`. This is problematic, since Perl will not treat `'f'` as false! It is possible to improve matters by using a “transform” (see CREATE TRANSFORM). Suitable transforms are provided by the `bool_plperl` extension. To use it, install the extension:

```
CREATE EXTENSION bool_plperl;  -- or bool_plperlu for PL/PerlU
```

Then use the `TRANSFORM` function attribute for a PL/Perl function that takes or returns `bool`, for example:

```
CREATE FUNCTION perl_and(bool, bool) RETURNS bool
TRANSFORM FOR TYPE bool
AS $$
  my ($a, $b) = @_;
  return $a && $b;
$$ LANGUAGE plperl;
```

When this transform is applied, `bool` arguments will be seen by Perl as being `1` or empty, thus properly true or false. If the function result is type `bool`, it will be true or false according to whether Perl would evaluate the returned value as true. Similar transformations are also performed for boolean query arguments and results of SPI queries performed inside the function (Section 47.3.1).

Perl can return PostgreSQL arrays as references to Perl arrays. Here is an example:

```
CREATE OR REPLACE function returns_array()
RETURNS text[][] AS $$
    return [['a"b','c,d'],['e\\f','g']];
$$ LANGUAGE plperl;

select returns_array();
```

Perl passes PostgreSQL arrays as a blessed `PostgreSQL::InServer::ARRAY` object. This object may be treated as an array reference or a string, allowing for backward compatibility with Perl code written for PostgreSQL versions below 9.1 to run. For example:

```
CREATE OR REPLACE FUNCTION concat_array_elements(text[]) RETURNS TEXT AS $$
    my $arg = shift;
    my $result = "";
    return undef if (!defined $arg);

    # as an array reference
    for (@$arg) {
        $result .= $_;
    }

    # also works as a string
    $result .= $arg;

    return $result;
$$ LANGUAGE plperl;

SELECT concat_array_elements(ARRAY['PL','/','Perl']);
```

> **Note**
>
> Multidimensional arrays are represented as references to lower-dimensional arrays of references in a way common to every Perl programmer.

Composite-type arguments are passed to the function as references to hashes. The keys of the hash are the attribute names of the composite type. Here is an example:

```
CREATE TABLE employee (
    name text,
    basesalary integer,
    bonus integer
);
```

```
CREATE FUNCTION empcomp(employee) RETURNS integer AS $$
    my ($emp) = @_;
    return $emp->{basesalary} + $emp->{bonus};
$$ LANGUAGE plperl;

SELECT name, empcomp(employee.*) FROM employee;
```

A PL/Perl function can return a composite-type result using the same approach: return a reference to a hash that has the required attributes. For example:

```
CREATE TYPE testrowperl AS (f1 integer, f2 text, f3 text);

CREATE OR REPLACE FUNCTION perl_row() RETURNS testrowperl AS $$
    return {f2 => 'hello', f1 => 1, f3 => 'world'};
$$ LANGUAGE plperl;

SELECT * FROM perl_row();
```

Any columns in the declared result data type that are not present in the hash will be returned as null values.

Similarly, output arguments of procedures can be returned as a hash reference:

```
CREATE PROCEDURE perl_triple(INOUT a integer, INOUT b integer) AS $$
    my ($a, $b) = @_;
    return {a => $a * 3, b => $b * 3};
$$ LANGUAGE plperl;

CALL perl_triple(5, 10);
```

PL/Perl functions can also return sets of either scalar or composite types. Usually you'll want to return rows one at a time, both to speed up startup time and to keep from queuing up the entire result set in memory. You can do this with `return_next` as illustrated below. Note that after the last `return_next`, you must put either `return` or (better) `return undef`.

```
CREATE OR REPLACE FUNCTION perl_set_int(int)
RETURNS SETOF INTEGER AS $$
    foreach (0..$_[0]) {
        return_next($_);
    }
    return undef;
$$ LANGUAGE plperl;

SELECT * FROM perl_set_int(5);

CREATE OR REPLACE FUNCTION perl_set()
RETURNS SETOF testrowperl AS $$
    return_next({ f1 => 1, f2 => 'Hello', f3 => 'World' });
    return_next({ f1 => 2, f2 => 'Hello', f3 => 'PostgreSQL' });
    return_next({ f1 => 3, f2 => 'Hello', f3 => 'PL/Perl' });
    return undef;
$$ LANGUAGE plperl;
```

For small result sets, you can return a reference to an array that contains either scalars, references to arrays, or references to hashes for simple types, array types, and composite types, respectively. Here are some simple examples of returning the entire result set as an array reference:

```
CREATE OR REPLACE FUNCTION perl_set_int(int) RETURNS SETOF INTEGER AS $$
    return [0..$_[0]];
$$ LANGUAGE plperl;
```

```
SELECT * FROM perl_set_int(5);

CREATE OR REPLACE FUNCTION perl_set() RETURNS SETOF testrowperl AS $$
    return [
        { f1 => 1, f2 => 'Hello', f3 => 'World' },
        { f1 => 2, f2 => 'Hello', f3 => 'PostgreSQL' },
        { f1 => 3, f2 => 'Hello', f3 => 'PL/Perl' }
    ];
$$ LANGUAGE plperl;

SELECT * FROM perl_set();
```

If you wish to use the `strict` pragma with your code you have a few options. For temporary global use you can `SET plperl.use_strict` to true. This will affect subsequent compilations of PL/Perl functions, but not functions already compiled in the current session. For permanent global use you can set `plperl.use_strict` to true in the `postgresql.conf` file.

For permanent use in specific functions you can simply put:

```
use strict;
```

at the top of the function body.

The `feature` pragma is also available to `use` if your Perl is version 5.10.0 or higher.

47.2. Data Values in PL/Perl

The argument values supplied to a PL/Perl function's code are simply the input arguments converted to text form (just as if they had been displayed by a `SELECT` statement). Conversely, the `return` and `return_next` commands will accept any string that is acceptable input format for the function's declared return type.

If this behavior is inconvenient for a particular case, it can be improved by using a transform, as already illustrated for `bool` values. Several examples of transform modules are included in the PostgreSQL distribution.

47.3. Built-in Functions

47.3.1. Database Access from PL/Perl

Access to the database itself from your Perl function can be done via the following functions:

`spi_exec_query(`*`query`* `[, `*`limit`*`])`

`spi_exec_query` executes an SQL command and returns the entire row set as a reference to an array of hash references. If *`limit`* is specified and is greater than zero, then `spi_exec_query` retrieves at most *`limit`* rows, much as if the query included a `LIMIT` clause. Omitting *`limit`* or specifying it as zero results in no row limit.

You should only use this command when you know that the result set will be relatively small. Here is an example of a query (`SELECT` command) with the optional maximum number of rows:

```
$rv = spi_exec_query('SELECT * FROM my_table', 5);
```

This returns up to 5 rows from the table `my_table`. If `my_table` has a column `my_column`, you can get that value from row `$i` of the result like this:

```
$foo = $rv->{rows}[$i]->{my_column};
```

The total number of rows returned from a `SELECT` query can be accessed like this:

```
$nrows = $rv->{processed}
```

Here is an example using a different command type:

```
$query = "INSERT INTO my_table VALUES (1, 'test')";
$rv = spi_exec_query($query);
```

You can then access the command status (e.g., `SPI_OK_INSERT`) like this:

```
$res = $rv->{status};
```

To get the number of rows affected, do:

```
$nrows = $rv->{processed};
```

Here is a complete example:

```
CREATE TABLE test (
    i int,
    v varchar
);

INSERT INTO test (i, v) VALUES (1, 'first line');
INSERT INTO test (i, v) VALUES (2, 'second line');
INSERT INTO test (i, v) VALUES (3, 'third line');
INSERT INTO test (i, v) VALUES (4, 'immortal');

CREATE OR REPLACE FUNCTION test_munge() RETURNS SETOF test AS $$
    my $rv = spi_exec_query('select i, v from test;');
    my $status = $rv->{status};
    my $nrows = $rv->{processed};
    foreach my $rn (0 .. $nrows - 1) {
        my $row = $rv->{rows}[$rn];
        $row->{i} += 200 if defined($row->{i});
        $row->{v} =~ tr/A-Za-z/a-zA-Z/ if (defined($row->{v}));
        return_next($row);
    }
    return undef;
$$ LANGUAGE plperl;

SELECT * FROM test_munge();
```

`spi_query(`*command*`)`
`spi_fetchrow(`*cursor*`)`
`spi_cursor_close(`*cursor*`)`

`spi_query` and `spi_fetchrow` work together as a pair for row sets which might be large, or for cases where you wish to return rows as they arrive. `spi_fetchrow` works *only* with `spi_query`. The following example illustrates how you use them together:

```
CREATE TYPE foo_type AS (the_num INTEGER, the_text TEXT);

CREATE OR REPLACE FUNCTION lotsa_md5 (INTEGER) RETURNS SETOF foo_type AS $$
    use Digest::MD5 qw(md5_hex);
    my $file = '/usr/share/dict/words';
    my $t = localtime;
    elog(NOTICE, "opening file $file at $t" );
    open my $fh, '<', $file # ooh, it's a file access!
        or elog(ERROR, "cannot open $file for reading: $!");
    my @words = <$fh>;
    close $fh;
    $t = localtime;
    elog(NOTICE, "closed file $file at $t");
    chomp(@words);
    my $row;
    my $sth = spi_query("SELECT * FROM generate_series(1,$_[0]) AS b(a)");
```

```
        while (defined ($row = spi_fetchrow($sth))) {
            return_next({
                the_num => $row->{a},
                the_text => md5_hex($words[rand @words])
            });
        }
        return;
    $$ LANGUAGE plperlu;

    SELECT * from lotsa_md5(500);
```

Normally, `spi_fetchrow` should be repeated until it returns `undef`, indicating that there are no more rows to read. The cursor returned by `spi_query` is automatically freed when `spi_fetchrow` returns `undef`. If you do not wish to read all the rows, instead call `spi_cursor_close` to free the cursor. Failure to do so will result in memory leaks.

```
spi_prepare(command, argument types)
spi_query_prepared(plan, arguments)
spi_exec_prepared(plan [, attributes], arguments)
spi_freeplan(plan)
```

`spi_prepare`, `spi_query_prepared`, `spi_exec_prepared`, and `spi_freeplan` implement the same functionality but for prepared queries. `spi_prepare` accepts a query string with numbered argument placeholders ($1, $2, etc) and a string list of argument types:

```
$plan = spi_prepare('SELECT * FROM test WHERE id > $1 AND name = $2',
                                                    'INTEGER', 'TEXT');
```

Once a query plan is prepared by a call to `spi_prepare`, the plan can be used instead of the string query, either in `spi_exec_prepared`, where the result is the same as returned by `spi_exec_query`, or in `spi_query_prepared` which returns a cursor exactly as `spi_query` does, which can be later passed to `spi_fetchrow`. The optional second parameter to `spi_exec_prepared` is a hash reference of attributes; the only attribute currently supported is `limit`, which sets the maximum number of rows returned from the query. Omitting `limit` or specifying it as zero results in no row limit.

The advantage of prepared queries is that is it possible to use one prepared plan for more than one query execution. After the plan is not needed anymore, it can be freed with `spi_freeplan`:

```
CREATE OR REPLACE FUNCTION init() RETURNS VOID AS $$
        $_SHARED{my_plan} = spi_prepare('SELECT (now() + $1)::date AS now',
                                        'INTERVAL');
$$ LANGUAGE plperl;

CREATE OR REPLACE FUNCTION add_time( INTERVAL ) RETURNS TEXT AS $$
        return spi_exec_prepared(
                $_SHARED{my_plan},
                $_[0]
        )->{rows}->[0]->{now};
$$ LANGUAGE plperl;

CREATE OR REPLACE FUNCTION done() RETURNS VOID AS $$
        spi_freeplan( $_SHARED{my_plan});
        undef $_SHARED{my_plan};
$$ LANGUAGE plperl;

SELECT init();
SELECT add_time('1 day'), add_time('2 days'), add_time('3 days');
SELECT done();

  add_time  |  add_time  |  add_time
```

```
------------+------------+------------
 2005-12-10 | 2005-12-11 | 2005-12-12
```

Note that the parameter subscript in `spi_prepare` is defined via $1, $2, $3, etc, so avoid declaring query strings in double quotes that might easily lead to hard-to-catch bugs.

Another example illustrates usage of an optional parameter in `spi_exec_prepared`:

```
CREATE TABLE hosts AS SELECT id, ('192.168.1.'||id)::inet AS address
                      FROM generate_series(1,3) AS id;

CREATE OR REPLACE FUNCTION init_hosts_query() RETURNS VOID AS $$
        $_SHARED{plan} = spi_prepare('SELECT * FROM hosts
                                      WHERE address << $1', 'inet');
$$ LANGUAGE plperl;

CREATE OR REPLACE FUNCTION query_hosts(inet) RETURNS SETOF hosts AS $$
        return spi_exec_prepared(
                $_SHARED{plan},
                {limit => 2},
                $_[0]
        )->{rows};
$$ LANGUAGE plperl;

CREATE OR REPLACE FUNCTION release_hosts_query() RETURNS VOID AS $$
        spi_freeplan($_SHARED{plan});
        undef $_SHARED{plan};
$$ LANGUAGE plperl;

SELECT init_hosts_query();
SELECT query_hosts('192.168.1.0/30');
SELECT release_hosts_query();

    query_hosts
-----------------
 (1,192.168.1.1)
 (2,192.168.1.2)
(2 rows)
```

`spi_commit()`
`spi_rollback()`

Commit or roll back the current transaction. This can only be called in a procedure or anonymous code block (`DO` command) called from the top level. (Note that it is not possible to run the SQL commands `COMMIT` or `ROLLBACK` via `spi_exec_query` or similar. It has to be done using these functions.) After a transaction is ended, a new transaction is automatically started, so there is no separate function for that.

Here is an example:

```
CREATE PROCEDURE transaction_test1()
LANGUAGE plperl
AS $$
foreach my $i (0..9) {
    spi_exec_query("INSERT INTO test1 (a) VALUES ($i)");
    if ($i % 2 == 0) {
        spi_commit();
    } else {
        spi_rollback();
    }
}
```

```
$$;

CALL transaction_test1();
```

47.3.2. Utility Functions in PL/Perl

`elog(level, msg)`

Emit a log or error message. Possible levels are `DEBUG`, `LOG`, `INFO`, `NOTICE`, `WARNING`, and `ERROR`. `ERROR` raises an error condition; if this is not trapped by the surrounding Perl code, the error propagates out to the calling query, causing the current transaction or subtransaction to be aborted. This is effectively the same as the Perl `die` command. The other levels only generate messages of different priority levels. Whether messages of a particular priority are reported to the client, written to the server log, or both is controlled by the log_min_messages and client_min_messages configuration variables. See Chapter 19 for more information.

`quote_literal(string)`

Return the given string suitably quoted to be used as a string literal in an SQL statement string. Embedded single-quotes and backslashes are properly doubled. Note that `quote_literal` returns undef on undef input; if the argument might be undef, `quote_nullable` is often more suitable.

`quote_nullable(string)`

Return the given string suitably quoted to be used as a string literal in an SQL statement string; or, if the argument is undef, return the unquoted string "NULL". Embedded single-quotes and backslashes are properly doubled.

`quote_ident(string)`

Return the given string suitably quoted to be used as an identifier in an SQL statement string. Quotes are added only if necessary (i.e., if the string contains non-identifier characters or would be case-folded). Embedded quotes are properly doubled.

`decode_bytea(string)`

Return the unescaped binary data represented by the contents of the given string, which should be `bytea` encoded.

`encode_bytea(string)`

Return the `bytea` encoded form of the binary data contents of the given string.

`encode_array_literal(array)`
`encode_array_literal(array, delimiter)`

Returns the contents of the referenced array as a string in array literal format (see Section 8.15.2). Returns the argument value unaltered if it's not a reference to an array. The delimiter used between elements of the array literal defaults to ", " if a delimiter is not specified or is undef.

`encode_typed_literal(value, typename)`

Converts a Perl variable to the value of the data type passed as a second argument and returns a string representation of this value. Correctly handles nested arrays and values of composite types.

`encode_array_constructor(array)`

Returns the contents of the referenced array as a string in array constructor format (see Section 4.2.12). Individual values are quoted using `quote_nullable`. Returns the argument value, quoted using `quote_nullable`, if it's not a reference to an array.

`looks_like_number(string)`

Returns a true value if the content of the given string looks like a number, according to Perl, returns false otherwise. Returns undef if the argument is undef. Leading and trailing space is ignored. `Inf` and `Infinity` are regarded as numbers.

`is_array_ref(`*argument*`)`

Returns a true value if the given argument may be treated as an array reference, that is, if ref of the argument is `ARRAY` or `PostgreSQL::InServer::ARRAY`. Returns false otherwise.

47.4. Global Values in PL/Perl

You can use the global hash `%_SHARED` to store data, including code references, between function calls for the lifetime of the current session.

Here is a simple example for shared data:

```
CREATE OR REPLACE FUNCTION set_var(name text, val text) RETURNS text AS $$
    if ($_SHARED{$_[0]} = $_[1]) {
        return 'ok';
    } else {
        return "cannot set shared variable $_[0] to $_[1]";
    }
$$ LANGUAGE plperl;

CREATE OR REPLACE FUNCTION get_var(name text) RETURNS text AS $$
    return $_SHARED{$_[0]};
$$ LANGUAGE plperl;

SELECT set_var('sample', 'Hello, PL/Perl!  How''s tricks?');
SELECT get_var('sample');
```

Here is a slightly more complicated example using a code reference:

```
CREATE OR REPLACE FUNCTION myfuncs() RETURNS void AS $$
    $_SHARED{myquote} = sub {
        my $arg = shift;
        $arg =~ s/(['\\])/\\$1/g;
        return "'$arg'";
    };
$$ LANGUAGE plperl;

SELECT myfuncs(); /* initializes the function */

/* Set up a function that uses the quote function */

CREATE OR REPLACE FUNCTION use_quote(TEXT) RETURNS text AS $$
    my $text_to_quote = shift;
    my $qfunc = $_SHARED{myquote};
    return &$qfunc($text_to_quote);
$$ LANGUAGE plperl;
```

(You could have replaced the above with the one-liner `return $_SHARED{myquote}->($_[0]);` at the expense of readability.)

For security reasons, PL/Perl executes functions called by any one SQL role in a separate Perl interpreter for that role. This prevents accidental or malicious interference by one user with the behavior of another user's PL/Perl functions. Each such interpreter has its own value of the `%_SHARED` variable and other global state. Thus, two PL/Perl functions will share the same value of `%_SHARED` if and only if they are executed by the same SQL role. In an application wherein a single session executes code under multiple SQL roles (via `SECURITY DEFINER` functions, use of `SET ROLE`, etc) you may need to take explicit steps to ensure that PL/Perl functions can share data via `%_SHARED`. To do that, make sure that functions that should communicate are owned by the same user, and mark them `SECURITY DEFINER`. You must of course take care that such functions can't be used to do anything unintended.

47.5. Trusted and Untrusted PL/Perl

Normally, PL/Perl is installed as a “trusted” programming language named `plperl`. In this setup, certain Perl operations are disabled to preserve security. In general, the operations that are restricted are those that interact with the environment. This includes file handle operations, `require`, and `use` (for external modules). There is no way to access internals of the database server process or to gain OS-level access with the permissions of the server process, as a C function can do. Thus, any unprivileged database user can be permitted to use this language.

> **Warning**
>
> Trusted PL/Perl relies on the Perl `Opcode` module to preserve security. Perl *documents* that the module is not effective for the trusted PL/Perl use case. If your security needs are incompatible with the uncertainty in that warning, consider executing `REVOKE USAGE ON LANGUAGE plperl FROM PUBLIC`.

Here is an example of a function that will not work because file system operations are not allowed for security reasons:

```
CREATE FUNCTION badfunc() RETURNS integer AS $$
    my $tmpfile = "/tmp/badfile";
    open my $fh, '>', $tmpfile
        or elog(ERROR, qq{could not open the file "$tmpfile": $!});
    print $fh "Testing writing to a file\n";
    close $fh or elog(ERROR, qq{could not close the file "$tmpfile": $!});
    return 1;
$$ LANGUAGE plperl;
```

The creation of this function will fail as its use of a forbidden operation will be caught by the validator.

Sometimes it is desirable to write Perl functions that are not restricted. For example, one might want a Perl function that sends mail. To handle these cases, PL/Perl can also be installed as an “untrusted” language (usually called PL/PerlU). In this case the full Perl language is available. When installing the language, the language name `plperlu` will select the untrusted PL/Perl variant.

The writer of a PL/PerlU function must take care that the function cannot be used to do anything unwanted, since it will be able to do anything that could be done by a user logged in as the database administrator. Note that the database system allows only database superusers to create functions in untrusted languages.

If the above function was created by a superuser using the language `plperlu`, execution would succeed.

In the same way, anonymous code blocks written in Perl can use restricted operations if the language is specified as `plperlu` rather than `plperl`, but the caller must be a superuser.

> **Note**
>
> While PL/Perl functions run in a separate Perl interpreter for each SQL role, all PL/PerlU functions executed in a given session run in a single Perl interpreter (which is not any of the ones used for PL/Perl functions). This allows PL/PerlU functions to share data freely, but no communication can occur between PL/Perl and PL/PerlU functions.

> **Note**
>
> Perl cannot support multiple interpreters within one process unless it was built with the appropriate flags, namely either `usemultiplicity` or `useithreads`. (`usemultiplicity` is preferred unless you actually need to use threads. For more details, see the perlembed man page.) If PL/Perl is used with a copy of Perl that was not built this way, then it is only possible to have one Perl

interpreter per session, and so any one session can only execute either PL/PerlU functions, or PL/Perl functions that are all called by the same SQL role.

47.6. PL/Perl Triggers

PL/Perl can be used to write trigger functions. In a trigger function, the hash reference `$_TD` contains information about the current trigger event. `$_TD` is a global variable, which gets a separate local value for each invocation of the trigger. The fields of the `$_TD` hash reference are:

`$_TD->{new}{foo}`

`NEW` value of column `foo`

`$_TD->{old}{foo}`

`OLD` value of column `foo`

`$_TD->{name}`

Name of the trigger being called

`$_TD->{event}`

Trigger event: `INSERT`, `UPDATE`, `DELETE`, `TRUNCATE`, or `UNKNOWN`

`$_TD->{when}`

When the trigger was called: `BEFORE`, `AFTER`, `INSTEAD OF`, or `UNKNOWN`

`$_TD->{level}`

The trigger level: `ROW`, `STATEMENT`, or `UNKNOWN`

`$_TD->{relid}`

OID of the table on which the trigger fired

`$_TD->{table_name}`

Name of the table on which the trigger fired

`$_TD->{relname}`

Name of the table on which the trigger fired. This has been deprecated, and could be removed in a future release. Please use $_TD->{table_name} instead.

`$_TD->{table_schema}`

Name of the schema in which the table on which the trigger fired, is

`$_TD->{argc}`

Number of arguments of the trigger function

`@{$_TD->{args}}`

Arguments of the trigger function. Does not exist if `$_TD->{argc}` is 0.

Row-level triggers can return one of the following:

`return;`

Execute the operation

`"SKIP"`

Don't execute the operation

`"MODIFY"`

Indicates that the `NEW` row was modified by the trigger function

Here is an example of a trigger function, illustrating some of the above:

```
CREATE TABLE test (
    i int,
    v varchar
);

CREATE OR REPLACE FUNCTION valid_id() RETURNS trigger AS $$
    if (($_TD->{new}{i} >= 100) || ($_TD->{new}{i} <= 0)) {
        return "SKIP";    # skip INSERT/UPDATE command
    } elsif ($_TD->{new}{v} ne "immortal") {
        $_TD->{new}{v} .= "(modified by trigger)";
        return "MODIFY";  # modify row and execute INSERT/UPDATE command
    } else {
        return;           # execute INSERT/UPDATE command
    }
$$ LANGUAGE plperl;

CREATE TRIGGER test_valid_id_trig
    BEFORE INSERT OR UPDATE ON test
    FOR EACH ROW EXECUTE FUNCTION valid_id();
```

47.7. PL/Perl Event Triggers

PL/Perl can be used to write event trigger functions. In an event trigger function, the hash reference `$_TD` contains information about the current trigger event. `$_TD` is a global variable, which gets a separate local value for each invocation of the trigger. The fields of the `$_TD` hash reference are:

`$_TD->{event}`

The name of the event the trigger is fired for.

`$_TD->{tag}`

The command tag for which the trigger is fired.

The return value of the trigger function is ignored.

Here is an example of an event trigger function, illustrating some of the above:

```
CREATE OR REPLACE FUNCTION perlsnitch() RETURNS event_trigger AS $$
  elog(NOTICE, "perlsnitch: " . $_TD->{event} . " " . $_TD->{tag} . " ");
$$ LANGUAGE plperl;

CREATE EVENT TRIGGER perl_a_snitch
    ON ddl_command_start
    EXECUTE FUNCTION perlsnitch();
```

47.8. PL/Perl Under the Hood

47.8.1. Configuration

This section lists configuration parameters that affect PL/Perl.

`plperl.on_init` (`string`)

Specifies Perl code to be executed when a Perl interpreter is first initialized, before it is specialized for use by `plperl` or `plperlu`. The SPI functions are not available when this code is executed. If the code fails with an error it will abort the initialization of the interpreter and propagate out to the calling query, causing the current transaction or subtransaction to be aborted.

The Perl code is limited to a single string. Longer code can be placed into a module and loaded by the `on_init` string. Examples:

```
plperl.on_init = 'require "plperlinit.pl"'
plperl.on_init = 'use lib "/my/app"; use MyApp::PgInit;'
```

Any modules loaded by `plperl.on_init`, either directly or indirectly, will be available for use by `plperl`. This may create a security risk. To see what modules have been loaded you can use:

```
DO 'elog(WARNING, join ", ", sort keys %INC)' LANGUAGE plperl;
```

Initialization will happen in the postmaster if the `plperl` library is included in shared_preload_libraries, in which case extra consideration should be given to the risk of destabilizing the postmaster. The principal reason for making use of this feature is that Perl modules loaded by `plperl.on_init` need be loaded only at postmaster start, and will be instantly available without loading overhead in individual database sessions. However, keep in mind that the overhead is avoided only for the first Perl interpreter used by a database session — either PL/PerlU, or PL/Perl for the first SQL role that calls a PL/Perl function. Any additional Perl interpreters created in a database session will have to execute `plperl.on_init` afresh. Also, on Windows there will be no savings whatsoever from preloading, since the Perl interpreter created in the postmaster process does not propagate to child processes.

This parameter can only be set in the `postgresql.conf` file or on the server command line.

`plperl.on_plperl_init` (`string`)
`plperl.on_plperlu_init` (`string`)

These parameters specify Perl code to be executed when a Perl interpreter is specialized for `plperl` or `plperlu` respectively. This will happen when a PL/Perl or PL/PerlU function is first executed in a database session, or when an additional interpreter has to be created because the other language is called or a PL/Perl function is called by a new SQL role. This follows any initialization done by `plperl.on_init`. The SPI functions are not available when this code is executed. The Perl code in `plperl.on_plperl_init` is executed after “locking down” the interpreter, and thus it can only perform trusted operations.

If the code fails with an error it will abort the initialization and propagate out to the calling query, causing the current transaction or subtransaction to be aborted. Any actions already done within Perl won't be undone; however, that interpreter won't be used again. If the language is used again the initialization will be attempted again within a fresh Perl interpreter.

Only superusers can change these settings. Although these settings can be changed within a session, such changes will not affect Perl interpreters that have already been used to execute functions.

`plperl.use_strict` (`boolean`)

When set true subsequent compilations of PL/Perl functions will have the `strict` pragma enabled. This parameter does not affect functions already compiled in the current session.

47.8.2. Limitations and Missing Features

The following features are currently missing from PL/Perl, but they would make welcome contributions.

- PL/Perl functions cannot call each other directly.
- SPI is not yet fully implemented.

- If you are fetching very large data sets using `spi_exec_query`, you should be aware that these will all go into memory. You can avoid this by using `spi_query`/`spi_fetchrow` as illustrated earlier.

  A similar problem occurs if a set-returning function passes a large set of rows back to Postgres Pro via `return`. You can avoid this problem too by instead using `return_next` for each row returned, as shown previously.

- When a session ends normally, not due to a fatal error, any `END` blocks that have been defined are executed. Currently no other actions are performed. Specifically, file handles are not automatically flushed and objects are not automatically destroyed.

Chapter 48. PL/Python — Python Procedural Language

The PL/Python procedural language allows Postgres Pro functions and procedures to be written in the *Python language*.

To install PL/Python in a particular database, use `CREATE EXTENSION plpythonu` (but see also Section 48.1).

> **Tip**
>
> If a language is installed into `template1`, all subsequently created databases will have the language installed automatically.

PL/Python is only available as an "untrusted" language, meaning it does not offer any way of restricting what users can do in it and is therefore named `plpythonu`. A trusted variant `plpython` might become available in the future if a secure execution mechanism is developed in Python. The writer of a function in untrusted PL/Python must take care that the function cannot be used to do anything unwanted, since it will be able to do anything that could be done by a user logged in as the database administrator. Only superusers can create functions in untrusted languages such as `plpythonu`.

> **Note**
>
> Users of source packages must specially enable the build of PL/Python during the installation process. (Refer to the installation instructions for more information.) Users of binary packages might find PL/Python in a separate subpackage.

48.1. Python 2 vs. Python 3

PL/Python supports both the Python 2 and Python 3 language variants. (The Postgres Pro installation instructions might contain more precise information about the exact supported minor versions of Python.) Because the Python 2 and Python 3 language variants are incompatible in some important aspects, the following naming and transitioning scheme is used by PL/Python to avoid mixing them:

- The PostgreSQL language named `plpython2u` implements PL/Python based on the Python 2 language variant.
- The PostgreSQL language named `plpython3u` implements PL/Python based on the Python 3 language variant.
- The language named `plpythonu` implements PL/Python based on the default Python language variant, which is currently Python 2. (This default is independent of what any local Python installations might consider to be their "default", for example, what `/usr/bin/python` might be.) The default will probably be changed to Python 3 in a distant future release of Postgres Pro, depending on the progress of the migration to Python 3 in the Python community.

This scheme is analogous to the recommendations in *PEP 394* regarding the naming and transitioning of the `python` command.

It depends on the build configuration or the installed packages whether PL/Python for Python 2 or Python 3 or both are available.

> **Tip**
>
> The built variant depends on which Python version was found during the installation or which version was explicitly set using the `PYTHON` environment variable. To make both variants of PL/Python available in one installation, the source tree has to be configured and built twice.

This results in the following usage and migration strategy:

- Existing users and users who are currently not interested in Python 3 use the language name `plpythonu` and don't have to change anything for the foreseeable future. It is recommended to gradually “future-proof” the code via migration to Python 2.6/2.7 to simplify the eventual migration to Python 3.

  In practice, many PL/Python functions will migrate to Python 3 with few or no changes.
- Users who know that they have heavily Python 2 dependent code and don't plan to ever change it can make use of the `plpython2u` language name. This will continue to work into the very distant future, until Python 2 support might be completely dropped by Postgres Pro.
- Users who want to dive into Python 3 can use the `plpython3u` language name, which will keep working forever by today's standards. In the distant future, when Python 3 might become the default, they might like to remove the “3” for aesthetic reasons.
- Daredevils, who want to build a Python-3-only operating system environment, can change the contents of `plpythonu`'s extension control and script files to make `plpythonu` be equivalent to `plpython3u`, keeping in mind that this would make their installation incompatible with most of the rest of the world.

See also the document *What's New In Python 3.0* for more information about porting to Python 3.

It is not allowed to use PL/Python based on Python 2 and PL/Python based on Python 3 in the same session, because the symbols in the dynamic modules would clash, which could result in crashes of the Postgres Pro server process. There is a check that prevents mixing Python major versions in a session, which will abort the session if a mismatch is detected. It is possible, however, to use both PL/Python variants in the same database, from separate sessions.

48.2. PL/Python Functions

Functions in PL/Python are declared via the standard CREATE FUNCTION syntax:

```
CREATE FUNCTION funcname (argument-list)
  RETURNS return-type
AS $$
  # PL/Python function body
$$ LANGUAGE plpythonu;
```

The body of a function is simply a Python script. When the function is called, its arguments are passed as elements of the list `args`; named arguments are also passed as ordinary variables to the Python script. Use of named arguments is usually more readable. The result is returned from the Python code in the usual way, with `return` or `yield` (in case of a result-set statement). If you do not provide a return value, Python returns the default `None`. PL/Python translates Python's `None` into the SQL null value. In a procedure, the result from the Python code must be `None` (typically achieved by ending the procedure without a `return` statement or by using a `return` statement without argument); otherwise, an error will be raised.

For example, a function to return the greater of two integers can be defined as:

```
CREATE FUNCTION pymax (a integer, b integer)
  RETURNS integer
AS $$
  if a > b:
```

```
    return a
  return b
$$ LANGUAGE plpythonu;
```

The Python code that is given as the body of the function definition is transformed into a Python function. For example, the above results in:

```
def __plpython_procedure_pymax_23456():
  if a > b:
    return a
  return b
```

assuming that 23456 is the OID assigned to the function by Postgres Pro.

The arguments are set as global variables. Because of the scoping rules of Python, this has the subtle consequence that an argument variable cannot be reassigned inside the function to the value of an expression that involves the variable name itself, unless the variable is redeclared as global in the block. For example, the following won't work:

```
CREATE FUNCTION pystrip(x text)
  RETURNS text
AS $$
  x = x.strip()  # error
  return x
$$ LANGUAGE plpythonu;
```

because assigning to `x` makes `x` a local variable for the entire block, and so the `x` on the right-hand side of the assignment refers to a not-yet-assigned local variable `x`, not the PL/Python function parameter. Using the `global` statement, this can be made to work:

```
CREATE FUNCTION pystrip(x text)
  RETURNS text
AS $$
  global x
  x = x.strip()  # ok now
  return x
$$ LANGUAGE plpythonu;
```

But it is advisable not to rely on this implementation detail of PL/Python. It is better to treat the function parameters as read-only.

48.3. Data Values

Generally speaking, the aim of PL/Python is to provide a “natural” mapping between the PostgreSQL and the Python worlds. This informs the data mapping rules described below.

48.3.1. Data Type Mapping

When a PL/Python function is called, its arguments are converted from their PostgreSQL data type to a corresponding Python type:

- PostgreSQL `boolean` is converted to Python `bool`.
- PostgreSQL `smallint` and `int` are converted to Python `int`. PostgreSQL `bigint` and `oid` are converted to `long` in Python 2 and to `int` in Python 3.
- PostgreSQL `real` and `double` are converted to Python `float`.
- PostgreSQL `numeric` is converted to Python `Decimal`. This type is imported from the `cdecimal` package if that is available. Otherwise, `decimal.Decimal` from the standard library will be used. `cdecimal` is significantly faster than `decimal`. In Python 3.3 and up, however, `cdecimal` has been integrated into the standard library under the name `decimal`, so there is no longer any difference.
- PostgreSQL `bytea` is converted to Python `str` in Python 2 and to `bytes` in Python 3. In Python 2, the string should be treated as a byte sequence without any character encoding.

- All other data types, including the PostgreSQL character string types, are converted to a Python `str`. In Python 2, this string will be in the Postgres Pro server encoding; in Python 3, it will be a Unicode string like all strings.
- For nonscalar data types, see below.

When a PL/Python function returns, its return value is converted to the function's declared PostgreSQL return data type as follows:

- When the PostgreSQL return type is `boolean`, the return value will be evaluated for truth according to the *Python* rules. That is, 0 and empty string are false, but notably `'f'` is true.
- When the PostgreSQL return type is `bytea`, the return value will be converted to a string (Python 2) or bytes (Python 3) using the respective Python built-ins, with the result being converted to `bytea`.
- For all other PostgreSQL return types, the return value is converted to a string using the Python built-in `str`, and the result is passed to the input function of the PostgreSQL data type. (If the Python value is a `float`, it is converted using the `repr` built-in instead of `str`, to avoid loss of precision.)

  Strings in Python 2 are required to be in the Postgres Pro server encoding when they are passed to Postgres Pro. Strings that are not valid in the current server encoding will raise an error, but not all encoding mismatches can be detected, so garbage data can still result when this is not done correctly. Unicode strings are converted to the correct encoding automatically, so it can be safer and more convenient to use those. In Python 3, all strings are Unicode strings.
- For nonscalar data types, see below.

Note that logical mismatches between the declared PostgreSQL return type and the Python data type of the actual return object are not flagged; the value will be converted in any case.

48.3.2. Null, None

If an SQL null value is passed to a function, the argument value will appear as `None` in Python. For example, the function definition of `pymax` shown in Section 48.2 will return the wrong answer for null inputs. We could add `STRICT` to the function definition to make Postgres Pro do something more reasonable: if a null value is passed, the function will not be called at all, but will just return a null result automatically. Alternatively, we could check for null inputs in the function body:

```
CREATE FUNCTION pymax (a integer, b integer)
  RETURNS integer
AS $$
  if (a is None) or (b is None):
    return None
  if a > b:
    return a
  return b
$$ LANGUAGE plpythonu;
```

As shown above, to return an SQL null value from a PL/Python function, return the value `None`. This can be done whether the function is strict or not.

48.3.3. Arrays, Lists

SQL array values are passed into PL/Python as a Python list. To return an SQL array value out of a PL/Python function, return a Python list:

```
CREATE FUNCTION return_arr()
  RETURNS int[]
AS $$
return [1, 2, 3, 4, 5]
$$ LANGUAGE plpythonu;
```

```
SELECT return_arr();
 return_arr
-------------
 {1,2,3,4,5}
(1 row)
```

Multidimensional arrays are passed into PL/Python as nested Python lists. A 2-dimensional array is a list of lists, for example. When returning a multi-dimensional SQL array out of a PL/Python function, the inner lists at each level must all be of the same size. For example:

```
CREATE FUNCTION test_type_conversion_array_int4(x int4[]) RETURNS int4[] AS $$
plpy.info(x, type(x))
return x
$$ LANGUAGE plpythonu;

SELECT * FROM test_type_conversion_array_int4(ARRAY[[1,2,3],[4,5,6]]);
INFO:  ([[1, 2, 3], [4, 5, 6]], <type 'list'>)
 test_type_conversion_array_int4
---------------------------------
 {{1,2,3},{4,5,6}}
(1 row)
```

Other Python sequences, like tuples, are also accepted for backwards-compatibility with PostgreSQL versions 9.6 and below, when multi-dimensional arrays were not supported. However, they are always treated as one-dimensional arrays, because they are ambiguous with composite types. For the same reason, when a composite type is used in a multi-dimensional array, it must be represented by a tuple, rather than a list.

Note that in Python, strings are sequences, which can have undesirable effects that might be familiar to Python programmers:

```
CREATE FUNCTION return_str_arr()
  RETURNS varchar[]
AS $$
return "hello"
$$ LANGUAGE plpythonu;

SELECT return_str_arr();
 return_str_arr
----------------
 {h,e,l,l,o}
(1 row)
```

48.3.4. Composite Types

Composite-type arguments are passed to the function as Python mappings. The element names of the mapping are the attribute names of the composite type. If an attribute in the passed row has the null value, it has the value `None` in the mapping. Here is an example:

```
CREATE TABLE employee (
  name text,
  salary integer,
  age integer
);

CREATE FUNCTION overpaid (e employee)
  RETURNS boolean
AS $$
  if e["salary"] > 200000:
    return True
  if (e["age"] < 30) and (e["salary"] > 100000):
```

```
    return True
  return False
$$ LANGUAGE plpythonu;
```

There are multiple ways to return row or composite types from a Python function. The following examples assume we have:

```
CREATE TYPE named_value AS (
  name   text,
  value  integer
);
```

A composite result can be returned as a:

Sequence type (a tuple or list, but not a set because it is not indexable)

Returned sequence objects must have the same number of items as the composite result type has fields. The item with index 0 is assigned to the first field of the composite type, 1 to the second and so on. For example:

```
CREATE FUNCTION make_pair (name text, value integer)
  RETURNS named_value
AS $$
  return ( name, value )
  # or alternatively, as list: return [ name, value ]
$$ LANGUAGE plpythonu;
```

To return an SQL null for any column, insert `None` at the corresponding position.

When an array of composite types is returned, it cannot be returned as a list, because it is ambiguous whether the Python list represents a composite type, or another array dimension.

Mapping (dictionary)

The value for each result type column is retrieved from the mapping with the column name as key. Example:

```
CREATE FUNCTION make_pair (name text, value integer)
  RETURNS named_value
AS $$
  return { "name": name, "value": value }
$$ LANGUAGE plpythonu;
```

Any extra dictionary key/value pairs are ignored. Missing keys are treated as errors. To return an SQL null value for any column, insert `None` with the corresponding column name as the key.

Object (any object providing method `__getattr__`)

This works the same as a mapping. Example:

```
CREATE FUNCTION make_pair (name text, value integer)
  RETURNS named_value
AS $$
  class named_value:
    def __init__ (self, n, v):
      self.name = n
      self.value = v
  return named_value(name, value)

  # or simply
  class nv: pass
  nv.name = name
  nv.value = value
  return nv
```

```
$$ LANGUAGE plpythonu;
```

Functions with `OUT` parameters are also supported. For example:

```
CREATE FUNCTION multiout_simple(OUT i integer, OUT j integer) AS $$
return (1, 2)
$$ LANGUAGE plpythonu;

SELECT * FROM multiout_simple();
```

Output parameters of procedures are passed back the same way. For example:

```
CREATE PROCEDURE python_triple(INOUT a integer, INOUT b integer) AS $$
return (a * 3, b * 3)
$$ LANGUAGE plpythonu;

CALL python_triple(5, 10);
```

48.3.5. Set-Returning Functions

A PL/Python function can also return sets of scalar or composite types. There are several ways to achieve this because the returned object is internally turned into an iterator. The following examples assume we have composite type:

```
CREATE TYPE greeting AS (
  how text,
  who text
);
```

A set result can be returned from a:

Sequence type (tuple, list, set)

```
CREATE FUNCTION greet (how text)
  RETURNS SETOF greeting
AS $$
  # return tuple containing lists as composite types
  # all other combinations work also
  return ( [ how, "World" ], [ how, "PostgreSQL" ], [ how, "PL/Python" ] )
$$ LANGUAGE plpythonu;
```

Iterator (any object providing `__iter__` and `next` methods)

```
CREATE FUNCTION greet (how text)
  RETURNS SETOF greeting
AS $$
  class producer:
    def __init__ (self, how, who):
      self.how = how
      self.who = who
      self.ndx = -1

    def __iter__ (self):
      return self

    def next (self):
      self.ndx += 1
      if self.ndx == len(self.who):
        raise StopIteration
      return ( self.how, self.who[self.ndx] )

  return producer(how, [ "World", "PostgreSQL", "PL/Python" ])
```

```
$$ LANGUAGE plpythonu;
```

Generator (`yield`)

```
CREATE FUNCTION greet (how text)
  RETURNS SETOF greeting
AS $$
  for who in [ "World", "PostgreSQL", "PL/Python" ]:
    yield ( how, who )
$$ LANGUAGE plpythonu;
```

Set-returning functions with `OUT` parameters (using `RETURNS SETOF record`) are also supported. For example:

```
CREATE FUNCTION multiout_simple_setof(n integer, OUT integer, OUT integer) RETURNS
 SETOF record AS $$
return [(1, 2)] * n
$$ LANGUAGE plpythonu;

SELECT * FROM multiout_simple_setof(3);
```

48.4. Sharing Data

The global dictionary `SD` is available to store private data between repeated calls to the same function. The global dictionary `GD` is public data, that is available to all Python functions within a session; use with care.

Each function gets its own execution environment in the Python interpreter, so that global data and function arguments from `myfunc` are not available to `myfunc2`. The exception is the data in the `GD` dictionary, as mentioned above.

48.5. Anonymous Code Blocks

PL/Python also supports anonymous code blocks called with the DO statement:

```
DO $$
    # PL/Python code
$$ LANGUAGE plpythonu;
```

An anonymous code block receives no arguments, and whatever value it might return is discarded. Otherwise it behaves just like a function.

48.6. Trigger Functions

When a function is used as a trigger, the dictionary `TD` contains trigger-related values:

`TD["event"]`

contains the event as a string: `INSERT`, `UPDATE`, `DELETE`, or `TRUNCATE`.

`TD["when"]`

contains one of `BEFORE`, `AFTER`, or `INSTEAD OF`.

`TD["level"]`

contains `ROW` or `STATEMENT`.

`TD["new"]`
`TD["old"]`

For a row-level trigger, one or both of these fields contain the respective trigger rows, depending on the trigger event.

`TD["name"]`

contains the trigger name.

`TD["table_name"]`

contains the name of the table on which the trigger occurred.

`TD["table_schema"]`

contains the schema of the table on which the trigger occurred.

`TD["relid"]`

contains the OID of the table on which the trigger occurred.

`TD["args"]`

If the `CREATE TRIGGER` command included arguments, they are available in `TD["args"][0]` to `TD["args"][`*n*`-1]`.

If `TD["when"]` is `BEFORE` or `INSTEAD OF` and `TD["level"]` is `ROW`, you can return `None` or `"OK"` from the Python function to indicate the row is unmodified, `"SKIP"` to abort the event, or if `TD["event"]` is `INSERT` or `UPDATE` you can return `"MODIFY"` to indicate you've modified the new row. Otherwise the return value is ignored.

48.7. Database Access

The PL/Python language module automatically imports a Python module called `plpy`. The functions and constants in this module are available to you in the Python code as `plpy.`*`foo`*.

48.7.1. Database Access Functions

The `plpy` module provides several functions to execute database commands:

`plpy.execute(`*`query`* `[,` *`limit`*`])`

Calling `plpy.execute` with a query string and an optional row limit argument causes that query to be run and the result to be returned in a result object.

If *`limit`* is specified and is greater than zero, then `plpy.execute` retrieves at most *`limit`* rows, much as if the query included a `LIMIT` clause. Omitting *`limit`* or specifying it as zero results in no row limit.

The result object emulates a list or dictionary object. The result object can be accessed by row number and column name. For example:

```
rv = plpy.execute("SELECT * FROM my_table", 5)
```

returns up to 5 rows from `my_table`. If `my_table` has a column `my_column`, it would be accessed as:

```
foo = rv[i]["my_column"]
```

The number of rows returned can be obtained using the built-in `len` function.

The result object has these additional methods:

`nrows()`

Returns the number of rows processed by the command. Note that this is not necessarily the same as the number of rows returned. For example, an `UPDATE` command will set this value but won't return any rows (unless `RETURNING` is used).

`status()`

The `SPI_execute()` return value.

`colnames()`
`coltypes()`
`coltypmods()`

Return a list of column names, list of column type OIDs, and list of type-specific type modifiers for the columns, respectively.

These methods raise an exception when called on a result object from a command that did not produce a result set, e.g., `UPDATE` without `RETURNING`, or `DROP TABLE`. But it is OK to use these methods on a result set containing zero rows.

`__str__()`

The standard `__str__` method is defined so that it is possible for example to debug query execution results using `plpy.debug(rv)`.

The result object can be modified.

Note that calling `plpy.execute` will cause the entire result set to be read into memory. Only use that function when you are sure that the result set will be relatively small. If you don't want to risk excessive memory usage when fetching large results, use `plpy.cursor` rather than `plpy.execute`.

`plpy.prepare(`*query* `[, `*argtypes*`])`
`plpy.execute(`*plan* `[, `*arguments* `[, `*limit*`]])`

`plpy.prepare` prepares the execution plan for a query. It is called with a query string and a list of parameter types, if you have parameter references in the query. For example:

```
plan = plpy.prepare("SELECT last_name FROM my_users WHERE first_name = $1",
 ["text"])
```

`text` is the type of the variable you will be passing for `$1`. The second argument is optional if you don't want to pass any parameters to the query.

After preparing a statement, you use a variant of the function `plpy.execute` to run it:

```
rv = plpy.execute(plan, ["name"], 5)
```

Pass the plan as the first argument (instead of the query string), and a list of values to substitute into the query as the second argument. The second argument is optional if the query does not expect any parameters. The third argument is the optional row limit as before.

Alternatively, you can call the `execute` method on the plan object:

```
rv = plan.execute(["name"], 5)
```

Query parameters and result row fields are converted between PostgreSQL and Python data types as described in Section 48.3.

When you prepare a plan using the PL/Python module it is automatically saved. Read the SPI documentation (Chapter 49) for a description of what this means. In order to make effective use of this across function calls one needs to use one of the persistent storage dictionaries `SD` or `GD` (see Section 48.4). For example:

```
CREATE FUNCTION usesavedplan() RETURNS trigger AS $$
    if "plan" in SD:
        plan = SD["plan"]
    else:
        plan = plpy.prepare("SELECT 1")
        SD["plan"] = plan
    # rest of function
$$ LANGUAGE plpythonu;
```

```
plpy.cursor(query)
plpy.cursor(plan [, arguments])
```

The `plpy.cursor` function accepts the same arguments as `plpy.execute` (except for the row limit) and returns a cursor object, which allows you to process large result sets in smaller chunks. As with `plpy.execute`, either a query string or a plan object along with a list of arguments can be used, or the `cursor` function can be called as a method of the plan object.

The cursor object provides a `fetch` method that accepts an integer parameter and returns a result object. Each time you call `fetch`, the returned object will contain the next batch of rows, never larger than the parameter value. Once all rows are exhausted, `fetch` starts returning an empty result object. Cursor objects also provide an *iterator interface*, yielding one row at a time until all rows are exhausted. Data fetched that way is not returned as result objects, but rather as dictionaries, each dictionary corresponding to a single result row.

An example of two ways of processing data from a large table is:

```
CREATE FUNCTION count_odd_iterator() RETURNS integer AS $$
odd = 0
for row in plpy.cursor("select num from largetable"):
    if row['num'] % 2:
         odd += 1
return odd
$$ LANGUAGE plpythonu;

CREATE FUNCTION count_odd_fetch(batch_size integer) RETURNS integer AS $$
odd = 0
cursor = plpy.cursor("select num from largetable")
while True:
    rows = cursor.fetch(batch_size)
    if not rows:
        break
    for row in rows:
        if row['num'] % 2:
            odd += 1
return odd
$$ LANGUAGE plpythonu;

CREATE FUNCTION count_odd_prepared() RETURNS integer AS $$
odd = 0
plan = plpy.prepare("select num from largetable where num % $1 <> 0", ["integer"])
rows = list(plpy.cursor(plan, [2]))  # or: = list(plan.cursor([2]))

return len(rows)
$$ LANGUAGE plpythonu;
```

Cursors are automatically disposed of. But if you want to explicitly release all resources held by a cursor, use the `close` method. Once closed, a cursor cannot be fetched from anymore.

> **Tip**
>
> Do not confuse objects created by `plpy.cursor` with DB-API cursors as defined by the *Python Database API specification*. They don't have anything in common except for the name.

48.7.2. Trapping Errors

Functions accessing the database might encounter errors, which will cause them to abort and raise an exception. Both `plpy.execute` and `plpy.prepare` can raise an instance of a subclass of `plpy.SPIError`,

which by default will terminate the function. This error can be handled just like any other Python exception, by using the `try/except` construct. For example:

```
CREATE FUNCTION try_adding_joe() RETURNS text AS $$
    try:
        plpy.execute("INSERT INTO users(username) VALUES ('joe')")
    except plpy.SPIError:
        return "something went wrong"
    else:
        return "Joe added"
$$ LANGUAGE plpythonu;
```

The actual class of the exception being raised corresponds to the specific condition that caused the error. Refer to Table A.1 for a list of possible conditions. The module `plpy.spiexceptions` defines an exception class for each Postgres Pro condition, deriving their names from the condition name. For instance, `division_by_zero` becomes `DivisionByZero`, `unique_violation` becomes `UniqueViolation`, `fdw_error` becomes `FdwError`, and so on. Each of these exception classes inherits from `SPIError`. This separation makes it easier to handle specific errors, for instance:

```
CREATE FUNCTION insert_fraction(numerator int, denominator int) RETURNS text AS $$
from plpy import spiexceptions
try:
    plan = plpy.prepare("INSERT INTO fractions (frac) VALUES ($1 / $2)", ["int",
 "int"])
    plpy.execute(plan, [numerator, denominator])
except spiexceptions.DivisionByZero:
    return "denominator cannot equal zero"
except spiexceptions.UniqueViolation:
    return "already have that fraction"
except plpy.SPIError as e:
    return "other error, SQLSTATE %s" % e.sqlstate
else:
    return "fraction inserted"
$$ LANGUAGE plpythonu;
```

Note that because all exceptions from the `plpy.spiexceptions` module inherit from `SPIError`, an `except` clause handling it will catch any database access error.

As an alternative way of handling different error conditions, you can catch the `SPIError` exception and determine the specific error condition inside the `except` block by looking at the `sqlstate` attribute of the exception object. This attribute is a string value containing the “SQLSTATE” error code. This approach provides approximately the same functionality

48.8. Explicit Subtransactions

Recovering from errors caused by database access as described in Section 48.7.2 can lead to an undesirable situation where some operations succeed before one of them fails, and after recovering from that error the data is left in an inconsistent state. PL/Python offers a solution to this problem in the form of explicit subtransactions.

48.8.1. Subtransaction Context Managers

Consider a function that implements a transfer between two accounts:

```
CREATE FUNCTION transfer_funds() RETURNS void AS $$
try:
    plpy.execute("UPDATE accounts SET balance = balance - 100 WHERE account_name =
 'joe'")
    plpy.execute("UPDATE accounts SET balance = balance + 100 WHERE account_name =
 'mary'")
except plpy.SPIError as e:
```

```
    result = "error transferring funds: %s" % e.args
else:
    result = "funds transferred correctly"
plan = plpy.prepare("INSERT INTO operations (result) VALUES ($1)", ["text"])
plpy.execute(plan, [result])
$$ LANGUAGE plpythonu;
```

If the second `UPDATE` statement results in an exception being raised, this function will report the error, but the result of the first `UPDATE` will nevertheless be committed. In other words, the funds will be withdrawn from Joe's account, but will not be transferred to Mary's account.

To avoid such issues, you can wrap your `plpy.execute` calls in an explicit subtransaction. The `plpy` module provides a helper object to manage explicit subtransactions that gets created with the `plpy.subtransaction()` function. Objects created by this function implement the *context manager interface*. Using explicit subtransactions we can rewrite our function as:

```
CREATE FUNCTION transfer_funds2() RETURNS void AS $$
try:
    with plpy.subtransaction():
        plpy.execute("UPDATE accounts SET balance = balance - 100 WHERE account_name =
 'joe'")
        plpy.execute("UPDATE accounts SET balance = balance + 100 WHERE account_name =
 'mary'")
except plpy.SPIError as e:
    result = "error transferring funds: %s" % e.args
else:
    result = "funds transferred correctly"
plan = plpy.prepare("INSERT INTO operations (result) VALUES ($1)", ["text"])
plpy.execute(plan, [result])
$$ LANGUAGE plpythonu;
```

Note that the use of `try`/`except` is still required. Otherwise the exception would propagate to the top of the Python stack and would cause the whole function to abort with a Postgres Pro error, so that the `operations` table would not have any row inserted into it. The subtransaction context manager does not trap errors, it only assures that all database operations executed inside its scope will be atomically committed or rolled back. A rollback of the subtransaction block occurs on any kind of exception exit, not only ones caused by errors originating from database access. A regular Python exception raised inside an explicit subtransaction block would also cause the subtransaction to be rolled back.

48.8.2. Older Python Versions

Context managers syntax using the `with` keyword is available by default in Python 2.6. For compatibility with older Python versions, you can call the subtransaction manager's `__enter__` and `__exit__` functions using the `enter` and `exit` convenience aliases. The example function that transfers funds could be written as:

```
CREATE FUNCTION transfer_funds_old() RETURNS void AS $$
try:
    subxact = plpy.subtransaction()
    subxact.enter()
    try:
        plpy.execute("UPDATE accounts SET balance = balance - 100 WHERE account_name =
 'joe'")
        plpy.execute("UPDATE accounts SET balance = balance + 100 WHERE account_name =
 'mary'")
    except:
        import sys
        subxact.exit(*sys.exc_info())
        raise
    else:
```

```
        subxact.exit(None, None, None)
except plpy.SPIError as e:
    result = "error transferring funds: %s" % e.args
else:
    result = "funds transferred correctly"

plan = plpy.prepare("INSERT INTO operations (result) VALUES ($1)", ["text"])
plpy.execute(plan, [result])
$$ LANGUAGE plpythonu;
```

48.9. Transaction Management

In a procedure called from the top level or an anonymous code block (`DO` command) called from the top level it is possible to control transactions. To commit the current transaction, call `plpy.commit()`. To roll back the current transaction, call `plpy.rollback()`. (Note that it is not possible to run the SQL commands `COMMIT` or `ROLLBACK` via `plpy.execute` or similar. It has to be done using these functions.) After a transaction is ended, a new transaction is automatically started, so there is no separate function for that.

Here is an example:

```
CREATE PROCEDURE transaction_test1()
LANGUAGE plpythonu
AS $$
for i in range(0, 10):
    plpy.execute("INSERT INTO test1 (a) VALUES (%d)" % i)
    if i % 2 == 0:
        plpy.commit()
    else:
        plpy.rollback()
$$;

CALL transaction_test1();
```

Transactions cannot be ended when an explicit subtransaction is active.

48.10. Utility Functions

The `plpy` module also provides the functions

```
plpy.debug( msg, **kwargs )
plpy.log( msg, **kwargs )
plpy.info( msg, **kwargs )
plpy.notice( msg, **kwargs )
plpy.warning( msg, **kwargs )
plpy.error( msg, **kwargs )
plpy.fatal( msg, **kwargs )
```

`plpy.error` and `plpy.fatal` actually raise a Python exception which, if uncaught, propagates out to the calling query, causing the current transaction or subtransaction to be aborted. `raise plpy.Error(msg)` and `raise plpy.Fatal(msg)` are equivalent to calling `plpy.error(msg)` and `plpy.fatal(msg)`, respectively but the `raise` form does not allow passing keyword arguments. The other functions only generate messages of different priority levels. Whether messages of a particular priority are reported to the client, written to the server log, or both is controlled by the log_min_messages and client_min_messages configuration variables. See Chapter 19 for more information.

The *msg* argument is given as a positional argument. For backward compatibility, more than one positional argument can be given. In that case, the string representation of the tuple of positional arguments becomes the message reported to the client.

The following keyword-only arguments are accepted:

```
detail
hint
sqlstate
schema_name
table_name
column_name
datatype_name
constraint_name
```

The string representation of the objects passed as keyword-only arguments is used to enrich the messages reported to the client. For example:

```
CREATE FUNCTION raise_custom_exception() RETURNS void AS $$
plpy.error("custom exception message",
           detail="some info about exception",
           hint="hint for users")
$$ LANGUAGE plpythonu;

=# SELECT raise_custom_exception();
ERROR:  plpy.Error: custom exception message
DETAIL:  some info about exception
HINT:  hint for users
CONTEXT:  Traceback (most recent call last):
  PL/Python function "raise_custom_exception", line 4, in <module>
    hint="hint for users")
PL/Python function "raise_custom_exception"
```

Another set of utility functions are `plpy.quote_literal(`*`string`*`)`, `plpy.quote_nullable(`*`string`*`)`, and `plpy.quote_ident(`*`string`*`)`. They are equivalent to the built-in quoting functions described in Section 9.4. They are useful when constructing ad-hoc queries. A PL/Python equivalent of dynamic SQL from Example 45.1 would be:

```
plpy.execute("UPDATE tbl SET %s = %s WHERE key = %s" % (
    plpy.quote_ident(colname),
    plpy.quote_nullable(newvalue),
    plpy.quote_literal(keyvalue)))
```

48.11. Environment Variables

Some of the environment variables that are accepted by the Python interpreter can also be used to affect PL/Python behavior. They would need to be set in the environment of the main Postgres Pro server process, for example in a start script. The available environment variables depend on the version of Python; see the Python documentation for details. At the time of this writing, the following environment variables have an affect on PL/Python, assuming an adequate Python version:

- `PYTHONHOME`
- `PYTHONPATH`
- `PYTHONY2K`
- `PYTHONOPTIMIZE`
- `PYTHONDEBUG`
- `PYTHONVERBOSE`
- `PYTHONCASEOK`
- `PYTHONDONTWRITEBYTECODE`
- `PYTHONIOENCODING`

- `PYTHONUSERBASE`
- `PYTHONHASHSEED`

(It appears to be a Python implementation detail beyond the control of PL/Python that some of the environment variables listed on the `python` man page are only effective in a command-line interpreter and not an embedded Python interpreter.)

Chapter 49. Server Programming Interface

The *Server Programming Interface* (SPI) gives writers of user-defined C functions the ability to run SQL commands inside their functions or procedures. SPI is a set of interface functions to simplify access to the parser, planner, and executor. SPI also does some memory management.

> **Note**
>
> The available procedural languages provide various means to execute SQL commands from functions. Most of these facilities are based on SPI, so this documentation might be of use for users of those languages as well.

Note that if a command invoked via SPI fails, then control will not be returned to your C function. Rather, the transaction or subtransaction in which your C function executes will be rolled back. (This might seem surprising given that the SPI functions mostly have documented error-return conventions. Those conventions only apply for errors detected within the SPI functions themselves, however.) It is possible to recover control after an error by establishing your own subtransaction surrounding SPI calls that might fail.

SPI functions return a nonnegative result on success (either via a returned integer value or in the global variable `SPI_result`, as described below). On error, a negative result or `NULL` will be returned.

Source code files that use SPI must include the header file `executor/spi.h`.

49.1. Interface Functions

SPI_connect

SPI_connect, SPI_connect_ext — connect a C function to the SPI manager

Synopsis

```
int SPI_connect(void)
```

```
int SPI_connect_ext(int options)
```

Description

`SPI_connect` opens a connection from a C function invocation to the SPI manager. You must call this function if you want to execute commands through SPI. Some utility SPI functions can be called from unconnected C functions.

`SPI_connect_ext` does the same but has an argument that allows passing option flags. Currently, the following option values are available:

`SPI_OPT_NONATOMIC`

Sets the SPI connection to be *nonatomic*, which means that transaction control calls (`SPI_commit`, `SPI_rollback`) are allowed. Otherwise, calling those functions will result in an immediate error.

`SPI_connect()` is equivalent to `SPI_connect_ext(0)`.

Return Value

`SPI_OK_CONNECT`

on success

`SPI_ERROR_CONNECT`

on error

SPI_finish

SPI_finish — disconnect a C function from the SPI manager

Synopsis

```
int SPI_finish(void)
```

Description

`SPI_finish` closes an existing connection to the SPI manager. You must call this function after completing the SPI operations needed during your C function's current invocation. You do not need to worry about making this happen, however, if you abort the transaction via `elog(ERROR)`. In that case SPI will clean itself up automatically.

Return Value

`SPI_OK_FINISH`

if properly disconnected

`SPI_ERROR_UNCONNECTED`

if called from an unconnected C function

SPI_execute

SPI_execute — execute a command

Synopsis

```
int SPI_execute(const char * command, bool read_only, long count)
```

Description

`SPI_execute` executes the specified SQL command for *`count`* rows. If *`read_only`* is `true`, the command must be read-only, and execution overhead is somewhat reduced.

This function can only be called from a connected C function.

If *`count`* is zero then the command is executed for all rows that it applies to. If *`count`* is greater than zero, then no more than *`count`* rows will be retrieved; execution stops when the count is reached, much like adding a `LIMIT` clause to the query. For example,

```
SPI_execute("SELECT * FROM foo", true, 5);
```

will retrieve at most 5 rows from the table. Note that such a limit is only effective when the command actually returns rows. For example,

```
SPI_execute("INSERT INTO foo SELECT * FROM bar", false, 5);
```

inserts all rows from `bar`, ignoring the *`count`* parameter. However, with

```
SPI_execute("INSERT INTO foo SELECT * FROM bar RETURNING *", false, 5);
```

at most 5 rows would be inserted, since execution would stop after the fifth `RETURNING` result row is retrieved.

You can pass multiple commands in one string; `SPI_execute` returns the result for the command executed last. The *`count`* limit applies to each command separately (even though only the last result will actually be returned). The limit is not applied to any hidden commands generated by rules.

When *`read_only`* is `false`, `SPI_execute` increments the command counter and computes a new *snapshot* before executing each command in the string. The snapshot does not actually change if the current transaction isolation level is `SERIALIZABLE` or `REPEATABLE READ`, but in `READ COMMITTED` mode the snapshot update allows each command to see the results of newly committed transactions from other sessions. This is essential for consistent behavior when the commands are modifying the database.

When *`read_only`* is `true`, `SPI_execute` does not update either the snapshot or the command counter, and it allows only plain `SELECT` commands to appear in the command string. The commands are executed using the snapshot previously established for the surrounding query. This execution mode is somewhat faster than the read/write mode due to eliminating per-command overhead. It also allows genuinely *stable* functions to be built: since successive executions will all use the same snapshot, there will be no change in the results.

It is generally unwise to mix read-only and read-write commands within a single function using SPI; that could result in very confusing behavior, since the read-only queries would not see the results of any database updates done by the read-write queries.

The actual number of rows for which the (last) command was executed is returned in the global variable `SPI_processed`. If the return value of the function is `SPI_OK_SELECT`, `SPI_OK_INSERT_RETURNING`, `SPI_OK_DELETE_RETURNING`, or `SPI_OK_UPDATE_RETURNING`, then you can use the global pointer `SPITupleTable *SPI_tuptable` to access the result rows. Some utility commands (such as `EXPLAIN`) also return row sets, and `SPI_tuptable` will contain the result in these cases too. Some utility commands (`COPY`, `CREATE TABLE AS`) don't return a row set, so `SPI_tuptable` is NULL, but they still return the number of rows processed in `SPI_processed`.

The structure `SPITupleTable` is defined thus:

```
typedef struct SPITupleTable
{
    /* Public members */
    TupleDesc   tupdesc;        /* tuple descriptor */
    HeapTuple  *vals;           /* array of tuples */
    uint64      numvals;        /* number of valid tuples */

    /* Private members, not intended for external callers */
    uint64      alloced;        /* allocated length of vals array */
    MemoryContext tuptabcxt;    /* memory context of result table */
    slist_node  next;           /* link for internal bookkeeping */
    SubTransactionId subid;     /* subxact in which tuptable was created */
} SPITupleTable;
```

The fields `tupdesc`, `vals`, and `numvals` can be used by SPI callers; the remaining fields are internal. `vals` is an array of pointers to rows. The number of rows is given by `numvals` (for somewhat historical reasons, this count is also returned in `SPI_processed`). `tupdesc` is a row descriptor which you can pass to SPI functions dealing with rows.

`SPI_finish` frees all `SPITupleTable`s allocated during the current C function. You can free a particular result table earlier, if you are done with it, by calling `SPI_freetuptable`.

Arguments

`const char * command`

string containing command to execute

`bool read_only`

`true` for read-only execution

`long count`

maximum number of rows to return, or `0` for no limit

Return Value

If the execution of the command was successful then one of the following (nonnegative) values will be returned:

`SPI_OK_SELECT`

if a `SELECT` (but not `SELECT INTO`) was executed

`SPI_OK_SELINTO`

if a `SELECT INTO` was executed

`SPI_OK_INSERT`

if an `INSERT` was executed

`SPI_OK_DELETE`

if a `DELETE` was executed

`SPI_OK_UPDATE`

if an `UPDATE` was executed

`SPI_OK_INSERT_RETURNING`

if an `INSERT RETURNING` was executed

`SPI_OK_DELETE_RETURNING`

if a `DELETE RETURNING` was executed

`SPI_OK_UPDATE_RETURNING`

if an `UPDATE RETURNING` was executed

`SPI_OK_UTILITY`

if a utility command (e.g., `CREATE TABLE`) was executed

`SPI_OK_REWRITTEN`

if the command was rewritten into another kind of command (e.g., `UPDATE` became an `INSERT`) by a rule.

On error, one of the following negative values is returned:

`SPI_ERROR_ARGUMENT`

if *`command`* is `NULL` or *`count`* is less than 0

`SPI_ERROR_COPY`

if `COPY TO stdout` or `COPY FROM stdin` was attempted

`SPI_ERROR_TRANSACTION`

if a transaction manipulation command was attempted (`BEGIN`, `COMMIT`, `ROLLBACK`, `SAVEPOINT`, `PREPARE TRANSACTION`, `COMMIT PREPARED`, `ROLLBACK PREPARED`, or any variant thereof)

`SPI_ERROR_OPUNKNOWN`

if the command type is unknown (shouldn't happen)

`SPI_ERROR_UNCONNECTED`

if called from an unconnected C function

Notes

All SPI query-execution functions set both `SPI_processed` and `SPI_tuptable` (just the pointer, not the contents of the structure). Save these two global variables into local C function variables if you need to access the result table of `SPI_execute` or another query-execution function across later calls.

SPI_exec

SPI_exec — execute a read/write command

Synopsis

```
int SPI_exec(const char * command, long count)
```

Description

`SPI_exec` is the same as `SPI_execute`, with the latter's *`read_only`* parameter always taken as `false`.

Arguments

`const char * command`

string containing command to execute

`long count`

maximum number of rows to return, or `0` for no limit

Return Value

See `SPI_execute`.

SPI_execute_extended

SPI_execute_extended — execute a command with out-of-line parameters

Synopsis

```
int SPI_execute_extended(const char *command,
                         const SPIExecuteOptions * options)
```

Description

`SPI_execute_extended` executes a command that might include references to externally supplied parameters. The command text refers to a parameter as `$n`, and the *`options->params`* object (if supplied) provides values and type information for each such symbol. Various execution options can be specified in the *`options`* struct, too.

The *`options->params`* object should normally mark each parameter with the `PARAM_FLAG_CONST` flag, since a one-shot plan is always used for the query.

If *`options->dest`* is not NULL, then result tuples are passed to that object as they are generated by the executor, instead of being accumulated in `SPI_tuptable`. Using a caller-supplied `DestReceiver` object is particularly helpful for queries that might generate many tuples, since the data can be processed on-the-fly instead of being accumulated in memory.

Arguments

`const char * command`

command string

`const SPIExecuteOptions * options`

struct containing optional arguments

Callers should always zero out the entire *`options`* struct, then fill whichever fields they want to set. This ensures forward compatibility of code, since any fields that are added to the struct in future will be defined to behave backwards-compatibly if they are zero. The currently available *`options`* fields are:

`ParamListInfo params`

data structure containing query parameter types and values; NULL if none

`bool read_only`

`true` for read-only execution

`bool allow_nonatomic`

`true` allows non-atomic execution of CALL and DO statements (but this field is ignored unless the `SPI_OPT_NONATOMIC` flag was passed to `SPI_connect_ext`)

`bool must_return_tuples`

if `true`, raise error if the query is not of a kind that returns tuples (this does not forbid the case where it happens to return zero tuples)

`uint64 tcount`

maximum number of rows to return, or `0` for no limit

`DestReceiver * dest`

`DestReceiver` object that will receive any tuples emitted by the query; if NULL, result tuples are accumulated into a `SPI_tuptable` structure, as in `SPI_execute`

`ResourceOwner` *`owner`*

This field is present for consistency with `SPI_execute_plan_extended`, but it is ignored, since the plan used by `SPI_execute_extended` is never saved.

Return Value

The return value is the same as for `SPI_execute`.

When *`options->dest`* is NULL, `SPI_processed` and `SPI_tuptable` are set as in `SPI_execute`. When *`options->dest`* is not NULL, `SPI_processed` is set to zero and `SPI_tuptable` is set to NULL. If a tuple count is required, the caller's `DestReceiver` object must calculate it.

SPI_execute_with_args

SPI_execute_with_args — execute a command with out-of-line parameters

Synopsis

```
int SPI_execute_with_args(const char *command,
                          int nargs, Oid *argtypes,
                          Datum *values, const char *nulls,
                          bool read_only, long count)
```

Description

`SPI_execute_with_args` executes a command that might include references to externally supplied parameters. The command text refers to a parameter as `$n`, and the call specifies data types and values for each such symbol. *`read_only`* and *`count`* have the same interpretation as in `SPI_execute`.

The main advantage of this routine compared to `SPI_execute` is that data values can be inserted into the command without tedious quoting/escaping, and thus with much less risk of SQL-injection attacks.

Similar results can be achieved with `SPI_prepare` followed by `SPI_execute_plan`; however, when using this function the query plan is always customized to the specific parameter values provided. For one-time query execution, this function should be preferred. If the same command is to be executed with many different parameters, either method might be faster, depending on the cost of re-planning versus the benefit of custom plans.

Arguments

`const char * command`

command string

`int nargs`

number of input parameters (`$1`, `$2`, etc.)

`Oid * argtypes`

an array of length *`nargs`*, containing the OIDs of the data types of the parameters

`Datum * values`

an array of length *`nargs`*, containing the actual parameter values

`const char * nulls`

an array of length *`nargs`*, describing which parameters are null

If *`nulls`* is `NULL` then `SPI_execute_with_args` assumes that no parameters are null. Otherwise, each entry of the *`nulls`* array should be `' '` if the corresponding parameter value is non-null, or `'n'` if the corresponding parameter value is null. (In the latter case, the actual value in the corresponding *`values`* entry doesn't matter.) Note that *`nulls`* is not a text string, just an array: it does not need a `'\0'` terminator.

`bool read_only`

`true` for read-only execution

`long count`

maximum number of rows to return, or `0` for no limit

Return Value

The return value is the same as for `SPI_execute`.

`SPI_processed` and `SPI_tuptable` are set as in `SPI_execute` if successful.

SPI_prepare

SPI_prepare — prepare a statement, without executing it yet

Synopsis

```
SPIPlanPtr SPI_prepare(const char * command, int nargs, Oid * argtypes)
```

Description

`SPI_prepare` creates and returns a prepared statement for the specified command, but doesn't execute the command. The prepared statement can later be executed repeatedly using `SPI_execute_plan`.

When the same or a similar command is to be executed repeatedly, it is generally advantageous to perform parse analysis only once, and might furthermore be advantageous to re-use an execution plan for the command. `SPI_prepare` converts a command string into a prepared statement that encapsulates the results of parse analysis. The prepared statement also provides a place for caching an execution plan if it is found that generating a custom plan for each execution is not helpful.

A prepared command can be generalized by writing parameters (`$1`, `$2`, etc.) in place of what would be constants in a normal command. The actual values of the parameters are then specified when `SPI_execute_plan` is called. This allows the prepared command to be used over a wider range of situations than would be possible without parameters.

The statement returned by `SPI_prepare` can be used only in the current invocation of the C function, since `SPI_finish` frees memory allocated for such a statement. But the statement can be saved for longer using the functions `SPI_keepplan` or `SPI_saveplan`.

Arguments

`const char * command`

command string

`int nargs`

number of input parameters (`$1`, `$2`, etc.)

`Oid * argtypes`

pointer to an array containing the OIDs of the data types of the parameters

Return Value

`SPI_prepare` returns a non-null pointer to an `SPIPlan`, which is an opaque struct representing a prepared statement. On error, `NULL` will be returned, and `SPI_result` will be set to one of the same error codes used by `SPI_execute`, except that it is set to `SPI_ERROR_ARGUMENT` if *`command`* is `NULL`, or if *`nargs`* is less than 0, or if *`nargs`* is greater than 0 and *`argtypes`* is `NULL`.

Notes

If no parameters are defined, a generic plan will be created at the first use of `SPI_execute_plan`, and used for all subsequent executions as well. If there are parameters, the first few uses of `SPI_execute_plan` will generate custom plans that are specific to the supplied parameter values. After enough uses of the same prepared statement, `SPI_execute_plan` will build a generic plan, and if that is not too much more expensive than the custom plans, it will start using the generic plan instead of re-planning each time. If this default behavior is unsuitable, you can alter it by passing the `CURSOR_OPT_GENERIC_PLAN` or `CURSOR_OPT_CUSTOM_PLAN` flag to `SPI_prepare_cursor`, to force use of generic or custom plans respectively.

Although the main point of a prepared statement is to avoid repeated parse analysis and planning of the statement, Postgres Pro will force re-analysis and re-planning of the statement before using it whenever

database objects used in the statement have undergone definitional (DDL) changes since the previous use of the prepared statement. Also, if the value of search_path changes from one use to the next, the statement will be re-parsed using the new `search_path`. (This latter behavior is new as of PostgreSQL 9.3.) See PREPARE for more information about the behavior of prepared statements.

This function should only be called from a connected C function.

`SPIPlanPtr` is declared as a pointer to an opaque struct type in `spi.h`. It is unwise to try to access its contents directly, as that makes your code much more likely to break in future revisions of Postgres Pro.

The name `SPIPlanPtr` is somewhat historical, since the data structure no longer necessarily contains an execution plan.

SPI_prepare_cursor

SPI_prepare_cursor — prepare a statement, without executing it yet

Synopsis

```
SPIPlanPtr SPI_prepare_cursor(const char * command, int nargs,
                              Oid * argtypes, int cursorOptions)
```

Description

`SPI_prepare_cursor` is identical to `SPI_prepare`, except that it also allows specification of the planner's "cursor options" parameter. This is a bit mask having the values shown in `nodes/parsenodes.h` for the `options` field of `DeclareCursorStmt`. `SPI_prepare` always takes the cursor options as zero.

This function is now deprecated in favor of `SPI_prepare_extended`.

Arguments

`const char * command`

command string

`int nargs`

number of input parameters (`$1`, `$2`, etc.)

`Oid * argtypes`

pointer to an array containing the OIDs of the data types of the parameters

`int cursorOptions`

integer bit mask of cursor options; zero produces default behavior

Return Value

`SPI_prepare_cursor` has the same return conventions as `SPI_prepare`.

Notes

Useful bits to set in *cursorOptions* include `CURSOR_OPT_SCROLL`, `CURSOR_OPT_NO_SCROLL`, `CURSOR_OPT_FAST_PLAN`, `CURSOR_OPT_GENERIC_PLAN`, and `CURSOR_OPT_CUSTOM_PLAN`. Note in particular that `CURSOR_OPT_HOLD` is ignored.

SPI_prepare_extended

SPI_prepare_extended — prepare a statement, without executing it yet

Synopsis

```
SPIPlanPtr SPI_prepare_extended(const char * command,
                                const SPIPrepareOptions * options)
```

Description

`SPI_prepare_extended` creates and returns a prepared statement for the specified command, but doesn't execute the command. This function is equivalent to `SPI_prepare`, with the addition that the caller can specify options to control the parsing of external parameter references, as well as other facets of query parsing and planning.

Arguments

`const char * command`

command string

`const SPIPrepareOptions * options`

struct containing optional arguments

Callers should always zero out the entire *`options`* struct, then fill whichever fields they want to set. This ensures forward compatibility of code, since any fields that are added to the struct in future will be defined to behave backwards-compatibly if they are zero. The currently available *`options`* fields are:

`ParserSetupHook parserSetup`

Parser hook setup function

`void * parserSetupArg`

pass-through argument for *`parserSetup`*

`RawParseMode parseMode`

mode for raw parsing; `RAW_PARSE_DEFAULT` (zero) produces default behavior

`int cursorOptions`

integer bit mask of cursor options; zero produces default behavior

Return Value

`SPI_prepare_extended` has the same return conventions as `SPI_prepare`.

SPI_prepare_params

SPI_prepare_params — prepare a statement, without executing it yet

Synopsis

```
SPIPlanPtr SPI_prepare_params(const char * command,
                              ParserSetupHook parserSetup,
                              void * parserSetupArg,
                              int cursorOptions)
```

Description

`SPI_prepare_params` creates and returns a prepared statement for the specified command, but doesn't execute the command. This function is equivalent to `SPI_prepare_cursor`, with the addition that the caller can specify parser hook functions to control the parsing of external parameter references.

This function is now deprecated in favor of `SPI_prepare_extended`.

Arguments

`const char * command`

command string

`ParserSetupHook parserSetup`

Parser hook setup function

`void * parserSetupArg`

pass-through argument for *parserSetup*

`int cursorOptions`

integer bit mask of cursor options; zero produces default behavior

Return Value

`SPI_prepare_params` has the same return conventions as `SPI_prepare`.

SPI_getargcount

SPI_getargcount — return the number of arguments needed by a statement prepared by `SPI_prepare`

Synopsis

```
int SPI_getargcount(SPIPlanPtr plan)
```

Description

`SPI_getargcount` returns the number of arguments needed to execute a statement prepared by `SPI_prepare`.

Arguments

`SPIPlanPtr` *`plan`*

prepared statement (returned by `SPI_prepare`)

Return Value

The count of expected arguments for the *`plan`*. If the *`plan`* is `NULL` or invalid, `SPI_result` is set to `SPI_ERROR_ARGUMENT` and -1 is returned.

SPI_getargtypeid

SPI_getargtypeid — return the data type OID for an argument of a statement prepared by `SPI_prepare`

Synopsis

```
Oid SPI_getargtypeid(SPIPlanPtr plan, int argIndex)
```

Description

`SPI_getargtypeid` returns the OID representing the type for the *`argIndex`*'th argument of a statement prepared by `SPI_prepare`. First argument is at index zero.

Arguments

`SPIPlanPtr` *`plan`*

prepared statement (returned by `SPI_prepare`)

`int` *`argIndex`*

zero based index of the argument

Return Value

The type OID of the argument at the given index. If the *`plan`* is `NULL` or invalid, or *`argIndex`* is less than 0 or not less than the number of arguments declared for the *`plan`*, `SPI_result` is set to `SPI_ERROR_ARGUMENT` and `InvalidOid` is returned.

SPI_is_cursor_plan

SPI_is_cursor_plan — return `true` if a statement prepared by `SPI_prepare` can be used with `SPI_cursor_open`

Synopsis

```
bool SPI_is_cursor_plan(SPIPlanPtr plan)
```

Description

`SPI_is_cursor_plan` returns `true` if a statement prepared by `SPI_prepare` can be passed as an argument to `SPI_cursor_open`, or `false` if that is not the case. The criteria are that the *`plan`* represents one single command and that this command returns tuples to the caller; for example, `SELECT` is allowed unless it contains an `INTO` clause, and `UPDATE` is allowed only if it contains a `RETURNING` clause.

Arguments

`SPIPlanPtr` *`plan`*

prepared statement (returned by `SPI_prepare`)

Return Value

`true` or `false` to indicate if the *`plan`* can produce a cursor or not, with `SPI_result` set to zero. If it is not possible to determine the answer (for example, if the *`plan`* is `NULL` or invalid, or if called when not connected to SPI), then `SPI_result` is set to a suitable error code and `false` is returned.

SPI_execute_plan

SPI_execute_plan — execute a statement prepared by SPI_prepare

Synopsis

```
int SPI_execute_plan(SPIPlanPtr plan, Datum * values, const char * nulls,
                     bool read_only, long count)
```

Description

SPI_execute_plan executes a statement prepared by SPI_prepare or one of its siblings. *read_only* and *count* have the same interpretation as in SPI_execute.

Arguments

SPIPlanPtr *plan*

prepared statement (returned by SPI_prepare)

Datum * *values*

An array of actual parameter values. Must have same length as the statement's number of arguments.

const char * *nulls*

An array describing which parameters are null. Must have same length as the statement's number of arguments.

If *nulls* is NULL then SPI_execute_plan assumes that no parameters are null. Otherwise, each entry of the *nulls* array should be ' ' if the corresponding parameter value is non-null, or 'n' if the corresponding parameter value is null. (In the latter case, the actual value in the corresponding *values* entry doesn't matter.) Note that *nulls* is not a text string, just an array: it does not need a '\0' terminator.

bool *read_only*

true for read-only execution

long *count*

maximum number of rows to return, or 0 for no limit

Return Value

The return value is the same as for SPI_execute, with the following additional possible error (negative) results:

SPI_ERROR_ARGUMENT

if *plan* is NULL or invalid, or *count* is less than 0

SPI_ERROR_PARAM

if *values* is NULL and *plan* was prepared with some parameters

SPI_processed and SPI_tuptable are set as in SPI_execute if successful.

SPI_execute_plan_extended

SPI_execute_plan_extended — execute a statement prepared by SPI_prepare

Synopsis

```
int SPI_execute_plan_extended(SPIPlanPtr plan,
                              const SPIExecuteOptions * options)
```

Description

SPI_execute_plan_extended executes a statement prepared by SPI_prepare or one of its siblings. This function is equivalent to SPI_execute_plan, except that information about the parameter values to be passed to the query is presented differently, and additional execution-controlling options can be passed.

Query parameter values are represented by a ParamListInfo struct, which is convenient for passing down values that are already available in that format. Dynamic parameter sets can also be used, via hook functions specified in ParamListInfo.

Also, instead of always accumulating the result tuples into a SPI_tuptable structure, tuples can be passed to a caller-supplied DestReceiver object as they are generated by the executor. This is particularly helpful for queries that might generate many tuples, since the data can be processed on-the-fly instead of being accumulated in memory.

Arguments

SPIPlanPtr *plan*

prepared statement (returned by SPI_prepare)

const SPIExecuteOptions * *options*

struct containing optional arguments

Callers should always zero out the entire *options* struct, then fill whichever fields they want to set. This ensures forward compatibility of code, since any fields that are added to the struct in future will be defined to behave backwards-compatibly if they are zero. The currently available *options* fields are:

ParamListInfo *params*

data structure containing query parameter types and values; NULL if none

bool *read_only*

true for read-only execution

bool *allow_nonatomic*

true allows non-atomic execution of CALL and DO statements (but this field is ignored unless the SPI_OPT_NONATOMIC flag was passed to SPI_connect_ext)

bool *must_return_tuples*

if true, raise error if the query is not of a kind that returns tuples (this does not forbid the case where it happens to return zero tuples)

uint64 *tcount*

maximum number of rows to return, or 0 for no limit

DestReceiver * *dest*

DestReceiver object that will receive any tuples emitted by the query; if NULL, result tuples are accumulated into a SPI_tuptable structure, as in SPI_execute_plan

`ResourceOwner` *`owner`*

The resource owner that will hold a reference count on the plan while it is executed. If NULL, CurrentResourceOwner is used. Ignored for non-saved plans, as SPI does not acquire reference counts on those.

Return Value

The return value is the same as for `SPI_execute_plan`.

When *`options->dest`* is NULL, `SPI_processed` and `SPI_tuptable` are set as in `SPI_execute_plan`. When *`options->dest`* is not NULL, `SPI_processed` is set to zero and `SPI_tuptable` is set to NULL. If a tuple count is required, the caller's `DestReceiver` object must calculate it.

SPI_execute_plan_with_paramlist

SPI_execute_plan_with_paramlist — execute a statement prepared by SPI_prepare

Synopsis

```
int SPI_execute_plan_with_paramlist(SPIPlanPtr plan,
                                    ParamListInfo params,
                                    bool read_only,
                                    long count)
```

Description

SPI_execute_plan_with_paramlist executes a statement prepared by SPI_prepare. This function is equivalent to SPI_execute_plan except that information about the parameter values to be passed to the query is presented differently. The ParamListInfo representation can be convenient for passing down values that are already available in that format. It also supports use of dynamic parameter sets via hook functions specified in ParamListInfo.

This function is now deprecated in favor of SPI_execute_plan_extended.

Arguments

SPIPlanPtr *plan*

prepared statement (returned by SPI_prepare)

ParamListInfo *params*

data structure containing parameter types and values; NULL if none

bool *read_only*

true for read-only execution

long *count*

maximum number of rows to return, or 0 for no limit

Return Value

The return value is the same as for SPI_execute_plan.

SPI_processed and SPI_tuptable are set as in SPI_execute_plan if successful.

SPI_execp

SPI_execp — execute a statement in read/write mode

Synopsis

```
int SPI_execp(SPIPlanPtr plan, Datum * values, const char * nulls, long count)
```

Description

`SPI_execp` is the same as `SPI_execute_plan`, with the latter's *`read_only`* parameter always taken as `false`.

Arguments

`SPIPlanPtr` *`plan`*

prepared statement (returned by `SPI_prepare`)

`Datum *` *`values`*

An array of actual parameter values. Must have same length as the statement's number of arguments.

`const char *` *`nulls`*

An array describing which parameters are null. Must have same length as the statement's number of arguments.

If *`nulls`* is `NULL` then `SPI_execp` assumes that no parameters are null. Otherwise, each entry of the *`nulls`* array should be `' '` if the corresponding parameter value is non-null, or `'n'` if the corresponding parameter value is null. (In the latter case, the actual value in the corresponding *`values`* entry doesn't matter.) Note that *`nulls`* is not a text string, just an array: it does not need a `'\0'` terminator.

`long` *`count`*

maximum number of rows to return, or `0` for no limit

Return Value

See `SPI_execute_plan`.

`SPI_processed` and `SPI_tuptable` are set as in `SPI_execute` if successful.

SPI_cursor_open

SPI_cursor_open — set up a cursor using a statement created with SPI_prepare

Synopsis

```
Portal SPI_cursor_open(const char * name, SPIPlanPtr plan,
                       Datum * values, const char * nulls,
                       bool read_only)
```

Description

SPI_cursor_open sets up a cursor (internally, a portal) that will execute a statement prepared by SPI_prepare. The parameters have the same meanings as the corresponding parameters to SPI_execute_plan.

Using a cursor instead of executing the statement directly has two benefits. First, the result rows can be retrieved a few at a time, avoiding memory overrun for queries that return many rows. Second, a portal can outlive the current C function (it can, in fact, live to the end of the current transaction). Returning the portal name to the C function's caller provides a way of returning a row set as result.

The passed-in parameter data will be copied into the cursor's portal, so it can be freed while the cursor still exists.

Arguments

`const char * name`

name for portal, or NULL to let the system select a name

`SPIPlanPtr plan`

prepared statement (returned by SPI_prepare)

`Datum * values`

An array of actual parameter values. Must have same length as the statement's number of arguments.

`const char * nulls`

An array describing which parameters are null. Must have same length as the statement's number of arguments.

If *nulls* is NULL then SPI_cursor_open assumes that no parameters are null. Otherwise, each entry of the *nulls* array should be `' '` if the corresponding parameter value is non-null, or `'n'` if the corresponding parameter value is null. (In the latter case, the actual value in the corresponding *values* entry doesn't matter.) Note that *nulls* is not a text string, just an array: it does not need a `'\0'` terminator.

`bool read_only`

true for read-only execution

Return Value

Pointer to portal containing the cursor. Note there is no error return convention; any error will be reported via elog.

SPI_cursor_open_with_args

SPI_cursor_open_with_args — set up a cursor using a query and parameters

Synopsis

```
Portal SPI_cursor_open_with_args(const char *name,
                                 const char *command,
                                 int nargs, Oid *argtypes,
                                 Datum *values, const char *nulls,
                                 bool read_only, int cursorOptions)
```

Description

`SPI_cursor_open_with_args` sets up a cursor (internally, a portal) that will execute the specified query. Most of the parameters have the same meanings as the corresponding parameters to `SPI_prepare_cursor` and `SPI_cursor_open`.

For one-time query execution, this function should be preferred over `SPI_prepare_cursor` followed by `SPI_cursor_open`. If the same command is to be executed with many different parameters, either method might be faster, depending on the cost of re-planning versus the benefit of custom plans.

The passed-in parameter data will be copied into the cursor's portal, so it can be freed while the cursor still exists.

This function is now deprecated in favor of `SPI_cursor_parse_open`, which provides equivalent functionality using a more modern API for handling query parameters.

Arguments

`const char * name`

name for portal, or `NULL` to let the system select a name

`const char * command`

command string

`int nargs`

number of input parameters (`$1`, `$2`, etc.)

`Oid * argtypes`

an array of length *nargs*, containing the OIDs of the data types of the parameters

`Datum * values`

an array of length *nargs*, containing the actual parameter values

`const char * nulls`

an array of length *nargs*, describing which parameters are null

If *nulls* is `NULL` then `SPI_cursor_open_with_args` assumes that no parameters are null. Otherwise, each entry of the *nulls* array should be `' '` if the corresponding parameter value is non-null, or `'n'` if the corresponding parameter value is null. (In the latter case, the actual value in the corresponding *values* entry doesn't matter.) Note that *nulls* is not a text string, just an array: it does not need a `'\0'` terminator.

`bool read_only`

`true` for read-only execution

`int` *`cursorOptions`*

integer bit mask of cursor options; zero produces default behavior

Return Value

Pointer to portal containing the cursor. Note there is no error return convention; any error will be reported via `elog`.

SPI_cursor_open_with_paramlist

SPI_cursor_open_with_paramlist — set up a cursor using parameters

Synopsis

```
Portal SPI_cursor_open_with_paramlist(const char *name,
                                      SPIPlanPtr plan,
                                      ParamListInfo params,
                                      bool read_only)
```

Description

`SPI_cursor_open_with_paramlist` sets up a cursor (internally, a portal) that will execute a statement prepared by `SPI_prepare`. This function is equivalent to `SPI_cursor_open` except that information about the parameter values to be passed to the query is presented differently. The `ParamListInfo` representation can be convenient for passing down values that are already available in that format. It also supports use of dynamic parameter sets via hook functions specified in `ParamListInfo`.

The passed-in parameter data will be copied into the cursor's portal, so it can be freed while the cursor still exists.

Arguments

`const char * name`

name for portal, or `NULL` to let the system select a name

`SPIPlanPtr plan`

prepared statement (returned by `SPI_prepare`)

`ParamListInfo params`

data structure containing parameter types and values; NULL if none

`bool read_only`

`true` for read-only execution

Return Value

Pointer to portal containing the cursor. Note there is no error return convention; any error will be reported via `elog`.

SPI_cursor_parse_open

SPI_cursor_parse_open — set up a cursor using a query string and parameters

Synopsis

```
Portal SPI_cursor_parse_open(const char *name,
                             const char *command,
                             const SPIParseOpenOptions * options)
```

Description

`SPI_cursor_parse_open` sets up a cursor (internally, a portal) that will execute the specified query string. This is comparable to `SPI_prepare_cursor` followed by `SPI_cursor_open_with_paramlist`, except that parameter references within the query string are handled entirely by supplying a `ParamListInfo` object.

For one-time query execution, this function should be preferred over `SPI_prepare_cursor` followed by `SPI_cursor_open_with_paramlist`. If the same command is to be executed with many different parameters, either method might be faster, depending on the cost of re-planning versus the benefit of custom plans.

The *`options->params`* object should normally mark each parameter with the `PARAM_FLAG_CONST` flag, since a one-shot plan is always used for the query.

The passed-in parameter data will be copied into the cursor's portal, so it can be freed while the cursor still exists.

Arguments

`const char *` *`name`*

name for portal, or `NULL` to let the system select a name

`const char *` *`command`*

command string

`const SPIParseOpenOptions *` *`options`*

struct containing optional arguments

Callers should always zero out the entire *`options`* struct, then fill whichever fields they want to set. This ensures forward compatibility of code, since any fields that are added to the struct in future will be defined to behave backwards-compatibly if they are zero. The currently available *`options`* fields are:

`ParamListInfo` *`params`*

data structure containing query parameter types and values; NULL if none

`int` *`cursorOptions`*

integer bit mask of cursor options; zero produces default behavior

`bool` *`read_only`*

`true` for read-only execution

Return Value

Pointer to portal containing the cursor. Note there is no error return convention; any error will be reported via `elog`.

SPI_cursor_find

SPI_cursor_find — find an existing cursor by name

Synopsis

```
Portal SPI_cursor_find(const char * name)
```

Description

`SPI_cursor_find` finds an existing portal by name. This is primarily useful to resolve a cursor name returned as text by some other function.

Arguments

`const char * name`

name of the portal

Return Value

pointer to the portal with the specified name, or `NULL` if none was found

Notes

Beware that this function can return a `Portal` object that does not have cursor-like properties; for example it might not return tuples. If you simply pass the `Portal` pointer to other SPI functions, they can defend themselves against such cases, but caution is appropriate when directly inspecting the `Portal`.

SPI_cursor_fetch

SPI_cursor_fetch — fetch some rows from a cursor

Synopsis

```
void SPI_cursor_fetch(Portal portal, bool forward, long count)
```

Description

`SPI_cursor_fetch` fetches some rows from a cursor. This is equivalent to a subset of the SQL command `FETCH` (see `SPI_scroll_cursor_fetch` for more functionality).

Arguments

`Portal` *`portal`*

portal containing the cursor

`bool` *`forward`*

true for fetch forward, false for fetch backward

`long` *`count`*

maximum number of rows to fetch

Return Value

`SPI_processed` and `SPI_tuptable` are set as in `SPI_execute` if successful.

Notes

Fetching backward may fail if the cursor's plan was not created with the `CURSOR_OPT_SCROLL` option.

SPI_cursor_move

SPI_cursor_move — move a cursor

Synopsis

```
void SPI_cursor_move(Portal portal, bool forward, long count)
```

Description

`SPI_cursor_move` skips over some number of rows in a cursor. This is equivalent to a subset of the SQL command `MOVE` (see `SPI_scroll_cursor_move` for more functionality).

Arguments

`Portal` *`portal`*

portal containing the cursor

`bool` *`forward`*

true for move forward, false for move backward

`long` *`count`*

maximum number of rows to move

Notes

Moving backward may fail if the cursor's plan was not created with the `CURSOR_OPT_SCROLL` option.

SPI_scroll_cursor_fetch

SPI_scroll_cursor_fetch — fetch some rows from a cursor

Synopsis

```
void SPI_scroll_cursor_fetch(Portal portal, FetchDirection direction,
                             long count)
```

Description

`SPI_scroll_cursor_fetch` fetches some rows from a cursor. This is equivalent to the SQL command `FETCH`.

Arguments

`Portal` *`portal`*

portal containing the cursor

`FetchDirection` *`direction`*

one of `FETCH_FORWARD`, `FETCH_BACKWARD`, `FETCH_ABSOLUTE` or `FETCH_RELATIVE`

`long` *`count`*

number of rows to fetch for `FETCH_FORWARD` or `FETCH_BACKWARD`; absolute row number to fetch for `FETCH_ABSOLUTE`; or relative row number to fetch for `FETCH_RELATIVE`

Return Value

`SPI_processed` and `SPI_tuptable` are set as in `SPI_execute` if successful.

Notes

See the SQL FETCH command for details of the interpretation of the *`direction`* and *`count`* parameters.

Direction values other than `FETCH_FORWARD` may fail if the cursor's plan was not created with the `CURSOR_OPT_SCROLL` option.

SPI_scroll_cursor_move

SPI_scroll_cursor_move — move a cursor

Synopsis

```
void SPI_scroll_cursor_move(Portal portal, FetchDirection direction,
                            long count)
```

Description

`SPI_scroll_cursor_move` skips over some number of rows in a cursor. This is equivalent to the SQL command `MOVE`.

Arguments

`Portal` *`portal`*

portal containing the cursor

`FetchDirection` *`direction`*

one of `FETCH_FORWARD`, `FETCH_BACKWARD`, `FETCH_ABSOLUTE` or `FETCH_RELATIVE`

`long` *`count`*

number of rows to move for `FETCH_FORWARD` or `FETCH_BACKWARD`; absolute row number to move to for `FETCH_ABSOLUTE`; or relative row number to move to for `FETCH_RELATIVE`

Return Value

`SPI_processed` is set as in `SPI_execute` if successful. `SPI_tuptable` is set to `NULL`, since no rows are returned by this function.

Notes

See the SQL FETCH command for details of the interpretation of the *`direction`* and *`count`* parameters.

Direction values other than `FETCH_FORWARD` may fail if the cursor's plan was not created with the `CURSOR_OPT_SCROLL` option.

SPI_cursor_close

SPI_cursor_close — close a cursor

Synopsis

```
void SPI_cursor_close(Portal portal)
```

Description

`SPI_cursor_close` closes a previously created cursor and releases its portal storage.

All open cursors are closed automatically at the end of a transaction. `SPI_cursor_close` need only be invoked if it is desirable to release resources sooner.

Arguments

`Portal portal`

portal containing the cursor

SPI_keepplan

SPI_keepplan — save a prepared statement

Synopsis

```
int SPI_keepplan(SPIPlanPtr plan)
```

Description

`SPI_keepplan` saves a passed statement (prepared by `SPI_prepare`) so that it will not be freed by `SPI_finish` nor by the transaction manager. This gives you the ability to reuse prepared statements in the subsequent invocations of your C function in the current session.

Arguments

`SPIPlanPtr` *`plan`*

the prepared statement to be saved

Return Value

0 on success; `SPI_ERROR_ARGUMENT` if *`plan`* is `NULL` or invalid

Notes

The passed-in statement is relocated to permanent storage by means of pointer adjustment (no data copying is required). If you later wish to delete it, use `SPI_freeplan` on it.

SPI_saveplan

SPI_saveplan — save a prepared statement

Synopsis

```
SPIPlanPtr SPI_saveplan(SPIPlanPtr plan)
```

Description

`SPI_saveplan` copies a passed statement (prepared by `SPI_prepare`) into memory that will not be freed by `SPI_finish` nor by the transaction manager, and returns a pointer to the copied statement. This gives you the ability to reuse prepared statements in the subsequent invocations of your C function in the current session.

Arguments

`SPIPlanPtr` *`plan`*

the prepared statement to be saved

Return Value

Pointer to the copied statement; or `NULL` if unsuccessful. On error, `SPI_result` is set thus:

`SPI_ERROR_ARGUMENT`

if *`plan`* is `NULL` or invalid

`SPI_ERROR_UNCONNECTED`

if called from an unconnected C function

Notes

The originally passed-in statement is not freed, so you might wish to do `SPI_freeplan` on it to avoid leaking memory until `SPI_finish`.

In most cases, `SPI_keepplan` is preferred to this function, since it accomplishes largely the same result without needing to physically copy the prepared statement's data structures.

SPI_register_relation

SPI_register_relation — make an ephemeral named relation available by name in SPI queries

Synopsis

```
int SPI_register_relation(EphemeralNamedRelation enr)
```

Description

`SPI_register_relation` makes an ephemeral named relation, with associated information, available to queries planned and executed through the current SPI connection.

Arguments

`EphemeralNamedRelation` *`enr`*

the ephemeral named relation registry entry

Return Value

If the execution of the command was successful then the following (nonnegative) value will be returned:

`SPI_OK_REL_REGISTER`

if the relation has been successfully registered by name

On error, one of the following negative values is returned:

`SPI_ERROR_ARGUMENT`

if *`enr`* is `NULL` or its `name` field is `NULL`

`SPI_ERROR_UNCONNECTED`

if called from an unconnected C function

`SPI_ERROR_REL_DUPLICATE`

if the name specified in the `name` field of *`enr`* is already registered for this connection

SPI_unregister_relation

SPI_unregister_relation — remove an ephemeral named relation from the registry

Synopsis

```
int SPI_unregister_relation(const char * name)
```

Description

`SPI_unregister_relation` removes an ephemeral named relation from the registry for the current connection.

Arguments

`const char *` *`name`*

the relation registry entry name

Return Value

If the execution of the command was successful then the following (nonnegative) value will be returned:

`SPI_OK_REL_UNREGISTER`

if the tuplestore has been successfully removed from the registry

On error, one of the following negative values is returned:

`SPI_ERROR_ARGUMENT`

if *`name`* is `NULL`

`SPI_ERROR_UNCONNECTED`

if called from an unconnected C function

`SPI_ERROR_REL_NOT_FOUND`

if *`name`* is not found in the registry for the current connection

SPI_register_trigger_data

SPI_register_trigger_data — make ephemeral trigger data available in SPI queries

Synopsis

```
int SPI_register_trigger_data(TriggerData *tdata)
```

Description

`SPI_register_trigger_data` makes any ephemeral relations captured by a trigger available to queries planned and executed through the current SPI connection. Currently, this means the transition tables captured by an `AFTER` trigger defined with a `REFERENCING OLD/NEW TABLE AS` ... clause. This function should be called by a PL trigger handler function after connecting.

Arguments

`TriggerData *tdata`

the `TriggerData` object passed to a trigger handler function as `fcinfo->context`

Return Value

If the execution of the command was successful then the following (nonnegative) value will be returned:

`SPI_OK_TD_REGISTER`

if the captured trigger data (if any) has been successfully registered

On error, one of the following negative values is returned:

`SPI_ERROR_ARGUMENT`

if *tdata* is `NULL`

`SPI_ERROR_UNCONNECTED`

if called from an unconnected C function

`SPI_ERROR_REL_DUPLICATE`

if the name of any trigger data transient relation is already registered for this connection

49.2. Interface Support Functions

The functions described here provide an interface for extracting information from result sets returned by `SPI_execute` and other SPI functions.

All functions described in this section can be used by both connected and unconnected C functions.

SPI_fname

SPI_fname — determine the column name for the specified column number

Synopsis

```
char * SPI_fname(TupleDesc rowdesc, int colnumber)
```

Description

`SPI_fname` returns a copy of the column name of the specified column. (You can use `pfree` to release the copy of the name when you don't need it anymore.)

Arguments

`TupleDesc` *`rowdesc`*

input row description

`int` *`colnumber`*

column number (count starts at 1)

Return Value

The column name; `NULL` if *`colnumber`* is out of range. `SPI_result` set to `SPI_ERROR_NOATTRIBUTE` on error.

SPI_fnumber

SPI_fnumber — determine the column number for the specified column name

Synopsis

```
int SPI_fnumber(TupleDesc rowdesc, const char * colname)
```

Description

`SPI_fnumber` returns the column number for the column with the specified name.

If *`colname`* refers to a system column (e.g., `ctid`) then the appropriate negative column number will be returned. The caller should be careful to test the return value for exact equality to `SPI_ERROR_NOATTRIBUTE` to detect an error; testing the result for less than or equal to 0 is not correct unless system columns should be rejected.

Arguments

`TupleDesc` *`rowdesc`*

input row description

`const char *` *`colname`*

column name

Return Value

Column number (count starts at 1 for user-defined columns), or `SPI_ERROR_NOATTRIBUTE` if the named column was not found.

SPI_getvalue

SPI_getvalue — return the string value of the specified column

Synopsis

```
char * SPI_getvalue(HeapTuple row, TupleDesc rowdesc, int colnumber)
```

Description

`SPI_getvalue` returns the string representation of the value of the specified column.

The result is returned in memory allocated using `palloc`. (You can use `pfree` to release the memory when you don't need it anymore.)

Arguments

`HeapTuple` *`row`*

input row to be examined

`TupleDesc` *`rowdesc`*

input row description

`int` *`colnumber`*

column number (count starts at 1)

Return Value

Column value, or `NULL` if the column is null, *`colnumber`* is out of range (`SPI_result` is set to `SPI_ERROR_NOATTRIBUTE`), or no output function is available (`SPI_result` is set to `SPI_ERROR_NOOUTFUNC`).

SPI_getbinval

SPI_getbinval — return the binary value of the specified column

Synopsis

```
Datum SPI_getbinval(HeapTuple row, TupleDesc rowdesc, int colnumber,
                    bool * isnull)
```

Description

`SPI_getbinval` returns the value of the specified column in the internal form (as type `Datum`).

This function does not allocate new space for the datum. In the case of a pass-by-reference data type, the return value will be a pointer into the passed row.

Arguments

`HeapTuple` *`row`*

input row to be examined

`TupleDesc` *`rowdesc`*

input row description

`int` *`colnumber`*

column number (count starts at 1)

`bool *` *`isnull`*

flag for a null value in the column

Return Value

The binary value of the column is returned. The variable pointed to by *`isnull`* is set to true if the column is null, else to false.

`SPI_result` is set to `SPI_ERROR_NOATTRIBUTE` on error.

SPI_gettype

SPI_gettype — return the data type name of the specified column

Synopsis

```
char * SPI_gettype(TupleDesc rowdesc, int colnumber)
```

Description

`SPI_gettype` returns a copy of the data type name of the specified column. (You can use `pfree` to release the copy of the name when you don't need it anymore.)

Arguments

`TupleDesc` *`rowdesc`*

input row description

`int` *`colnumber`*

column number (count starts at 1)

Return Value

The data type name of the specified column, or `NULL` on error. `SPI_result` is set to `SPI_ERROR_NOATTRIBUTE` on error.

SPI_gettypeid

SPI_gettypeid — return the data type OID of the specified column

Synopsis

```
Oid SPI_gettypeid(TupleDesc rowdesc, int colnumber)
```

Description

`SPI_gettypeid` returns the OID of the data type of the specified column.

Arguments

`TupleDesc` *`rowdesc`*

input row description

`int` *`colnumber`*

column number (count starts at 1)

Return Value

The OID of the data type of the specified column or `InvalidOid` on error. On error, `SPI_result` is set to `SPI_ERROR_NOATTRIBUTE`.

SPI_getrelname

SPI_getrelname — return the name of the specified relation

Synopsis

```
char * SPI_getrelname(Relation rel)
```

Description

`SPI_getrelname` returns a copy of the name of the specified relation. (You can use `pfree` to release the copy of the name when you don't need it anymore.)

Arguments

`Relation rel`

input relation

Return Value

The name of the specified relation.

SPI_getnspname

SPI_getnspname — return the namespace of the specified relation

Synopsis

```
char * SPI_getnspname(Relation rel)
```

Description

`SPI_getnspname` returns a copy of the name of the namespace that the specified `Relation` belongs to. This is equivalent to the relation's schema. You should `pfree` the return value of this function when you are finished with it.

Arguments

`Relation rel`

input relation

Return Value

The name of the specified relation's namespace.

SPI_result_code_string

SPI_result_code_string — return error code as string

Synopsis

```
const char * SPI_result_code_string(int code);
```

Description

`SPI_result_code_string` returns a string representation of the result code returned by various SPI functions or stored in `SPI_result`.

Arguments

`int code`

result code

Return Value

A string representation of the result code.

49.3. Memory Management

Postgres Pro allocates memory within *memory contexts*, which provide a convenient method of managing allocations made in many different places that need to live for differing amounts of time. Destroying a context releases all the memory that was allocated in it. Thus, it is not necessary to keep track of individual objects to avoid memory leaks; instead only a relatively small number of contexts have to be managed. `palloc` and related functions allocate memory from the “current” context.

`SPI_connect` creates a new memory context and makes it current. `SPI_finish` restores the previous current memory context and destroys the context created by `SPI_connect`. These actions ensure that transient memory allocations made inside your C function are reclaimed at C function exit, avoiding memory leakage.

However, if your C function needs to return an object in allocated memory (such as a value of a pass-by-reference data type), you cannot allocate that memory using `palloc`, at least not while you are connected to SPI. If you try, the object will be deallocated by `SPI_finish`, and your C function will not work reliably. To solve this problem, use `SPI_palloc` to allocate memory for your return object. `SPI_palloc` allocates memory in the “upper executor context”, that is, the memory context that was current when `SPI_connect` was called, which is precisely the right context for a value returned from your C function. Several of the other utility functions described in this section also return objects created in the upper executor context.

When `SPI_connect` is called, the private context of the C function, which is created by `SPI_connect`, is made the current context. All allocations made by `palloc`, `repalloc`, or SPI utility functions (except as described in this section) are made in this context. When a C function disconnects from the SPI manager (via `SPI_finish`) the current context is restored to the upper executor context, and all allocations made in the C function memory context are freed and cannot be used any more.

SPI_palloc

SPI_palloc — allocate memory in the upper executor context

Synopsis

```
void * SPI_palloc(Size size)
```

Description

`SPI_palloc` allocates memory in the upper executor context.

This function can only be used while connected to SPI. Otherwise, it throws an error.

Arguments

`Size size`

size in bytes of storage to allocate

Return Value

pointer to new storage space of the specified size

SPI_repalloc

SPI_repalloc — reallocate memory in the upper executor context

Synopsis

```
void * SPI_repalloc(void * pointer, Size size)
```

Description

`SPI_repalloc` changes the size of a memory segment previously allocated using `SPI_palloc`.

This function is no longer different from plain `repalloc`. It's kept just for backward compatibility of existing code.

Arguments

`void * pointer`

pointer to existing storage to change

`Size size`

size in bytes of storage to allocate

Return Value

pointer to new storage space of specified size with the contents copied from the existing area

SPI_pfree

SPI_pfree — free memory in the upper executor context

Synopsis

```
void SPI_pfree(void * pointer)
```

Description

`SPI_pfree` frees memory previously allocated using `SPI_palloc` or `SPI_repalloc`.

This function is no longer different from plain `pfree`. It's kept just for backward compatibility of existing code.

Arguments

`void * pointer`

pointer to existing storage to free

SPI_copytuple

SPI_copytuple — make a copy of a row in the upper executor context

Synopsis

```
HeapTuple SPI_copytuple(HeapTuple row)
```

Description

`SPI_copytuple` makes a copy of a row in the upper executor context. This is normally used to return a modified row from a trigger. In a function declared to return a composite type, use `SPI_returntuple` instead.

This function can only be used while connected to SPI. Otherwise, it returns NULL and sets `SPI_result` to `SPI_ERROR_UNCONNECTED`.

Arguments

`HeapTuple` *`row`*

row to be copied

Return Value

the copied row, or `NULL` on error (see `SPI_result` for an error indication)

SPI_returntuple

SPI_returntuple — prepare to return a tuple as a Datum

Synopsis

```
HeapTupleHeader SPI_returntuple(HeapTuple row, TupleDesc rowdesc)
```

Description

`SPI_returntuple` makes a copy of a row in the upper executor context, returning it in the form of a row type `Datum`. The returned pointer need only be converted to `Datum` via `PointerGetDatum` before returning.

This function can only be used while connected to SPI. Otherwise, it returns NULL and sets `SPI_result` to `SPI_ERROR_UNCONNECTED`.

Note that this should be used for functions that are declared to return composite types. It is not used for triggers; use `SPI_copytuple` for returning a modified row in a trigger.

Arguments

`HeapTuple` *`row`*

row to be copied

`TupleDesc` *`rowdesc`*

descriptor for row (pass the same descriptor each time for most effective caching)

Return Value

`HeapTupleHeader` pointing to copied row, or `NULL` on error (see `SPI_result` for an error indication)

SPI_modifytuple

SPI_modifytuple — create a row by replacing selected fields of a given row

Synopsis

```
HeapTuple SPI_modifytuple(Relation rel, HeapTuple row, int ncols,
                          int * colnum, Datum * values, const char * nulls)
```

Description

`SPI_modifytuple` creates a new row by substituting new values for selected columns, copying the original row's columns at other positions. The input row is not modified. The new row is returned in the upper executor context.

This function can only be used while connected to SPI. Otherwise, it returns NULL and sets `SPI_result` to `SPI_ERROR_UNCONNECTED`.

Arguments

`Relation` *`rel`*

Used only as the source of the row descriptor for the row. (Passing a relation rather than a row descriptor is a misfeature.)

`HeapTuple` *`row`*

row to be modified

`int` *`ncols`*

number of columns to be changed

`int *` *`colnum`*

an array of length *`ncols`*, containing the numbers of the columns that are to be changed (column numbers start at 1)

`Datum *` *`values`*

an array of length *`ncols`*, containing the new values for the specified columns

`const char *` *`nulls`*

an array of length *`ncols`*, describing which new values are null

If *`nulls`* is `NULL` then `SPI_modifytuple` assumes that no new values are null. Otherwise, each entry of the *`nulls`* array should be `' '` if the corresponding new value is non-null, or `'n'` if the corresponding new value is null. (In the latter case, the actual value in the corresponding *`values`* entry doesn't matter.) Note that *`nulls`* is not a text string, just an array: it does not need a `'\0'` terminator.

Return Value

new row with modifications, allocated in the upper executor context, or `NULL` on error (see `SPI_result` for an error indication)

On error, `SPI_result` is set as follows:

`SPI_ERROR_ARGUMENT`

if *`rel`* is `NULL`, or if *`row`* is `NULL`, or if *`ncols`* is less than or equal to 0, or if *`colnum`* is `NULL`, or if *`values`* is `NULL`.

`SPI_ERROR_NOATTRIBUTE`

if *`colnum`* contains an invalid column number (less than or equal to 0 or greater than the number of columns in *`row`*)

`SPI_ERROR_UNCONNECTED`

if SPI is not active

SPI_freetuple

SPI_freetuple — free a row allocated in the upper executor context

Synopsis

```
void SPI_freetuple(HeapTuple row)
```

Description

`SPI_freetuple` frees a row previously allocated in the upper executor context.

This function is no longer different from plain `heap_freetuple`. It's kept just for backward compatibility of existing code.

Arguments

`HeapTuple` *`row`*

row to free

SPI_freetuptable

SPI_freetuptable — free a row set created by `SPI_execute` or a similar function

Synopsis

```
void SPI_freetuptable(SPITupleTable * tuptable)
```

Description

`SPI_freetuptable` frees a row set created by a prior SPI command execution function, such as `SPI_execute`. Therefore, this function is often called with the global variable `SPI_tuptable` as argument.

This function is useful if an SPI-using C function needs to execute multiple commands and does not want to keep the results of earlier commands around until it ends. Note that any unfreed row sets will be freed anyway at `SPI_finish`. Also, if a subtransaction is started and then aborted within execution of an SPI-using C function, SPI automatically frees any row sets created while the subtransaction was running.

Beginning in PostgreSQL 9.3, `SPI_freetuptable` contains guard logic to protect against duplicate deletion requests for the same row set. In previous releases, duplicate deletions would lead to crashes.

Arguments

`SPITupleTable * tuptable`

pointer to row set to free, or NULL to do nothing

SPI_freeplan

SPI_freeplan — free a previously saved prepared statement

Synopsis

```
int SPI_freeplan(SPIPlanPtr plan)
```

Description

`SPI_freeplan` releases a prepared statement previously returned by `SPI_prepare` or saved by `SPI_keepplan` or `SPI_saveplan`.

Arguments

`SPIPlanPtr` *`plan`*

pointer to statement to free

Return Value

0 on success; `SPI_ERROR_ARGUMENT` if *`plan`* is `NULL` or invalid

49.4. Transaction Management

It is not possible to run transaction control commands such as `COMMIT` and `ROLLBACK` through SPI functions such as `SPI_execute`. There are, however, separate interface functions that allow transaction control through SPI.

It is not generally safe and sensible to start and end transactions in arbitrary user-defined SQL-callable functions without taking into account the context in which they are called. For example, a transaction boundary in the middle of a function that is part of a complex SQL expression that is part of some SQL command will probably result in obscure internal errors or crashes. The interface functions presented here are primarily intended to be used by procedural language implementations to support transaction management in SQL-level procedures that are invoked by the `CALL` command, taking the context of the `CALL` invocation into account. SPI-using procedures implemented in C can implement the same logic, but the details of that are beyond the scope of this documentation.

SPI_commit

SPI_commit, SPI_commit_and_chain — commit the current transaction

Synopsis

```
void SPI_commit(void)

void SPI_commit_and_chain(void)
```

Description

`SPI_commit` commits the current transaction. It is approximately equivalent to running the SQL command `COMMIT`. After the transaction is committed, a new transaction is automatically started using default transaction characteristics, so that the caller can continue using SPI facilities. If there is a failure during commit, the current transaction is instead rolled back and a new transaction is started, after which the error is thrown in the usual way.

`SPI_commit_and_chain` is the same, but the new transaction is started with the same transaction characteristics as the just finished one, like with the SQL command `COMMIT AND CHAIN`.

These functions can only be executed if the SPI connection has been set as nonatomic in the call to `SPI_connect_ext`.

SPI_rollback

SPI_rollback, SPI_rollback_and_chain — abort the current transaction

Synopsis

```
void SPI_rollback(void)

void SPI_rollback_and_chain(void)
```

Description

`SPI_rollback` rolls back the current transaction. It is approximately equivalent to running the SQL command `ROLLBACK`. After the transaction is rolled back, a new transaction is automatically started using default transaction characteristics, so that the caller can continue using SPI facilities.

`SPI_rollback_and_chain` is the same, but the new transaction is started with the same transaction characteristics as the just finished one, like with the SQL command `ROLLBACK AND CHAIN`.

These functions can only be executed if the SPI connection has been set as nonatomic in the call to `SPI_connect_ext`.

SPI_start_transaction

SPI_start_transaction — obsolete function

Synopsis

```
void SPI_start_transaction(void)
```

Description

`SPI_start_transaction` does nothing, and exists only for code compatibility with earlier PostgreSQL releases. It used to be required after calling `SPI_commit` or `SPI_rollback`, but now those functions start a new transaction automatically.

49.5. Visibility of Data Changes

The following rules govern the visibility of data changes in functions that use SPI (or any other C function):

- During the execution of an SQL command, any data changes made by the command are invisible to the command itself. For example, in:

  ```
  INSERT INTO a SELECT * FROM a;
  ```

  the inserted rows are invisible to the `SELECT` part.
- Changes made by a command C are visible to all commands that are started after C, no matter whether they are started inside C (during the execution of C) or after C is done.
- Commands executed via SPI inside a function called by an SQL command (either an ordinary function or a trigger) follow one or the other of the above rules depending on the read/write flag passed to SPI. Commands executed in read-only mode follow the first rule: they cannot see changes of the calling command. Commands executed in read-write mode follow the second rule: they can see all changes made so far.
- All standard procedural languages set the SPI read-write mode depending on the volatility attribute of the function. Commands of `STABLE` and `IMMUTABLE` functions are done in read-only mode, while commands of `VOLATILE` functions are done in read-write mode. While authors of C functions are able to violate this convention, it's unlikely to be a good idea to do so.

The next section contains an example that illustrates the application of these rules.

49.6. Examples

This section contains a very simple example of SPI usage. The C function `execq` takes an SQL command as its first argument and a row count as its second, executes the command using `SPI_exec` and returns the number of rows that were processed by the command. You can find more complex examples for SPI in the spi module.

```
#include "postgres.h"

#include "executor/spi.h"
#include "utils/builtins.h"

PG_MODULE_MAGIC;

PG_FUNCTION_INFO_V1(execq);

Datum
execq(PG_FUNCTION_ARGS)
{
    char *command;
    int cnt;
```

```
    int ret;
    uint64 proc;

    /* Convert given text object to a C string */
    command = text_to_cstring(PG_GETARG_TEXT_PP(0));
    cnt = PG_GETARG_INT32(1);

    SPI_connect();

    ret = SPI_exec(command, cnt);

    proc = SPI_processed;

    /*
     * If some rows were fetched, print them via elog(INFO).
     */
    if (ret > 0 && SPI_tuptable != NULL)
    {
        SPITupleTable *tuptable = SPI_tuptable;
        TupleDesc tupdesc = tuptable->tupdesc;
        char buf[8192];
        uint64 j;

        for (j = 0; j < tuptable->numvals; j++)
        {
            HeapTuple tuple = tuptable->vals[j];
            int i;

            for (i = 1, buf[0] = 0; i <= tupdesc->natts; i++)
                snprintf(buf + strlen(buf), sizeof(buf) - strlen(buf), " %s%s",
                        SPI_getvalue(tuple, tupdesc, i),
                        (i == tupdesc->natts) ? " " : " |");
            elog(INFO, "EXECQ: %s", buf);
        }
    }

    SPI_finish();
    pfree(command);

    PG_RETURN_INT64(proc);
}
```

This is how you declare the function after having compiled it into a shared library (details are in Section 40.10.5.):

```
CREATE FUNCTION execq(text, integer) RETURNS int8
    AS 'filename'
    LANGUAGE C STRICT;
```

Here is a sample session:

```
=> SELECT execq('CREATE TABLE a (x integer)', 0);
 execq
-------
     0
(1 row)

=> INSERT INTO a VALUES (execq('INSERT INTO a VALUES (0)', 0));
INSERT 0 1
=> SELECT execq('SELECT * FROM a', 0);
```

```
INFO:  EXECQ:  0    -- inserted by execq
INFO:  EXECQ:  1    -- returned by execq and inserted by upper INSERT

 execq
-------
     2
(1 row)

=> SELECT execq('INSERT INTO a SELECT x + 2 FROM a RETURNING *', 1);
INFO:  EXECQ:  2    -- 0 + 2, then execution was stopped by count
 execq
-------
     1
(1 row)

=> SELECT execq('SELECT * FROM a', 10);
INFO:  EXECQ:  0
INFO:  EXECQ:  1
INFO:  EXECQ:  2

 execq
-------
     3              -- 10 is the max value only, 3 is the real number of rows
(1 row)

=> SELECT execq('INSERT INTO a SELECT x + 10 FROM a', 1);
 execq
-------
     3              -- all rows processed; count does not stop it, because nothing is
 returned
(1 row)

=> SELECT * FROM a;
 x
----
  0
  1
  2
 10
 11
 12
(6 rows)

=> DELETE FROM a;
DELETE 6
=> INSERT INTO a VALUES (execq('SELECT * FROM a', 0) + 1);
INSERT 0 1
=> SELECT * FROM a;
 x
---
 1                  -- 0 (no rows in a) + 1
(1 row)

=> INSERT INTO a VALUES (execq('SELECT * FROM a', 0) + 1);
INFO:  EXECQ:  1
INSERT 0 1
=> SELECT * FROM a;
 x
```

```
---
 1
 2                  -- 1 (there was one row in a) + 1
(2 rows)

-- This demonstrates the data changes visibility rule.
-- execq is called twice and sees different numbers of rows each time:

=> INSERT INTO a SELECT execq('SELECT * FROM a', 0) * x FROM a;
INFO:  EXECQ:  1    -- results from first execq
INFO:  EXECQ:  2
INFO:  EXECQ:  1    -- results from second execq
INFO:  EXECQ:  2
INFO:  EXECQ:  2
INSERT 0 2
=> SELECT * FROM a;
 x
---
 1
 2
 2                  -- 2 rows * 1 (x in first row)
 6                  -- 3 rows (2 + 1 just inserted) * 2 (x in second row)
(4 rows)
```

Chapter 50. Background Worker Processes

Postgres Pro can be extended to run user-supplied code in separate processes. Such processes are started, stopped and monitored by `postgres`, which permits them to have a lifetime closely linked to the server's status. These processes have the option to attach to Postgres Pro's shared memory area and to connect to databases internally; they can also run multiple transactions serially, just like a regular client-connected server process. Also, by linking to libpq they can connect to the server and behave like a regular client application.

> **Warning**
>
> There are considerable robustness and security risks in using background worker processes because, being written in the `C` language, they have unrestricted access to data. Administrators wishing to enable modules that include background worker processes should exercise extreme caution. Only carefully audited modules should be permitted to run background worker processes.

Background workers can be initialized at the time that Postgres Pro is started by including the module name in `shared_preload_libraries`. A module wishing to run a background worker can register it by calling `RegisterBackgroundWorker(BackgroundWorker *worker)` from its `_PG_init()` function. Background workers can also be started after the system is up and running by calling `RegisterDynamicBackgroundWorker(BackgroundWorker *worker, BackgroundWorkerHandle **handle)`. Unlike `RegisterBackgroundWorker`, which can only be called from within the postmaster process, `RegisterDynamicBackgroundWorker` must be called from a regular backend or another background worker.

The structure `BackgroundWorker` is defined thus:

```
typedef void (*bgworker_main_type)(Datum main_arg);
typedef struct BackgroundWorker
{
    char        bgw_name[BGW_MAXLEN];
    char        bgw_type[BGW_MAXLEN];
    int         bgw_flags;
    BgWorkerStartTime bgw_start_time;
    int         bgw_restart_time;       /* in seconds, or BGW_NEVER_RESTART */
    char        bgw_library_name[BGW_MAXLEN];
    char        bgw_function_name[BGW_MAXLEN];
    Datum       bgw_main_arg;
    char        bgw_extra[BGW_EXTRALEN];
    int         bgw_notify_pid;
} BackgroundWorker;
```

`bgw_name` and `bgw_type` are strings to be used in log messages, process listings and similar contexts. `bgw_type` should be the same for all background workers of the same type, so that it is possible to group such workers in a process listing, for example. `bgw_name` on the other hand can contain additional information about the specific process. (Typically, the string for `bgw_name` will contain the type somehow, but that is not strictly required.)

`bgw_flags` is a bitwise-or'd bit mask indicating the capabilities that the module wants. Possible values are:

`BGWORKER_SHMEM_ACCESS`

Requests shared memory access. Workers without shared memory access cannot access any of Postgres Pro's shared data structures, such as heavyweight or lightweight locks, shared buffers, or any custom data structures which the worker itself may wish to create and use.

BGWORKER_BACKEND_DATABASE_CONNECTION

Requests the ability to establish a database connection through which it can later run transactions and queries. A background worker using BGWORKER_BACKEND_DATABASE_CONNECTION to connect to a database must also attach shared memory using BGWORKER_SHMEM_ACCESS, or worker start-up will fail.

bgw_start_time is the server state during which postgres should start the process; it can be one of BgWorkerStart_PostmasterStart (start as soon as postgres itself has finished its own initialization; processes requesting this are not eligible for database connections), BgWorkerStart_ConsistentState (start as soon as a consistent state has been reached in a hot standby, allowing processes to connect to databases and run read-only queries), and BgWorkerStart_RecoveryFinished (start as soon as the system has entered normal read-write state). Note the last two values are equivalent in a server that's not a hot standby. Note that this setting only indicates when the processes are to be started; they do not stop when a different state is reached.

bgw_restart_time is the interval, in seconds, that postgres should wait before restarting the process in the event that it crashes. It can be any positive value, or BGW_NEVER_RESTART, indicating not to restart the process in case of a crash.

bgw_library_name is the name of a library in which the initial entry point for the background worker should be sought. The named library will be dynamically loaded by the worker process and bgw_function_name will be used to identify the function to be called. If loading a function from the core code, this must be set to "postgres".

bgw_function_name is the name of a function in a dynamically loaded library which should be used as the initial entry point for a new background worker.

bgw_main_arg is the Datum argument to the background worker main function. This main function should take a single argument of type Datum and return void. bgw_main_arg will be passed as the argument. In addition, the global variable MyBgworkerEntry points to a copy of the BackgroundWorker structure passed at registration time; the worker may find it helpful to examine this structure.

On Windows (and anywhere else where EXEC_BACKEND is defined) or in dynamic background workers it is not safe to pass a Datum by reference, only by value. If an argument is required, it is safest to pass an int32 or other small value and use that as an index into an array allocated in shared memory. If a value like a cstring or text is passed then the pointer won't be valid from the new background worker process.

bgw_extra can contain extra data to be passed to the background worker. Unlike bgw_main_arg, this data is not passed as an argument to the worker's main function, but it can be accessed via MyBgworkerEntry, as discussed above.

bgw_notify_pid is the PID of a Postgres Pro backend process to which the postmaster should send SIGUSR1 when the process is started or exits. It should be 0 for workers registered at postmaster startup time, or when the backend registering the worker does not wish to wait for the worker to start up. Otherwise, it should be initialized to MyProcPid.

Once running, the process can connect to a database by calling BackgroundWorkerInitializeConnection(*char *dbname*, *char *username*, *uint32 flags*) or BackgroundWorkerInitializeConnectionByOid(*Oid dboid*, *Oid useroid*, *uint32 flags*). This allows the process to run transactions and queries using the SPI interface. If dbname is NULL or dboid is InvalidOid, the session is not connected to any particular database, but shared catalogs can be accessed. If username is NULL or useroid is InvalidOid, the process will run as the superuser created during initdb. If BGWORKER_BYPASS_ALLOWCONN is specified as flags it is possible to bypass the restriction to connect to databases not allowing user connections. A background worker can only call one of these two functions, and only once. It is not possible to switch databases.

Signals are initially blocked when control reaches the background worker's main function, and must be unblocked by it; this is to allow the process to customize its signal handlers, if necessary. Signals can

be unblocked in the new process by calling `BackgroundWorkerUnblockSignals` and blocked by calling `BackgroundWorkerBlockSignals`.

If `bgw_restart_time` for a background worker is configured as `BGW_NEVER_RESTART`, or if it exits with an exit code of 0 or is terminated by `TerminateBackgroundWorker`, it will be automatically unregistered by the postmaster on exit. Otherwise, it will be restarted after the time period configured via `bgw_restart_time`, or immediately if the postmaster reinitializes the cluster due to a backend failure. Backends which need to suspend execution only temporarily should use an interruptible sleep rather than exiting; this can be achieved by calling `WaitLatch()`. Make sure the `WL_POSTMASTER_DEATH` flag is set when calling that function, and verify the return code for a prompt exit in the emergency case that `postgres` itself has terminated.

When a background worker is registered using the `RegisterDynamicBackgroundWorker` function, it is possible for the backend performing the registration to obtain information regarding the status of the worker. Backends wishing to do this should pass the address of a `BackgroundWorkerHandle *` as the second argument to `RegisterDynamicBackgroundWorker`. If the worker is successfully registered, this pointer will be initialized with an opaque handle that can subsequently be passed to `GetBackgroundWorkerPid(`*`BackgroundWorkerHandle *`*`, `*`pid_t *`*`)` or `TerminateBackgroundWorker(`*`BackgroundWorkerHandle *`*`)`. `GetBackgroundWorkerPid` can be used to poll the status of the worker: a return value of `BGWH_NOT_YET_STARTED` indicates that the worker has not yet been started by the postmaster; `BGWH_STOPPED` indicates that it has been started but is no longer running; and `BGWH_STARTED` indicates that it is currently running. In this last case, the PID will also be returned via the second argument. `TerminateBackgroundWorker` causes the postmaster to send `SIGTERM` to the worker if it is running, and to unregister it as soon as it is not.

In some cases, a process which registers a background worker may wish to wait for the worker to start up. This can be accomplished by initializing `bgw_notify_pid` to `MyProcPid` and then passing the `BackgroundWorkerHandle *` obtained at registration time to `WaitForBackgroundWorkerStartup(`*`BackgroundWorkerHandle *handle`*`, `*`pid_t *`*`)` function. This function will block until the postmaster has attempted to start the background worker, or until the postmaster dies. If the background worker is running, the return value will be `BGWH_STARTED`, and the PID will be written to the provided address. Otherwise, the return value will be `BGWH_STOPPED` or `BGWH_POSTMASTER_DIED`.

A process can also wait for a background worker to shut down, by using the `WaitForBackgroundWorkerShutdown(`*`BackgroundWorkerHandle *handle`*`)` function and passing the `BackgroundWorkerHandle *` obtained at registration. This function will block until the background worker exits, or postmaster dies. When the background worker exits, the return value is `BGWH_STOPPED`, if postmaster dies it will return `BGWH_POSTMASTER_DIED`.

Background workers can send asynchronous notification messages, either by using the `NOTIFY` command via SPI, or directly via `Async_Notify()`. Such notifications will be sent at transaction commit. Background workers should not register to receive asynchronous notifications with the `LISTEN` command, as there is no infrastructure for a worker to consume such notifications.

The maximum number of registered background workers is limited by max_worker_processes.

Chapter 51. Logical Decoding

Postgres Pro provides infrastructure to stream the modifications performed via SQL to external consumers. This functionality can be used for a variety of purposes, including replication solutions and auditing.

Changes are sent out in streams identified by logical replication slots.

The format in which those changes are streamed is determined by the output plugin used. An example plugin is provided in the Postgres Pro distribution. Additional plugins can be written to extend the choice of available formats without modifying any core code. Every output plugin has access to each individual new row produced by `INSERT` and the new row version created by `UPDATE`. Availability of old row versions for `UPDATE` and `DELETE` depends on the configured replica identity (see `REPLICA IDENTITY`).

Changes can be consumed either using the streaming replication protocol (see Section 55.4 and Section 51.3), or by calling functions via SQL (see Section 51.4). It is also possible to write additional methods of consuming the output of a replication slot without modifying core code (see Section 51.7).

51.1. Logical Decoding Examples

The following example demonstrates controlling logical decoding using the SQL interface.

Before you can use logical decoding, you must set wal_level to `logical` and max_replication_slots to at least 1. Then, you should connect to the target database (in the example below, `postgres`) as a superuser.

```
postgres=# -- Create a slot named 'regression_slot' using the output plugin
 'test_decoding'
postgres=# SELECT * FROM pg_create_logical_replication_slot('regression_slot',
 'test_decoding', false, true);
    slot_name    |    lsn
-----------------+-----------
 regression_slot | 0/16B1970
(1 row)

postgres=# SELECT slot_name, plugin, slot_type, database, active, restart_lsn,
 confirmed_flush_lsn FROM pg_replication_slots;
    slot_name    |    plugin     | slot_type | database | active | restart_lsn |
 confirmed_flush_lsn
-----------------+---------------+-----------+----------+--------+-------------
+-----------------
 regression_slot | test_decoding | logical   | postgres | f      | 0/16A4408   |
 0/16A4440
(1 row)

postgres=# -- There are no changes to see yet
postgres=# SELECT * FROM pg_logical_slot_get_changes('regression_slot', NULL, NULL);
 lsn | xid | data
-----+-----+------
(0 rows)

postgres=# CREATE TABLE data(id serial primary key, data text);
CREATE TABLE

postgres=# -- DDL isn't replicated, so all you'll see is the transaction
postgres=# SELECT * FROM pg_logical_slot_get_changes('regression_slot', NULL, NULL);
    lsn    |  xid  |     data
-----------+-------+--------------
 0/BA2DA58 | 10297 | BEGIN 10297
 0/BA5A5A0 | 10297 | COMMIT 10297
```

```
(2 rows)

postgres=# -- Once changes are read, they're consumed and not emitted
postgres=# -- in a subsequent call:
postgres=# SELECT * FROM pg_logical_slot_get_changes('regression_slot', NULL, NULL);
 lsn | xid | data
-----+-----+------
(0 rows)

postgres=# BEGIN;
postgres=*# INSERT INTO data(data) VALUES('1');
postgres=*# INSERT INTO data(data) VALUES('2');
postgres=*# COMMIT;

postgres=# SELECT * FROM pg_logical_slot_get_changes('regression_slot', NULL, NULL);
    lsn    |  xid  |                          data
-----------+-------+--------------------------------------------------------
 0/BA5A688 | 10298 | BEGIN 10298
 0/BA5A6F0 | 10298 | table public.data: INSERT: id[integer]:1 data[text]:'1'
 0/BA5A7F8 | 10298 | table public.data: INSERT: id[integer]:2 data[text]:'2'
 0/BA5A8A8 | 10298 | COMMIT 10298
(4 rows)

postgres=# INSERT INTO data(data) VALUES('3');

postgres=# -- You can also peek ahead in the change stream without consuming changes
postgres=# SELECT * FROM pg_logical_slot_peek_changes('regression_slot', NULL, NULL);
    lsn    |  xid  |                          data
-----------+-------+--------------------------------------------------------
 0/BA5A8E0 | 10299 | BEGIN 10299
 0/BA5A8E0 | 10299 | table public.data: INSERT: id[integer]:3 data[text]:'3'
 0/BA5A990 | 10299 | COMMIT 10299
(3 rows)

postgres=# -- The next call to pg_logical_slot_peek_changes() returns the same changes
 again
postgres=# SELECT * FROM pg_logical_slot_peek_changes('regression_slot', NULL, NULL);
    lsn    |  xid  |                          data
-----------+-------+--------------------------------------------------------
 0/BA5A8E0 | 10299 | BEGIN 10299
 0/BA5A8E0 | 10299 | table public.data: INSERT: id[integer]:3 data[text]:'3'
 0/BA5A990 | 10299 | COMMIT 10299
(3 rows)

postgres=# -- options can be passed to output plugin, to influence the formatting
postgres=# SELECT * FROM pg_logical_slot_peek_changes('regression_slot', NULL, NULL,
 'include-timestamp', 'on');
    lsn    |  xid  |                          data
-----------+-------+--------------------------------------------------------
 0/BA5A8E0 | 10299 | BEGIN 10299
 0/BA5A8E0 | 10299 | table public.data: INSERT: id[integer]:3 data[text]:'3'
 0/BA5A990 | 10299 | COMMIT 10299 (at 2017-05-10 12:07:21.272494-04)
(3 rows)

postgres=# -- Remember to destroy a slot you no longer need to stop it consuming
postgres=# -- server resources:
postgres=# SELECT pg_drop_replication_slot('regression_slot');
 pg_drop_replication_slot
```

```
----------------------

(1 row)
```

The following example shows how logical decoding is controlled over the streaming replication protocol, using the program pg_recvlogical included in the Postgres Pro distribution. This requires that client authentication is set up to allow replication connections (see Section 26.2.5.1) and that `max_wal_senders` is set sufficiently high to allow an additional connection.

```
$ pg_recvlogical -d postgres --slot=test --create-slot
$ pg_recvlogical -d postgres --slot=test --start -f -
Control+Z
$ psql -d postgres -c "INSERT INTO data(data) VALUES('4');"
$ fg
BEGIN 693
table public.data: INSERT: id[integer]:4 data[text]:'4'
COMMIT 693
Control+C
$ pg_recvlogical -d postgres --slot=test --drop-slot
```

The following example shows SQL interface that can be used to decode prepared transactions. Before you use two-phase commit commands, you must set `max_prepared_transactions` to at least 1. You must also have set the two-phase parameter as 'true' while creating the slot using `pg_create_logical_replication_slot` Note that we will stream the entire transaction after the commit if it is not already decoded.

```
postgres=# BEGIN;
postgres=*# INSERT INTO data(data) VALUES('5');
postgres=*# PREPARE TRANSACTION 'test_prepared1';

postgres=# SELECT * FROM pg_logical_slot_get_changes('regression_slot', NULL, NULL);
    lsn     | xid |                          data
------------+-----+--------------------------------------------------------
 0/1689DC0 | 529 | BEGIN 529
 0/1689DC0 | 529 | table public.data: INSERT: id[integer]:3 data[text]:'5'
 0/1689FC0 | 529 | PREPARE TRANSACTION 'test_prepared1', txid 529
(3 rows)

postgres=# COMMIT PREPARED 'test_prepared1';
postgres=# select * from pg_logical_slot_get_changes('regression_slot', NULL, NULL);
    lsn     | xid |                    data
------------+-----+-------------------------------------------
 0/168A060 | 529 | COMMIT PREPARED 'test_prepared1', txid 529
(4 row)

postgres=#-- you can also rollback a prepared transaction
postgres=# BEGIN;
postgres=*# INSERT INTO data(data) VALUES('6');
postgres=*# PREPARE TRANSACTION 'test_prepared2';
postgres=# select * from pg_logical_slot_get_changes('regression_slot', NULL, NULL);
    lsn     | xid |                          data
------------+-----+--------------------------------------------------------
 0/168A180 | 530 | BEGIN 530
 0/168A1E8 | 530 | table public.data: INSERT: id[integer]:4 data[text]:'6'
 0/168A430 | 530 | PREPARE TRANSACTION 'test_prepared2', txid 530
(3 rows)

postgres=# ROLLBACK PREPARED 'test_prepared2';
postgres=# select * from pg_logical_slot_get_changes('regression_slot', NULL, NULL);
    lsn     | xid |                    data
```

```
-----------+-----+-------------------------------------------
 0/168A4B8 | 530 | ROLLBACK PREPARED 'test_prepared2', txid 530
(1 row)
```

51.2. Logical Decoding Concepts

51.2.1. Logical Decoding

Logical decoding is the process of extracting all persistent changes to a database's tables into a coherent, easy to understand format which can be interpreted without detailed knowledge of the database's internal state.

In Postgres Pro, logical decoding is implemented by decoding the contents of the write-ahead log, which describe changes on a storage level, into an application-specific form such as a stream of tuples or SQL statements.

51.2.2. Replication Slots

In the context of logical replication, a slot represents a stream of changes that can be replayed to a client in the order they were made on the origin server. Each slot streams a sequence of changes from a single database.

> **Note**
>
> Postgres Pro also has streaming replication slots (see Section 26.2.5), but they are used somewhat differently there.

A replication slot has an identifier that is unique across all databases in a Postgres Pro cluster. Slots persist independently of the connection using them and are crash-safe.

A logical slot will emit each change just once in normal operation. The current position of each slot is persisted only at checkpoint, so in the case of a crash the slot may return to an earlier LSN, which will then cause recent changes to be sent again when the server restarts. Logical decoding clients are responsible for avoiding ill effects from handling the same message more than once. Clients may wish to record the last LSN they saw when decoding and skip over any repeated data or (when using the replication protocol) request that decoding start from that LSN rather than letting the server determine the start point. The Replication Progress Tracking feature is designed for this purpose, refer to replication origins.

Multiple independent slots may exist for a single database. Each slot has its own state, allowing different consumers to receive changes from different points in the database change stream. For most applications, a separate slot will be required for each consumer.

A logical replication slot knows nothing about the state of the receiver(s). It's even possible to have multiple different receivers using the same slot at different times; they'll just get the changes following on from when the last receiver stopped consuming them. Only one receiver may consume changes from a slot at any given time.

> **Caution**
>
> Replication slots persist across crashes and know nothing about the state of their consumer(s). They will prevent removal of required resources even when there is no connection using them. This consumes storage because neither required WAL nor required rows from the system catalogs can be removed by `VACUUM` as long as they are required by a replication slot. In extreme cases this could cause the database to shut down to prevent transaction ID wraparound (see Section 24.1.5). So if a slot is no longer required it should be dropped.

51.2.3. Output Plugins

Output plugins transform the data from the write-ahead log's internal representation into the format the consumer of a replication slot desires.

51.2.4. Exported Snapshots

When a new replication slot is created using the streaming replication interface (see CREATE_REPLICATION_SLOT), a snapshot is exported (see Section 9.27.5), which will show exactly the state of the database after which all changes will be included in the change stream. This can be used to create a new replica by using `SET TRANSACTION SNAPSHOT` to read the state of the database at the moment the slot was created. This transaction can then be used to dump the database's state at that point in time, which afterwards can be updated using the slot's contents without losing any changes.

Creation of a snapshot is not always possible. In particular, it will fail when connected to a hot standby. Applications that do not require snapshot export may suppress it with the `NOEXPORT_SNAPSHOT` option.

51.3. Streaming Replication Protocol Interface

The commands

- `CREATE_REPLICATION_SLOT` *`slot_name`* `LOGICAL` *`output_plugin`*
- `DROP_REPLICATION_SLOT` *`slot_name`* [`WAIT`]
- `START_REPLICATION SLOT` *`slot_name`* `LOGICAL ...`

are used to create, drop, and stream changes from a replication slot, respectively. These commands are only available over a replication connection; they cannot be used via SQL. See Section 55.4 for details on these commands.

The command pg_recvlogical can be used to control logical decoding over a streaming replication connection. (It uses these commands internally.)

51.4. Logical Decoding SQL Interface

See Section 9.27.6 for detailed documentation on the SQL-level API for interacting with logical decoding.

Synchronous replication (see Section 26.2.8) is only supported on replication slots used over the streaming replication interface. The function interface and additional, non-core interfaces do not support synchronous replication.

51.5. System Catalogs Related to Logical Decoding

The `pg_replication_slots` view and the `pg_stat_replication` view provide information about the current state of replication slots and streaming replication connections respectively. These views apply to both physical and logical replication. The `pg_stat_replication_slots` view provides statistics information about the logical replication slots.

51.6. Logical Decoding Output Plugins

An example output plugin can be found in the `contrib/test_decoding` subdirectory of the Postgres Pro source tree.

51.6.1. Initialization Function

An output plugin is loaded by dynamically loading a shared library with the output plugin's name as the library base name. The normal library search path is used to locate the library. To provide the required output plugin callbacks and to indicate that the library is actually an output plugin it needs to provide a function named `_PG_output_plugin_init`. This function is passed a struct that needs to be filled with the callback function pointers for individual actions.

```
typedef struct OutputPluginCallbacks
```

```
{
    LogicalDecodeStartupCB startup_cb;
    LogicalDecodeBeginCB begin_cb;
    LogicalDecodeChangeCB change_cb;
    LogicalDecodeTruncateCB truncate_cb;
    LogicalDecodeCommitCB commit_cb;
    LogicalDecodeMessageCB message_cb;
    LogicalDecodeFilterByOriginCB filter_by_origin_cb;
    LogicalDecodeShutdownCB shutdown_cb;
    LogicalDecodeFilterPrepareCB filter_prepare_cb;
    LogicalDecodeBeginPrepareCB begin_prepare_cb;
    LogicalDecodePrepareCB prepare_cb;
    LogicalDecodeCommitPreparedCB commit_prepared_cb;
    LogicalDecodeRollbackPreparedCB rollback_prepared_cb;
    LogicalDecodeStreamStartCB stream_start_cb;
    LogicalDecodeStreamStopCB stream_stop_cb;
    LogicalDecodeStreamAbortCB stream_abort_cb;
    LogicalDecodeStreamPrepareCB stream_prepare_cb;
    LogicalDecodeStreamCommitCB stream_commit_cb;
    LogicalDecodeStreamChangeCB stream_change_cb;
    LogicalDecodeStreamMessageCB stream_message_cb;
    LogicalDecodeStreamTruncateCB stream_truncate_cb;
} OutputPluginCallbacks;

typedef void (*LogicalOutputPluginInit) (struct OutputPluginCallbacks *cb);
```

The `begin_cb`, `change_cb` and `commit_cb` callbacks are required, while `startup_cb`, `filter_by_origin_cb`, `truncate_cb`, and `shutdown_cb` are optional. If `truncate_cb` is not set but a `TRUNCATE` is to be decoded, the action will be ignored.

An output plugin may also define functions to support streaming of large, in-progress transactions. The `stream_start_cb`, `stream_stop_cb`, `stream_abort_cb`, `stream_commit_cb`, `stream_change_cb`, and `stream_prepare_cb` are required, while `stream_message_cb` and `stream_truncate_cb` are optional.

An output plugin may also define functions to support two-phase commits, which allows actions to be decoded on the `PREPARE TRANSACTION`. The `begin_prepare_cb`, `prepare_cb`, `stream_prepare_cb`, `commit_prepared_cb` and `rollback_prepared_cb` callbacks are required, while `filter_prepare_cb` is optional.

51.6.2. Capabilities

To decode, format and output changes, output plugins can use most of the backend's normal infrastructure, including calling output functions. Read only access to relations is permitted as long as only relations are accessed that either have been created by `initdb` in the `pg_catalog` schema, or have been marked as user provided catalog tables using

```
ALTER TABLE user_catalog_table SET (user_catalog_table = true);
CREATE TABLE another_catalog_table(data text) WITH (user_catalog_table = true);
```

Note that access to user catalog tables or regular system catalog tables in the output plugins has to be done via the `systable_*` scan APIs only. Access via the `heap_*` scan APIs will error out. Additionally, any actions leading to transaction ID assignment are prohibited. That, among others, includes writing to tables, performing DDL changes, and calling `pg_current_xact_id()`.

51.6.3. Output Modes

Output plugin callbacks can pass data to the consumer in nearly arbitrary formats. For some use cases, like viewing the changes via SQL, returning data in a data type that can contain arbitrary data (e.g., `bytea`) is cumbersome. If the output plugin only outputs textual data in the server's encoding, it can declare that by setting `OutputPluginOptions.output_type` to `OUTPUT_PLUGIN_TEXTUAL_OUTPUT` instead

of OUTPUT_PLUGIN_BINARY_OUTPUT in the startup callback. In that case, all the data has to be in the server's encoding so that a text datum can contain it. This is checked in assertion-enabled builds.

51.6.4. Output Plugin Callbacks

An output plugin gets notified about changes that are happening via various callbacks it needs to provide.

Concurrent transactions are decoded in commit order, and only changes belonging to a specific transaction are decoded between the begin and commit callbacks. Transactions that were rolled back explicitly or implicitly never get decoded. Successful savepoints are folded into the transaction containing them in the order they were executed within that transaction. A transaction that is prepared for a two-phase commit using PREPARE TRANSACTION will also be decoded if the output plugin callbacks needed for decoding them are provided. It is possible that the current prepared transaction which is being decoded is aborted concurrently via a ROLLBACK PREPARED command. In that case, the logical decoding of this transaction will be aborted too. All the changes of such a transaction are skipped once the abort is detected and the prepare_cb callback is invoked. Thus even in case of a concurrent abort, enough information is provided to the output plugin for it to properly deal with ROLLBACK PREPARED once that is decoded.

> **Note**
>
> Only transactions that have already safely been flushed to disk will be decoded. That can lead to a COMMIT not immediately being decoded in a directly following pg_logical_slot_get_changes() when synchronous_commit is set to off.

51.6.4.1. Startup Callback

The optional startup_cb callback is called whenever a replication slot is created or asked to stream changes, independent of the number of changes that are ready to be put out.

```
typedef void (*LogicalDecodeStartupCB) (struct LogicalDecodingContext *ctx,
                                        OutputPluginOptions *options,
                                        bool is_init);
```

The is_init parameter will be true when the replication slot is being created and false otherwise. *options* points to a struct of options that output plugins can set:

```
typedef struct OutputPluginOptions
{
    OutputPluginOutputType output_type;
    bool        receive_rewrites;
} OutputPluginOptions;
```

output_type has to either be set to OUTPUT_PLUGIN_TEXTUAL_OUTPUT or OUTPUT_PLUGIN_BINARY_OUTPUT. See also Section 51.6.3. If receive_rewrites is true, the output plugin will also be called for changes made by heap rewrites during certain DDL operations. These are of interest to plugins that handle DDL replication, but they require special handling.

The startup callback should validate the options present in ctx->output_plugin_options. If the output plugin needs to have a state, it can use ctx->output_plugin_private to store it.

51.6.4.2. Shutdown Callback

The optional shutdown_cb callback is called whenever a formerly active replication slot is not used anymore and can be used to deallocate resources private to the output plugin. The slot isn't necessarily being dropped, streaming is just being stopped.

```
typedef void (*LogicalDecodeShutdownCB) (struct LogicalDecodingContext *ctx);
```

51.6.4.3. Transaction Begin Callback

The required begin_cb callback is called whenever a start of a committed transaction has been decoded. Aborted transactions and their contents never get decoded.

```
typedef void (*LogicalDecodeBeginCB) (struct LogicalDecodingContext *ctx,
                                      ReorderBufferTXN *txn);
```

The *txn* parameter contains meta information about the transaction, like the time stamp at which it has been committed and its XID.

51.6.4.4. Transaction End Callback

The required commit_cb callback is called whenever a transaction commit has been decoded. The change_cb callbacks for all modified rows will have been called before this, if there have been any modified rows.

```
typedef void (*LogicalDecodeCommitCB) (struct LogicalDecodingContext *ctx,
                                       ReorderBufferTXN *txn,
                                       XLogRecPtr commit_lsn);
```

51.6.4.5. Change Callback

The required change_cb callback is called for every individual row modification inside a transaction, may it be an INSERT, UPDATE, or DELETE. Even if the original command modified several rows at once the callback will be called individually for each row. The change_cb callback may access system or user catalog tables to aid in the process of outputting the row modification details. In case of decoding a prepared (but yet uncommitted) transaction or decoding of an uncommitted transaction, this change callback might also error out due to simultaneous rollback of this very same transaction. In that case, the logical decoding of this aborted transaction is stopped gracefully.

```
typedef void (*LogicalDecodeChangeCB) (struct LogicalDecodingContext *ctx,
                                       ReorderBufferTXN *txn,
                                       Relation relation,
                                       ReorderBufferChange *change);
```

The *ctx* and *txn* parameters have the same contents as for the begin_cb and commit_cb callbacks, but additionally the relation descriptor *relation* points to the relation the row belongs to and a struct *change* describing the row modification are passed in.

> **Note**
>
> Only changes in user defined tables that are not unlogged (see UNLOGGED) and not temporary (see TEMPORARY or TEMP) can be extracted using logical decoding.

51.6.4.6. Truncate Callback

The truncate_cb callback is called for a TRUNCATE command.

```
typedef void (*LogicalDecodeTruncateCB) (struct LogicalDecodingContext *ctx,
                                         ReorderBufferTXN *txn,
                                         int nrelations,
                                         Relation relations[],
                                         ReorderBufferChange *change);
```

The parameters are analogous to the change_cb callback. However, because TRUNCATE actions on tables connected by foreign keys need to be executed together, this callback receives an array of relations instead of just a single one. See the description of the TRUNCATE statement for details.

51.6.4.7. Origin Filter Callback

The optional filter_by_origin_cb callback is called to determine whether data that has been replayed from *origin_id* is of interest to the output plugin.

```
typedef bool (*LogicalDecodeFilterByOriginCB) (struct LogicalDecodingContext *ctx,
                                               RepOriginId origin_id);
```

The *ctx* parameter has the same contents as for the other callbacks. No information but the origin is available. To signal that changes originating on the passed in node are irrelevant, return true, causing them to be filtered away; false otherwise. The other callbacks will not be called for transactions and changes that have been filtered away.

This is useful when implementing cascading or multidirectional replication solutions. Filtering by the origin allows to prevent replicating the same changes back and forth in such setups. While transactions and changes also carry information about the origin, filtering via this callback is noticeably more efficient.

51.6.4.8. Generic Message Callback

The optional message_cb callback is called whenever a logical decoding message has been decoded.

```
typedef void (*LogicalDecodeMessageCB) (struct LogicalDecodingContext *ctx,
                                        ReorderBufferTXN *txn,
                                        XLogRecPtr message_lsn,
                                        bool transactional,
                                        const char *prefix,
                                        Size message_size,
                                        const char *message);
```

The *txn* parameter contains meta information about the transaction, like the time stamp at which it has been committed and its XID. Note however that it can be NULL when the message is non-transactional and the XID was not assigned yet in the transaction which logged the message. The *lsn* has WAL location of the message. The *transactional* says if the message was sent as transactional or not. Similar to the change callback, in case of decoding a prepared (but yet uncommitted) transaction or decoding of an uncommitted transaction, this message callback might also error out due to simultaneous rollback of this very same transaction. In that case, the logical decoding of this aborted transaction is stopped gracefully. The *prefix* is arbitrary null-terminated prefix which can be used for identifying interesting messages for the current plugin. And finally the *message* parameter holds the actual message of *message_size* size.

Extra care should be taken to ensure that the prefix the output plugin considers interesting is unique. Using name of the extension or the output plugin itself is often a good choice.

51.6.4.9. Prepare Filter Callback

The optional filter_prepare_cb callback is called to determine whether data that is part of the current two-phase commit transaction should be considered for decoding at this prepare stage or later as a regular one-phase transaction at COMMIT PREPARED time. To signal that decoding should be skipped, return true; false otherwise. When the callback is not defined, false is assumed (i.e. no filtering, all transactions using two-phase commit are decoded in two phases as well).

```
typedef bool (*LogicalDecodeFilterPrepareCB) (struct LogicalDecodingContext *ctx,
                                              TransactionId xid,
                                              const char *gid);
```

The *ctx* parameter has the same contents as for the other callbacks. The parameters *xid* and *gid* provide two different ways to identify the transaction. The later COMMIT PREPARED or ROLLBACK PREPARED carries both identifiers, providing an output plugin the choice of what to use.

The callback may be invoked multiple times per transaction to decode and must provide the same static answer for a given pair of *xid* and *gid* every time it is called.

51.6.4.10. Transaction Begin Prepare Callback

The required begin_prepare_cb callback is called whenever the start of a prepared transaction has been decoded. The *gid* field, which is part of the *txn* parameter, can be used in this callback to check if the plugin has already received this PREPARE in which case it can either error out or skip the remaining changes of the transaction.

```
typedef void (*LogicalDecodeBeginPrepareCB) (struct LogicalDecodingContext *ctx,
                                             ReorderBufferTXN *txn);
```

51.6.4.11. Transaction Prepare Callback

The required `prepare_cb` callback is called whenever a transaction which is prepared for two-phase commit has been decoded. The `change_cb` callback for all modified rows will have been called before this, if there have been any modified rows. The *`gid`* field, which is part of the *`txn`* parameter, can be used in this callback.

```
typedef void (*LogicalDecodePrepareCB) (struct LogicalDecodingContext *ctx,
                                        ReorderBufferTXN *txn,
                                        XLogRecPtr prepare_lsn);
```

51.6.4.12. Transaction Commit Prepared Callback

The required `commit_prepared_cb` callback is called whenever a transaction `COMMIT PREPARED` has been decoded. The *`gid`* field, which is part of the *`txn`* parameter, can be used in this callback.

```
typedef void (*LogicalDecodeCommitPreparedCB) (struct LogicalDecodingContext *ctx,
                                               ReorderBufferTXN *txn,
                                               XLogRecPtr commit_lsn);
```

51.6.4.13. Transaction Rollback Prepared Callback

The required `rollback_prepared_cb` callback is called whenever a transaction `ROLLBACK PREPARED` has been decoded. The *`gid`* field, which is part of the *`txn`* parameter, can be used in this callback. The parameters *`prepare_end_lsn`* and *`prepare_time`* can be used to check if the plugin has received this `PREPARE TRANSACTION` in which case it can apply the rollback, otherwise, it can skip the rollback operation. The *`gid`* alone is not sufficient because the downstream node can have a prepared transaction with same identifier.

```
typedef void (*LogicalDecodeRollbackPreparedCB) (struct LogicalDecodingContext *ctx,
                                                 ReorderBufferTXN *txn,
                                                 XLogRecPtr prepare_end_lsn,
                                                 TimestampTz prepare_time);
```

51.6.4.14. Stream Start Callback

The `stream_start_cb` callback is called when opening a block of streamed changes from an in-progress transaction.

```
typedef void (*LogicalDecodeStreamStartCB) (struct LogicalDecodingContext *ctx,
                                            ReorderBufferTXN *txn);
```

51.6.4.15. Stream Stop Callback

The `stream_stop_cb` callback is called when closing a block of streamed changes from an in-progress transaction.

```
typedef void (*LogicalDecodeStreamStopCB) (struct LogicalDecodingContext *ctx,
                                           ReorderBufferTXN *txn);
```

51.6.4.16. Stream Abort Callback

The `stream_abort_cb` callback is called to abort a previously streamed transaction.

```
typedef void (*LogicalDecodeStreamAbortCB) (struct LogicalDecodingContext *ctx,
                                            ReorderBufferTXN *txn,
                                            XLogRecPtr abort_lsn);
```

51.6.4.17. Stream Prepare Callback

The `stream_prepare_cb` callback is called to prepare a previously streamed transaction as part of a two-phase commit.

```
typedef void (*LogicalDecodeStreamPrepareCB) (struct LogicalDecodingContext *ctx,
                                              ReorderBufferTXN *txn,
```

```
                                                XLogRecPtr prepare_lsn);
```

51.6.4.18. Stream Commit Callback

The `stream_commit_cb` callback is called to commit a previously streamed transaction.

```
typedef void (*LogicalDecodeStreamCommitCB) (struct LogicalDecodingContext *ctx,
                                             ReorderBufferTXN *txn,
                                             XLogRecPtr commit_lsn);
```

51.6.4.19. Stream Change Callback

The `stream_change_cb` callback is called when sending a change in a block of streamed changes (demarcated by `stream_start_cb` and `stream_stop_cb` calls). The actual changes are not displayed as the transaction can abort at a later point in time and we don't decode changes for aborted transactions.

```
typedef void (*LogicalDecodeStreamChangeCB) (struct LogicalDecodingContext *ctx,
                                             ReorderBufferTXN *txn,
                                             Relation relation,
                                             ReorderBufferChange *change);
```

51.6.4.20. Stream Message Callback

The `stream_message_cb` callback is called when sending a generic message in a block of streamed changes (demarcated by `stream_start_cb` and `stream_stop_cb` calls). The message contents for transactional messages are not displayed as the transaction can abort at a later point in time and we don't decode changes for aborted transactions.

```
typedef void (*LogicalDecodeStreamMessageCB) (struct LogicalDecodingContext *ctx,
                                              ReorderBufferTXN *txn,
                                              XLogRecPtr message_lsn,
                                              bool transactional,
                                              const char *prefix,
                                              Size message_size,
                                              const char *message);
```

51.6.4.21. Stream Truncate Callback

The `stream_truncate_cb` callback is called for a `TRUNCATE` command in a block of streamed changes (demarcated by `stream_start_cb` and `stream_stop_cb` calls).

```
typedef void (*LogicalDecodeStreamTruncateCB) (struct LogicalDecodingContext *ctx,
                                               ReorderBufferTXN *txn,
                                               int nrelations,
                                               Relation relations[],
                                               ReorderBufferChange *change);
```

The parameters are analogous to the `stream_change_cb` callback. However, because `TRUNCATE` actions on tables connected by foreign keys need to be executed together, this callback receives an array of relations instead of just a single one. See the description of the TRUNCATE statement for details.

51.6.5. Functions for Producing Output

To actually produce output, output plugins can write data to the `StringInfo` output buffer in `ctx->out` when inside the `begin_cb`, `commit_cb`, or `change_cb` callbacks. Before writing to the output buffer, `OutputPluginPrepareWrite(ctx, last_write)` has to be called, and after finishing writing to the buffer, `OutputPluginWrite(ctx, last_write)` has to be called to perform the write. The *`last_write`* indicates whether a particular write was the callback's last write.

The following example shows how to output data to the consumer of an output plugin:

```
OutputPluginPrepareWrite(ctx, true);
appendStringInfo(ctx->out, "BEGIN %u", txn->xid);
```

```
OutputPluginWrite(ctx, true);
```

51.7. Logical Decoding Output Writers

It is possible to add more output methods for logical decoding. Essentially, three functions need to be provided: one to read WAL, one to prepare writing output, and one to write the output (see Section 51.6.5).

51.8. Synchronous Replication Support for Logical Decoding

51.8.1. Overview

Logical decoding can be used to build synchronous replication solutions with the same user interface as synchronous replication for streaming replication. To do this, the streaming replication interface (see Section 51.3) must be used to stream out data. Clients have to send `Standby status update (F)` (see Section 55.4) messages, just like streaming replication clients do.

> **Note**
>
> A synchronous replica receiving changes via logical decoding will work in the scope of a single database. Since, in contrast to that, *`synchronous_standby_names`* currently is server wide, this means this technique will not work properly if more than one database is actively used.

51.8.2. Caveats

In synchronous replication setup, a deadlock can happen, if the transaction has locked [user] catalog tables exclusively. See Section 51.6.2 for information on user catalog tables. This is because logical decoding of transactions can lock catalog tables to access them. To avoid this users must refrain from taking an exclusive lock on [user] catalog tables. This can happen in the following ways:

- Issuing an explicit `LOCK` on `pg_class` in a transaction.
- Perform `CLUSTER` on `pg_class` in a transaction.
- `PREPARE TRANSACTION` after `LOCK` command on `pg_class` and allow logical decoding of two-phase transactions.
- `PREPARE TRANSACTION` after `CLUSTER` command on `pg_trigger` and allow logical decoding of two-phase transactions. This will lead to deadlock only when published table have a trigger.
- Executing `TRUNCATE` on [user] catalog table in a transaction.

Note that these commands that can cause deadlock apply to not only explicitly indicated system catalog tables above but also to any other [user] catalog table.

51.9. Streaming of Large Transactions for Logical Decoding

The basic output plugin callbacks (e.g., `begin_cb`, `change_cb`, `commit_cb` and `message_cb`) are only invoked when the transaction actually commits. The changes are still decoded from the transaction log, but are only passed to the output plugin at commit (and discarded if the transaction aborts).

This means that while the decoding happens incrementally, and may spill to disk to keep memory usage under control, all the decoded changes have to be transmitted when the transaction finally commits (or more precisely, when the commit is decoded from the transaction log). Depending on the size of the transaction and network bandwidth, the transfer time may significantly increase the apply lag.

To reduce the apply lag caused by large transactions, an output plugin may provide additional callback to support incremental streaming of in-progress transactions. There are multiple required

streaming callbacks (stream_start_cb, stream_stop_cb, stream_abort_cb, stream_commit_cb and stream_change_cb) and two optional callbacks (stream_message_cb and stream_truncate_cb).

When streaming an in-progress transaction, the changes (and messages) are streamed in blocks demarcated by stream_start_cb and stream_stop_cb callbacks. Once all the decoded changes are transmitted, the transaction can be committed using the the stream_commit_cb callback (or possibly aborted using the stream_abort_cb callback). If two-phase commits are supported, the transaction can be prepared using the stream_prepare_cb callback, COMMIT PREPARED using the commit_prepared_cb callback or aborted using the rollback_prepared_cb.

One example sequence of streaming callback calls for one transaction may look like this:

```
stream_start_cb(...);   <-- start of first block of changes
  stream_change_cb(...);
  stream_change_cb(...);
  stream_message_cb(...);
  stream_change_cb(...);
  ...
  stream_change_cb(...);
stream_stop_cb(...);    <-- end of first block of changes

stream_start_cb(...);   <-- start of second block of changes
  stream_change_cb(...);
  stream_change_cb(...);
  stream_change_cb(...);
  ...
  stream_message_cb(...);
  stream_change_cb(...);
stream_stop_cb(...);    <-- end of second block of changes

stream_commit_cb(...);  <-- commit of the streamed transaction
```

The actual sequence of callback calls may be more complicated, of course. There may be blocks for multiple streamed transactions, some of the transactions may get aborted, etc.

Similar to spill-to-disk behavior, streaming is triggered when the total amount of changes decoded from the WAL (for all in-progress transactions) exceeds the limit defined by logical_decoding_work_mem setting. At that point, the largest top-level transaction (measured by the amount of memory currently used for decoded changes) is selected and streamed. However, in some cases we still have to spill to disk even if streaming is enabled because we exceed the memory threshold but still have not decoded the complete tuple e.g., only decoded toast table insert but not the main table insert.

Even when streaming large transactions, the changes are still applied in commit order, preserving the same guarantees as the non-streaming mode.

51.10. Two-phase Commit Support for Logical Decoding

With the basic output plugin callbacks (eg., begin_cb, change_cb, commit_cb and message_cb) two-phase commit commands like PREPARE TRANSACTION, COMMIT PREPARED and ROLLBACK PREPARED are not decoded. While the PREPARE TRANSACTION is ignored, COMMIT PREPARED is decoded as a COMMIT and ROLLBACK PREPARED is decoded as a ROLLBACK.

To support the streaming of two-phase commands, an output plugin needs to provide additional callbacks. There are multiple two-phase commit callbacks that are required, (begin_prepare_cb, prepare_cb, commit_prepared_cb, rollback_prepared_cb and stream_prepare_cb) and an optional callback (filter_prepare_cb).

If the output plugin callbacks for decoding two-phase commit commands are provided, then on PREPARE TRANSACTION, the changes of that transaction are decoded, passed to the output plugin, and the pre-

pare_cb callback is invoked. This differs from the basic decoding setup where changes are only passed to the output plugin when a transaction is committed. The start of a prepared transaction is indicated by the begin_prepare_cb callback.

When a prepared transaction is rolled back using the ROLLBACK PREPARED, then the rollback_prepared_cb callback is invoked and when the prepared transaction is committed using COMMIT PREPARED, then the commit_prepared_cb callback is invoked.

Optionally the output plugin can define filtering rules via filter_prepare_cb to decode only specific transaction in two phases. This can be achieved by pattern matching on the *gid* or via lookups using the *xid*.

The users that want to decode prepared transactions need to be careful about below mentioned points:

- If the prepared transaction has locked [user] catalog tables exclusively then decoding prepare can block till the main transaction is committed.
- The logical replication solution that builds distributed two phase commit using this feature can deadlock if the prepared transaction has locked [user] catalog tables exclusively. To avoid this users must refrain from having locks on catalog tables (e.g. explicit LOCK command) in such transactions. See Section 51.8.2 for the details.

Chapter 52. Replication Progress Tracking

Replication origins are intended to make it easier to implement logical replication solutions on top of logical decoding. They provide a solution to two common problems:

- How to safely keep track of replication progress
- How to change replication behavior based on the origin of a row; for example, to prevent loops in bi-directional replication setups

Replication origins have just two properties, a name and an OID. The name, which is what should be used to refer to the origin across systems, is free-form `text`. It should be used in a way that makes conflicts between replication origins created by different replication solutions unlikely; e.g., by prefixing the replication solution's name to it. The OID is used only to avoid having to store the long version in situations where space efficiency is important. It should never be shared across systems.

Replication origins can be created using the function `pg_replication_origin_create()`; dropped using `pg_replication_origin_drop()`; and seen in the `pg_replication_origin` system catalog.

One nontrivial part of building a replication solution is to keep track of replay progress in a safe manner. When the applying process, or the whole cluster, dies, it needs to be possible to find out up to where data has successfully been replicated. Naive solutions to this, such as updating a row in a table for every replayed transaction, have problems like run-time overhead and database bloat.

Using the replication origin infrastructure a session can be marked as replaying from a remote node (using the `pg_replication_origin_session_setup()` function). Additionally the LSN and commit time stamp of every source transaction can be configured on a per transaction basis using `pg_replication_origin_xact_setup()`. If that's done replication progress will persist in a crash safe manner. Replay progress for all replication origins can be seen in the `pg_replication_origin_status` view. An individual origin's progress, e.g., when resuming replication, can be acquired using `pg_replication_origin_progress()` for any origin or `pg_replication_origin_session_progress()` for the origin configured in the current session.

In replication topologies more complex than replication from exactly one system to one other system, another problem can be that it is hard to avoid replicating replayed rows again. That can lead both to cycles in the replication and inefficiencies. Replication origins provide an optional mechanism to recognize and prevent that. When configured using the functions referenced in the previous paragraph, every change and transaction passed to output plugin callbacks (see Section 51.6) generated by the session is tagged with the replication origin of the generating session. This allows treating them differently in the output plugin, e.g., ignoring all but locally-originating rows. Additionally the `filter_by_origin_cb` callback can be used to filter the logical decoding change stream based on the source. While less flexible, filtering via that callback is considerably more efficient than doing it in the output plugin.

Part VI. Reference

The entries in this Reference are meant to provide in reasonable length an authoritative, complete, and formal summary about their respective subjects. More information about the use of Postgres Pro, in narrative, tutorial, or example form, can be found in other parts of this book. See the cross-references listed on each reference page.

The reference entries are also available as traditional “man” pages.

SQL Commands

This part contains reference information for the SQL commands supported by Postgres Pro. By “SQL” the language in general is meant; information about the standards conformance and compatibility of each command can be found on the respective reference page.

ABORT

ABORT — abort the current transaction

Synopsis

```
ABORT [ AUTONOMOUS ] [ WORK | TRANSACTION ] [ AND [ NO ] CHAIN ]
```

Description

`ABORT` rolls back the current transaction and causes all the updates made by the transaction to be discarded. This command is identical in behavior to the standard SQL command `ROLLBACK`, and is present only for historical reasons.

Parameters

`AUTONOMOUS`

Optional key word that can be used when aborting an autonomous transaction. For details on autonomous transactions, see Chapter 16.

`WORK`
`TRANSACTION`

Optional key words. They have no effect.

`AND CHAIN`

If `AND CHAIN` is specified, a new transaction is immediately started with the same transaction characteristics (see `SET TRANSACTION`) as the just finished one. Otherwise, no new transaction is started.

Notes

Use `COMMIT` to successfully terminate a transaction.

Issuing `ABORT` outside of a transaction block emits a warning and otherwise has no effect.

Examples

To abort all changes:

```
ABORT;
```

Compatibility

This command is a Postgres Pro extension present for historical reasons. `ROLLBACK` is the equivalent standard SQL command.

See Also

BEGIN, COMMIT, ROLLBACK

ALTER AGGREGATE

ALTER AGGREGATE — change the definition of an aggregate function

Synopsis

```
ALTER AGGREGATE name ( aggregate_signature ) RENAME TO new_name
ALTER AGGREGATE name ( aggregate_signature )
                 OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
ALTER AGGREGATE name ( aggregate_signature ) SET SCHEMA new_schema

where aggregate_signature is:

* |
[ argmode ] [ argname ] argtype [ , ... ] |
[ [ argmode ] [ argname ] argtype [ , ... ] ] ORDER BY [ argmode ] [ argname ] argtype
 [ , ... ]
```

Description

`ALTER AGGREGATE` changes the definition of an aggregate function.

You must own the aggregate function to use `ALTER AGGREGATE`. To change the schema of an aggregate function, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the aggregate function's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the aggregate function. However, a superuser can alter ownership of any aggregate function anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing aggregate function.

argmode

The mode of an argument: `IN` or `VARIADIC`. If omitted, the default is `IN`.

argname

The name of an argument. Note that `ALTER AGGREGATE` does not actually pay any attention to argument names, since only the argument data types are needed to determine the aggregate function's identity.

argtype

An input data type on which the aggregate function operates. To reference a zero-argument aggregate function, write `*` in place of the list of argument specifications. To reference an ordered-set aggregate function, write `ORDER BY` between the direct and aggregated argument specifications.

new_name

The new name of the aggregate function.

new_owner

The new owner of the aggregate function.

new_schema

The new schema for the aggregate function.

Notes

The recommended syntax for referencing an ordered-set aggregate is to write `ORDER BY` between the direct and aggregated argument specifications, in the same style as in `CREATE AGGREGATE`. However, it will also work to omit `ORDER BY` and just run the direct and aggregated argument specifications into a single list. In this abbreviated form, if `VARIADIC "any"` was used in both the direct and aggregated argument lists, write `VARIADIC "any"` only once.

Examples

To rename the aggregate function `myavg` for type `integer` to `my_average`:

```
ALTER AGGREGATE myavg(integer) RENAME TO my_average;
```

To change the owner of the aggregate function `myavg` for type `integer` to `joe`:

```
ALTER AGGREGATE myavg(integer) OWNER TO joe;
```

To move the ordered-set aggregate `mypercentile` with direct argument of type `float8` and aggregated argument of type `integer` into schema `myschema`:

```
ALTER AGGREGATE mypercentile(float8 ORDER BY integer) SET SCHEMA myschema;
```

This will work too:

```
ALTER AGGREGATE mypercentile(float8, integer) SET SCHEMA myschema;
```

Compatibility

There is no `ALTER AGGREGATE` statement in the SQL standard.

See Also

CREATE AGGREGATE, DROP AGGREGATE

ALTER COLLATION

ALTER COLLATION — change the definition of a collation

Synopsis

```
ALTER COLLATION name REFRESH VERSION

ALTER COLLATION name RENAME TO new_name
ALTER COLLATION name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER COLLATION name SET SCHEMA new_schema
```

Description

`ALTER COLLATION` changes the definition of a collation.

You must own the collation to use `ALTER COLLATION`. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the collation's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the collation. However, a superuser can alter ownership of any collation anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing collation.

new_name

The new name of the collation.

new_owner

The new owner of the collation.

new_schema

The new schema for the collation.

`REFRESH VERSION`

Update the collation's version. See Notes below.

Notes

When using collations provided by the ICU library, the ICU-specific version of the collator is recorded in the system catalog when the collation object is created. When the collation is used, the current version is checked against the recorded version, and a warning is issued when there is a mismatch, for example:

```
WARNING:  collation "xx-x-icu" has version mismatch
DETAIL:  The collation in the database was created using version 1.2.3.4, but the
 operating system provides version 2.3.4.5.
HINT:  Rebuild all objects affected by this collation and run ALTER COLLATION
 pg_catalog."xx-x-icu" REFRESH VERSION, or build Postgres Pro with the right library
 version.
```

A change in collation definitions can lead to corrupt indexes and other problems because the database system relies on stored objects having a certain sort order. Generally, this should be avoided, but it can happen in legitimate circumstances, such as when using `pg_upgrade` to upgrade to server binaries linked with a newer version of ICU. When this happens, all objects depending on the collation should

be rebuilt, for example, using `REINDEX`. When that is done, the collation version can be refreshed using the command `ALTER COLLATION ... REFRESH VERSION`. This will update the system catalog to record the current collator version and will make the warning go away. Note that this does not actually check whether all affected objects have been rebuilt correctly.

When using collations provided by `libc`, version information is recorded on systems using the GNU C library (most Linux systems), FreeBSD and Windows.

> **Note**
>
> When using the GNU C library for collations, the C library's version is used as a proxy for the collation version. Many Linux distributions change collation definitions only when upgrading the C library, but this approach is imperfect as maintainers are free to back-port newer collation definitions to older C library releases.
>
> When using Windows for collations, version information is only available for collations defined with BCP 47 language tags such as `en-US`.

Currently, there is no version tracking for the database default collation.

The following query can be used to identify all collations in the current database that need to be refreshed and the objects that depend on them:

```
SELECT pg_describe_object(refclassid, refobjid, refobjsubid) AS "Collation",
       pg_describe_object(classid, objid, objsubid) AS "Object"
  FROM pg_depend d JOIN pg_collation c
       ON refclassid = 'pg_collation'::regclass AND refobjid = c.oid
  WHERE c.collversion <> pg_collation_actual_version(c.oid)
  ORDER BY 1, 2;
```

Examples

To rename the collation `ru_RU` to `russian`:

```
ALTER COLLATION "ru_RU" RENAME TO russian;
```

To change the owner of the collation `en_US` to `joe`:

```
ALTER COLLATION "en_US" OWNER TO joe;
```

Compatibility

There is no `ALTER COLLATION` statement in the SQL standard.

See Also

CREATE COLLATION, DROP COLLATION

ALTER CONVERSION

ALTER CONVERSION — change the definition of a conversion

Synopsis

```
ALTER CONVERSION name RENAME TO new_name
ALTER CONVERSION name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER CONVERSION name SET SCHEMA new_schema
```

Description

`ALTER CONVERSION` changes the definition of a conversion.

You must own the conversion to use `ALTER CONVERSION`. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the conversion's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the conversion. However, a superuser can alter ownership of any conversion anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing conversion.

new_name

The new name of the conversion.

new_owner

The new owner of the conversion.

new_schema

The new schema for the conversion.

Examples

To rename the conversion `iso_8859_1_to_utf8` to `latin1_to_unicode`:

```
ALTER CONVERSION iso_8859_1_to_utf8 RENAME TO latin1_to_unicode;
```

To change the owner of the conversion `iso_8859_1_to_utf8` to `joe`:

```
ALTER CONVERSION iso_8859_1_to_utf8 OWNER TO joe;
```

Compatibility

There is no `ALTER CONVERSION` statement in the SQL standard.

See Also

CREATE CONVERSION, DROP CONVERSION

ALTER DATABASE

ALTER DATABASE — change a database

Synopsis

```
ALTER DATABASE name [ [ WITH ] option [ ... ] ]

where option can be:

    ALLOW_CONNECTIONS allowconn
    CONNECTION LIMIT connlimit
    IS_TEMPLATE istemplate

ALTER DATABASE name RENAME TO new_name

ALTER DATABASE name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }

ALTER DATABASE name SET TABLESPACE new_tablespace

ALTER DATABASE name SET configuration_parameter { TO | = } { value | DEFAULT }
ALTER DATABASE name SET configuration_parameter FROM CURRENT
ALTER DATABASE name RESET configuration_parameter
ALTER DATABASE name RESET ALL
```

Description

`ALTER DATABASE` changes the attributes of a database.

The first form changes certain per-database settings. (See below for details.) Only the database owner or a superuser can change these settings.

The second form changes the name of the database. Only the database owner or a superuser can rename a database; non-superuser owners must also have the `CREATEDB` privilege. The current database cannot be renamed. (Connect to a different database if you need to do that.)

The third form changes the owner of the database. To alter the owner, you must own the database and also be a direct or indirect member of the new owning role, and you must have the `CREATEDB` privilege. (Note that superusers have all these privileges automatically.)

The fourth form changes the default tablespace of the database. Only the database owner or a superuser can do this; you must also have create privilege for the new tablespace. This command physically moves any tables or indexes in the database's old default tablespace to the new tablespace. The new default tablespace must be empty for this database, and no one can be connected to the database. Tables and indexes in non-default tablespaces are unaffected.

The remaining forms change the session default for a run-time configuration variable for a Postgres Pro database. Whenever a new session is subsequently started in that database, the specified value becomes the session default value. The database-specific default overrides whatever setting is present in `postgresql.conf` or has been received from the `postgres` command line. Only the database owner or a superuser can change the session defaults for a database. Certain variables cannot be set this way, or can only be set by a superuser.

Parameters

name

The name of the database whose attributes are to be altered.

allowconn

If false then no one can connect to this database.

connlimit

How many concurrent connections can be made to this database. -1 means no limit.

istemplate

If true, then this database can be cloned by any user with `CREATEDB` privileges; if false, then only superusers or the owner of the database can clone it.

new_name

The new name of the database.

new_owner

The new owner of the database.

new_tablespace

The new default tablespace of the database.

This form of the command cannot be executed inside a transaction block.

configuration_parameter
value

Set this database's session default for the specified configuration parameter to the given value. If *value* is `DEFAULT` or, equivalently, `RESET` is used, the database-specific setting is removed, so the system-wide default setting will be inherited in new sessions. Use `RESET ALL` to clear all database-specific settings. `SET FROM CURRENT` saves the session's current value of the parameter as the database-specific value.

See SET and Chapter 19 for more information about allowed parameter names and values.

Notes

It is also possible to tie a session default to a specific role rather than to a database; see ALTER ROLE. Role-specific settings override database-specific ones if there is a conflict.

Examples

To disable index scans by default in the database `test`:

```
ALTER DATABASE test SET enable_indexscan TO off;
```

Compatibility

The `ALTER DATABASE` statement is a Postgres Pro extension.

See Also

CREATE DATABASE, DROP DATABASE, SET, CREATE TABLESPACE

ALTER DEFAULT PRIVILEGES

ALTER DEFAULT PRIVILEGES — define default access privileges

Synopsis

```
ALTER DEFAULT PRIVILEGES
    [ FOR { ROLE | USER } target_role [, ...] ]
    [ IN SCHEMA schema_name [, ...] ]
    abbreviated_grant_or_revoke

where abbreviated_grant_or_revoke is one of:

GRANT { { SELECT | INSERT | UPDATE | DELETE | TRUNCATE | REFERENCES | TRIGGER }
    [, ...] | ALL [ PRIVILEGES ] }
    ON TABLES
    TO { [ GROUP ] role_name | PUBLIC } [, ...] [ WITH GRANT OPTION ]

GRANT { { USAGE | SELECT | UPDATE }
    [, ...] | ALL [ PRIVILEGES ] }
    ON SEQUENCES
    TO { [ GROUP ] role_name | PUBLIC } [, ...] [ WITH GRANT OPTION ]

GRANT { EXECUTE | ALL [ PRIVILEGES ] }
    ON { FUNCTIONS | ROUTINES }
    TO { [ GROUP ] role_name | PUBLIC } [, ...] [ WITH GRANT OPTION ]

GRANT { USAGE | ALL [ PRIVILEGES ] }
    ON TYPES
    TO { [ GROUP ] role_name | PUBLIC } [, ...] [ WITH GRANT OPTION ]

GRANT { { USAGE | CREATE }
    [, ...] | ALL [ PRIVILEGES ] }
    ON SCHEMAS
    TO { [ GROUP ] role_name | PUBLIC } [, ...] [ WITH GRANT OPTION ]

REVOKE [ GRANT OPTION FOR ]
    { { SELECT | INSERT | UPDATE | DELETE | TRUNCATE | REFERENCES | TRIGGER }
    [, ...] | ALL [ PRIVILEGES ] }
    ON TABLES
    FROM { [ GROUP ] role_name | PUBLIC } [, ...]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { { USAGE | SELECT | UPDATE }
    [, ...] | ALL [ PRIVILEGES ] }
    ON SEQUENCES
    FROM { [ GROUP ] role_name | PUBLIC } [, ...]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { EXECUTE | ALL [ PRIVILEGES ] }
    ON { FUNCTIONS | ROUTINES }
    FROM { [ GROUP ] role_name | PUBLIC } [, ...]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
```

```
    { USAGE | ALL [ PRIVILEGES ] }
    ON TYPES
    FROM { [ GROUP ] role_name | PUBLIC } [, ...]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { { USAGE | CREATE }
    [, ...] | ALL [ PRIVILEGES ] }
    ON SCHEMAS
    FROM { [ GROUP ] role_name | PUBLIC } [, ...]
    [ CASCADE | RESTRICT ]
```

Description

`ALTER DEFAULT PRIVILEGES` allows you to set the privileges that will be applied to objects created in the future. (It does not affect privileges assigned to already-existing objects.) Currently, only the privileges for schemas, tables (including views and foreign tables), sequences, functions, and types (including domains) can be altered. For this command, functions include aggregates and procedures. The words `FUNCTIONS` and `ROUTINES` are equivalent in this command. (`ROUTINES` is preferred going forward as the standard term for functions and procedures taken together. In earlier Postgres Pro releases, only the word `FUNCTIONS` was allowed. It is not possible to set default privileges for functions and procedures separately.)

You can change default privileges only for objects that will be created by yourself or by roles that you are a member of. The privileges can be set globally (i.e., for all objects created in the current database), or just for objects created in specified schemas.

As explained in Section 5.7, the default privileges for any object type normally grant all grantable permissions to the object owner, and may grant some privileges to `PUBLIC` as well. However, this behavior can be changed by altering the global default privileges with `ALTER DEFAULT PRIVILEGES`.

Default privileges that are specified per-schema are added to whatever the global default privileges are for the particular object type. This means you cannot revoke privileges per-schema if they are granted globally (either by default, or according to a previous `ALTER DEFAULT PRIVILEGES` command that did not specify a schema). Per-schema `REVOKE` is only useful to reverse the effects of a previous per-schema `GRANT`.

Parameters

target_role

The name of an existing role of which the current role is a member. Default access privileges are not inherited, so member roles must use `SET ROLE` to access these privileges, or `ALTER DEFAULT PRIVILEGES` must be run for each member role. If `FOR ROLE` is omitted, the current role is assumed.

schema_name

The name of an existing schema. If specified, the default privileges are altered for objects later created in that schema. If `IN SCHEMA` is omitted, the global default privileges are altered. `IN SCHEMA` is not allowed when setting privileges for schemas, since schemas can't be nested.

role_name

The name of an existing role to grant or revoke privileges for. This parameter, and all the other parameters in *abbreviated_grant_or_revoke*, act as described under GRANT or REVOKE, except that one is setting permissions for a whole class of objects rather than specific named objects.

Notes

Use psql's `\ddp` command to obtain information about existing assignments of default privileges. The meaning of the privilege display is the same as explained for `\dp` in Section 5.7.

If you wish to drop a role for which the default privileges have been altered, it is necessary to reverse the changes in its default privileges or use `DROP OWNED BY` to get rid of the default privileges entry for the role.

Examples

Grant SELECT privilege to everyone for all tables (and views) you subsequently create in schema `myschema`, and allow role `webuser` to INSERT into them too:

```
ALTER DEFAULT PRIVILEGES IN SCHEMA myschema GRANT SELECT ON TABLES TO PUBLIC;
ALTER DEFAULT PRIVILEGES IN SCHEMA myschema GRANT INSERT ON TABLES TO webuser;
```

Undo the above, so that subsequently-created tables won't have any more permissions than normal:

```
ALTER DEFAULT PRIVILEGES IN SCHEMA myschema REVOKE SELECT ON TABLES FROM PUBLIC;
ALTER DEFAULT PRIVILEGES IN SCHEMA myschema REVOKE INSERT ON TABLES FROM webuser;
```

Remove the public EXECUTE permission that is normally granted on functions, for all functions subsequently created by role `admin`:

```
ALTER DEFAULT PRIVILEGES FOR ROLE admin REVOKE EXECUTE ON FUNCTIONS FROM PUBLIC;
```

Note however that you *cannot* accomplish that effect with a command limited to a single schema. This command has no effect, unless it is undoing a matching `GRANT`:

```
ALTER DEFAULT PRIVILEGES IN SCHEMA public REVOKE EXECUTE ON FUNCTIONS FROM PUBLIC;
```

That's because per-schema default privileges can only add privileges to the global setting, not remove privileges granted by it.

Compatibility

There is no `ALTER DEFAULT PRIVILEGES` statement in the SQL standard.

See Also

GRANT, REVOKE

ALTER DOMAIN

ALTER DOMAIN — change the definition of a domain

Synopsis

```
ALTER DOMAIN name
    { SET DEFAULT expression | DROP DEFAULT }
ALTER DOMAIN name
    { SET | DROP } NOT NULL
ALTER DOMAIN name
    ADD domain_constraint [ NOT VALID ]
ALTER DOMAIN name
    DROP CONSTRAINT [ IF EXISTS ] constraint_name [ RESTRICT | CASCADE ]
ALTER DOMAIN name
     RENAME CONSTRAINT constraint_name TO new_constraint_name
ALTER DOMAIN name
    VALIDATE CONSTRAINT constraint_name
ALTER DOMAIN name
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
ALTER DOMAIN name
    RENAME TO new_name
ALTER DOMAIN name
    SET SCHEMA new_schema

where domain_constraint is:

[ CONSTRAINT constraint_name ]
{ NOT NULL | CHECK (expression) }
```

Description

`ALTER DOMAIN` changes the definition of an existing domain. There are several sub-forms:

`SET/DROP DEFAULT`

These forms set or remove the default value for a domain. Note that defaults only apply to subsequent `INSERT` commands; they do not affect rows already in a table using the domain.

`SET/DROP NOT NULL`

These forms change whether a domain is marked to allow NULL values or to reject NULL values. You can only `SET NOT NULL` when the columns using the domain contain no null values.

`ADD domain_constraint [ NOT VALID ]`

This form adds a new constraint to a domain. When a new constraint is added to a domain, all columns using that domain will be checked against the newly added constraint. These checks can be suppressed by adding the new constraint using the `NOT VALID` option; the constraint can later be made valid using `ALTER DOMAIN ... VALIDATE CONSTRAINT`. Newly inserted or updated rows are always checked against all constraints, even those marked `NOT VALID`. `NOT VALID` is only accepted for `CHECK` constraints.

`DROP CONSTRAINT [ IF EXISTS ]`

This form drops constraints on a domain. If `IF EXISTS` is specified and the constraint does not exist, no error is thrown. In this case a notice is issued instead.

`RENAME CONSTRAINT`

This form changes the name of a constraint on a domain.

`VALIDATE CONSTRAINT`

This form validates a constraint previously added as `NOT VALID`, that is, it verifies that all values in table columns of the domain type satisfy the specified constraint.

`OWNER`

This form changes the owner of the domain to the specified user.

`RENAME`

This form changes the name of the domain.

`SET SCHEMA`

This form changes the schema of the domain. Any constraints associated with the domain are moved into the new schema as well.

You must own the domain to use `ALTER DOMAIN`. To change the schema of a domain, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the domain's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the domain. However, a superuser can alter ownership of any domain anyway.)

Parameters

name

The name (possibly schema-qualified) of an existing domain to alter.

domain_constraint

New domain constraint for the domain.

constraint_name

Name of an existing constraint to drop or rename.

`NOT VALID`

Do not verify existing stored data for constraint validity.

`CASCADE`

Automatically drop objects that depend on the constraint, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the constraint if there are any dependent objects. This is the default behavior.

new_name

The new name for the domain.

new_constraint_name

The new name for the constraint.

new_owner

The user name of the new owner of the domain.

new_schema

The new schema for the domain.

Notes

Although `ALTER DOMAIN ADD CONSTRAINT` attempts to verify that existing stored data satisfies the new constraint, this check is not bulletproof, because the command cannot "see" table rows that are newly inserted or updated and not yet committed. If there is a hazard that concurrent operations might insert bad data, the way to proceed is to add the constraint using the `NOT VALID` option, commit that command, wait until all transactions started before that commit have finished, and then issue `ALTER DOMAIN VALIDATE CONSTRAINT` to search for data violating the constraint. This method is reliable because once the constraint is committed, all new transactions are guaranteed to enforce it against new values of the domain type.

Currently, `ALTER DOMAIN ADD CONSTRAINT`, `ALTER DOMAIN VALIDATE CONSTRAINT`, and `ALTER DOMAIN SET NOT NULL` will fail if the named domain or any derived domain is used within a container-type column (a composite, array, or range column) in any table in the database. They should eventually be improved to be able to verify the new constraint for such nested values.

Examples

To add a `NOT NULL` constraint to a domain:

```
ALTER DOMAIN zipcode SET NOT NULL;
```

To remove a `NOT NULL` constraint from a domain:

```
ALTER DOMAIN zipcode DROP NOT NULL;
```

To add a check constraint to a domain:

```
ALTER DOMAIN zipcode ADD CONSTRAINT zipchk CHECK (char_length(VALUE) = 5);
```

To remove a check constraint from a domain:

```
ALTER DOMAIN zipcode DROP CONSTRAINT zipchk;
```

To rename a check constraint on a domain:

```
ALTER DOMAIN zipcode RENAME CONSTRAINT zipchk TO zip_check;
```

To move the domain into a different schema:

```
ALTER DOMAIN zipcode SET SCHEMA customers;
```

Compatibility

`ALTER DOMAIN` conforms to the SQL standard, except for the `OWNER`, `RENAME`, `SET SCHEMA`, and `VALIDATE CONSTRAINT` variants, which are Postgres Pro extensions. The `NOT VALID` clause of the `ADD CONSTRAINT` variant is also a Postgres Pro extension.

See Also

CREATE DOMAIN, DROP DOMAIN

ALTER EVENT TRIGGER

ALTER EVENT TRIGGER — change the definition of an event trigger

Synopsis

```
ALTER EVENT TRIGGER name DISABLE
ALTER EVENT TRIGGER name ENABLE [ REPLICA | ALWAYS ]
ALTER EVENT TRIGGER name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER EVENT TRIGGER name RENAME TO new_name
```

Description

`ALTER EVENT TRIGGER` changes properties of an existing event trigger.

You must be superuser to alter an event trigger.

Parameters

name

The name of an existing trigger to alter.

new_owner

The user name of the new owner of the event trigger.

new_name

The new name of the event trigger.

`DISABLE`/`ENABLE [ REPLICA | ALWAYS ]`

These forms configure the firing of event triggers. A disabled trigger is still known to the system, but is not executed when its triggering event occurs. See also session_replication_role.

Compatibility

There is no `ALTER EVENT TRIGGER` statement in the SQL standard.

See Also

CREATE EVENT TRIGGER, DROP EVENT TRIGGER

ALTER EXTENSION

ALTER EXTENSION — change the definition of an extension

Synopsis

```
ALTER EXTENSION name UPDATE [ TO new_version ]
ALTER EXTENSION name SET SCHEMA new_schema
ALTER EXTENSION name ADD member_object
ALTER EXTENSION name DROP member_object

where member_object is:

  ACCESS METHOD object_name |
  AGGREGATE aggregate_name ( aggregate_signature ) |
  CAST (source_type AS target_type) |
  COLLATION object_name |
  CONVERSION object_name |
  DOMAIN object_name |
  EVENT TRIGGER object_name |
  FOREIGN DATA WRAPPER object_name |
  FOREIGN TABLE object_name |
  FUNCTION function_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  MATERIALIZED VIEW object_name |
  OPERATOR operator_name (left_type, right_type) |
  OPERATOR CLASS object_name USING index_method |
  OPERATOR FAMILY object_name USING index_method |
  [ PROCEDURAL ] LANGUAGE object_name |
  PROCEDURE procedure_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  ROUTINE routine_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  SCHEMA object_name |
  SEQUENCE object_name |
  SERVER object_name |
  TABLE object_name |
  TEXT SEARCH CONFIGURATION object_name |
  TEXT SEARCH DICTIONARY object_name |
  TEXT SEARCH PARSER object_name |
  TEXT SEARCH TEMPLATE object_name |
  TRANSFORM FOR type_name LANGUAGE lang_name |
  TYPE object_name |
  VIEW object_name

and aggregate_signature is:

* |
[ argmode ] [ argname ] argtype [ , ... ] |
[ [ argmode ] [ argname ] argtype [ , ... ] ] ORDER BY [ argmode ] [ argname ] argtype
 [ , ... ]
```

Description

`ALTER EXTENSION` changes the definition of an installed extension. There are several subforms:

`UPDATE`

This form updates the extension to a newer version. The extension must supply a suitable update script (or series of scripts) that can modify the currently-installed version into the requested version.

`SET SCHEMA`

This form moves the extension's objects into another schema. The extension has to be *relocatable* for this command to succeed.

`ADD` *member_object*

This form adds an existing object to the extension. This is mainly useful in extension update scripts. The object will subsequently be treated as a member of the extension; notably, it can only be dropped by dropping the extension.

`DROP` *member_object*

This form removes a member object from the extension. This is mainly useful in extension update scripts. The object is not dropped, only disassociated from the extension.

See Section 40.17 for more information about these operations.

You must own the extension to use `ALTER EXTENSION`. The `ADD`/`DROP` forms require ownership of the added/dropped object as well.

Parameters

name

The name of an installed extension.

new_version

The desired new version of the extension. This can be written as either an identifier or a string literal. If not specified, `ALTER EXTENSION UPDATE` attempts to update to whatever is shown as the default version in the extension's control file.

new_schema

The new schema for the extension.

object_name
aggregate_name
function_name
operator_name
procedure_name
routine_name

The name of an object to be added to or removed from the extension. Names of tables, aggregates, domains, foreign tables, functions, operators, operator classes, operator families, procedures, routines, sequences, text search objects, types, and views can be schema-qualified.

source_type

The name of the source data type of the cast.

target_type

The name of the target data type of the cast.

argmode

The mode of a function, procedure, or aggregate argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN`. Note that `ALTER EXTENSION` does not actually pay any attention to `OUT` arguments, since only the input arguments are needed to determine the function's identity. So it is sufficient to list the `IN`, `INOUT`, and `VARIADIC` arguments.

argname

The name of a function, procedure, or aggregate argument. Note that `ALTER EXTENSION` does not actually pay any attention to argument names, since only the argument data types are needed to determine the function's identity.

argtype

The data type of a function, procedure, or aggregate argument.

left_type
right_type

The data type(s) of the operator's arguments (optionally schema-qualified). Write `NONE` for the missing argument of a prefix operator.

`PROCEDURAL`

This is a noise word.

type_name

The name of the data type of the transform.

lang_name

The name of the language of the transform.

Examples

To update the `hstore` extension to version 2.0:

```
ALTER EXTENSION hstore UPDATE TO '2.0';
```

To change the schema of the `hstore` extension to `utils`:

```
ALTER EXTENSION hstore SET SCHEMA utils;
```

To add an existing function to the `hstore` extension:

```
ALTER EXTENSION hstore ADD FUNCTION populate_record(anyelement, hstore);
```

Compatibility

`ALTER EXTENSION` is a Postgres Pro extension.

See Also

CREATE EXTENSION, DROP EXTENSION

ALTER FOREIGN DATA WRAPPER

ALTER FOREIGN DATA WRAPPER — change the definition of a foreign-data wrapper

Synopsis

```
ALTER FOREIGN DATA WRAPPER name
    [ HANDLER handler_function | NO HANDLER ]
    [ VALIDATOR validator_function | NO VALIDATOR ]
    [ OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ]) ]
ALTER FOREIGN DATA WRAPPER name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER FOREIGN DATA WRAPPER name RENAME TO new_name
```

Description

`ALTER FOREIGN DATA WRAPPER` changes the definition of a foreign-data wrapper. The first form of the command changes the support functions or the generic options of the foreign-data wrapper (at least one clause is required). The second form changes the owner of the foreign-data wrapper.

Only superusers can alter foreign-data wrappers. Additionally, only superusers can own foreign-data wrappers.

Parameters

name

The name of an existing foreign-data wrapper.

`HANDLER` *handler_function*

Specifies a new handler function for the foreign-data wrapper.

`NO HANDLER`

This is used to specify that the foreign-data wrapper should no longer have a handler function.

Note that foreign tables that use a foreign-data wrapper with no handler cannot be accessed.

`VALIDATOR` *validator_function*

Specifies a new validator function for the foreign-data wrapper.

Note that it is possible that pre-existing options of the foreign-data wrapper, or of dependent servers, user mappings, or foreign tables, are invalid according to the new validator. Postgres Pro does not check for this. It is up to the user to make sure that these options are correct before using the modified foreign-data wrapper. However, any options specified in this `ALTER FOREIGN DATA WRAPPER` command will be checked using the new validator.

`NO VALIDATOR`

This is used to specify that the foreign-data wrapper should no longer have a validator function.

`OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ] )`

Change options for the foreign-data wrapper. `ADD`, `SET`, and `DROP` specify the action to be performed. `ADD` is assumed if no operation is explicitly specified. Option names must be unique; names and values are also validated using the foreign data wrapper's validator function, if any.

new_owner

The user name of the new owner of the foreign-data wrapper.

new_name

The new name for the foreign-data wrapper.

Examples

Change a foreign-data wrapper `dbi`, add option `foo`, drop `bar`:

```
ALTER FOREIGN DATA WRAPPER dbi OPTIONS (ADD foo '1', DROP bar);
```

Change the foreign-data wrapper `dbi` validator to `bob.myvalidator`:

```
ALTER FOREIGN DATA WRAPPER dbi VALIDATOR bob.myvalidator;
```

Compatibility

`ALTER FOREIGN DATA WRAPPER` conforms to ISO/IEC 9075-9 (SQL/MED), except that the `HANDLER`, `VALIDATOR`, `OWNER TO`, and `RENAME` clauses are extensions.

See Also

CREATE FOREIGN DATA WRAPPER, DROP FOREIGN DATA WRAPPER

ALTER FOREIGN TABLE

ALTER FOREIGN TABLE — change the definition of a foreign table

Synopsis

```
ALTER FOREIGN TABLE [ IF EXISTS ] [ ONLY ] name [ * ]
    action [, ... ]
ALTER FOREIGN TABLE [ IF EXISTS ] [ ONLY ] name [ * ]
    RENAME [ COLUMN ] column_name TO new_column_name
ALTER FOREIGN TABLE [ IF EXISTS ] name
    RENAME TO new_name
ALTER FOREIGN TABLE [ IF EXISTS ] name
    SET SCHEMA new_schema

where action is one of:

    ADD [ COLUMN ] column_name data_type [ COLLATE collation ] [ column_constraint
 [ ... ] ]
    DROP [ COLUMN ] [ IF EXISTS ] column_name [ RESTRICT | CASCADE ]
    ALTER [ COLUMN ] column_name [ SET DATA ] TYPE data_type [ COLLATE collation ]
    ALTER [ COLUMN ] column_name SET DEFAULT expression
    ALTER [ COLUMN ] column_name DROP DEFAULT
    ALTER [ COLUMN ] column_name { SET | DROP } NOT NULL
    ALTER [ COLUMN ] column_name SET STATISTICS integer
    ALTER [ COLUMN ] column_name SET ( attribute_option = value [, ... ] )
    ALTER [ COLUMN ] column_name RESET ( attribute_option [, ... ] )
    ALTER [ COLUMN ] column_name SET STORAGE { PLAIN | EXTERNAL | EXTENDED | MAIN }
    ALTER [ COLUMN ] column_name OPTIONS ( [ ADD | SET | DROP ] option ['value']
 [, ... ])
    ADD table_constraint [ NOT VALID ]
    VALIDATE CONSTRAINT constraint_name
    DROP CONSTRAINT [ IF EXISTS ]  constraint_name [ RESTRICT | CASCADE ]
    DISABLE TRIGGER [ trigger_name | ALL | USER ]
    ENABLE TRIGGER [ trigger_name | ALL | USER ]
    ENABLE REPLICA TRIGGER trigger_name
    ENABLE ALWAYS TRIGGER trigger_name
    SET WITHOUT OIDS
    INHERIT parent_table
    NO INHERIT parent_table
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
    OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ])
```

Description

`ALTER FOREIGN TABLE` changes the definition of an existing foreign table. There are several subforms:

`ADD COLUMN`

This form adds a new column to the foreign table, using the same syntax as `CREATE FOREIGN TABLE`. Unlike the case when adding a column to a regular table, nothing happens to the underlying storage: this action simply declares that some new column is now accessible through the foreign table.

`DROP COLUMN [ IF EXISTS ]`

This form drops a column from a foreign table. You will need to say `CASCADE` if anything outside the table depends on the column; for example, views. If `IF EXISTS` is specified and the column does not exist, no error is thrown. In this case a notice is issued instead.

`SET DATA TYPE`

This form changes the type of a column of a foreign table. Again, this has no effect on any underlying storage: this action simply changes the type that Postgres Pro believes the column to have.

`SET/DROP DEFAULT`

These forms set or remove the default value for a column. Default values only apply in subsequent `INSERT` or `UPDATE` commands; they do not cause rows already in the table to change.

`SET/DROP NOT NULL`

Mark a column as allowing, or not allowing, null values.

`SET STATISTICS`

This form sets the per-column statistics-gathering target for subsequent `ANALYZE` operations. See the similar form of `ALTER TABLE` for more details.

`SET ( attribute_option = value [, ... ] )`
`RESET ( attribute_option [, ... ] )`

This form sets or resets per-attribute options. See the similar form of `ALTER TABLE` for more details.

`SET STORAGE`

This form sets the storage mode for a column. See the similar form of `ALTER TABLE` for more details. Note that the storage mode has no effect unless the table's foreign-data wrapper chooses to pay attention to it.

`ADD table_constraint [ NOT VALID ]`

This form adds a new constraint to a foreign table, using the same syntax as `CREATE FOREIGN TABLE`. Currently only `CHECK` constraints are supported.

Unlike the case when adding a constraint to a regular table, nothing is done to verify the constraint is correct; rather, this action simply declares that some new condition should be assumed to hold for all rows in the foreign table. (See the discussion in `CREATE FOREIGN TABLE`.) If the constraint is marked `NOT VALID`, then it isn't assumed to hold, but is only recorded for possible future use.

`VALIDATE CONSTRAINT`

This form marks as valid a constraint that was previously marked as `NOT VALID`. No action is taken to verify the constraint, but future queries will assume that it holds.

`DROP CONSTRAINT [ IF EXISTS ]`

This form drops the specified constraint on a foreign table. If `IF EXISTS` is specified and the constraint does not exist, no error is thrown. In this case a notice is issued instead.

`DISABLE/ENABLE [ REPLICA | ALWAYS ] TRIGGER`

These forms configure the firing of trigger(s) belonging to the foreign table. See the similar form of `ALTER TABLE` for more details.

`SET WITHOUT OIDS`

Backward compatibility syntax for removing the `oid` system column. As `oid` system columns cannot be added anymore, this never has an effect.

`INHERIT parent_table`

This form adds the target foreign table as a new child of the specified parent table. See the similar form of `ALTER TABLE` for more details.

`NO INHERIT` *parent_table*

This form removes the target foreign table from the list of children of the specified parent table.

`OWNER`

This form changes the owner of the foreign table to the specified user.

`OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ] )`

Change options for the foreign table or one of its columns. `ADD`, `SET`, and `DROP` specify the action to be performed. `ADD` is assumed if no operation is explicitly specified. Duplicate option names are not allowed (although it's OK for a table option and a column option to have the same name). Option names and values are also validated using the foreign data wrapper library.

`RENAME`

The `RENAME` forms change the name of a foreign table or the name of an individual column in a foreign table.

`SET SCHEMA`

This form moves the foreign table into another schema.

All the actions except `RENAME` and `SET SCHEMA` can be combined into a list of multiple alterations to apply in parallel. For example, it is possible to add several columns and/or alter the type of several columns in a single command.

If the command is written as `ALTER FOREIGN TABLE IF EXISTS ...` and the foreign table does not exist, no error is thrown. A notice is issued in this case.

You must own the table to use `ALTER FOREIGN TABLE`. To change the schema of a foreign table, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the table's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the table. However, a superuser can alter ownership of any table anyway.) To add a column or alter a column type, you must also have `USAGE` privilege on the data type.

Parameters

name

The name (possibly schema-qualified) of an existing foreign table to alter. If `ONLY` is specified before the table name, only that table is altered. If `ONLY` is not specified, the table and all its descendant tables (if any) are altered. Optionally, `*` can be specified after the table name to explicitly indicate that descendant tables are included.

column_name

Name of a new or existing column.

new_column_name

New name for an existing column.

new_name

New name for the table.

data_type

Data type of the new column, or new data type for an existing column.

table_constraint

New table constraint for the foreign table.

constraint_name

Name of an existing constraint to drop.

CASCADE

Automatically drop objects that depend on the dropped column or constraint (for example, views referencing the column), and in turn all objects that depend on those objects (see Section 5.14).

RESTRICT

Refuse to drop the column or constraint if there are any dependent objects. This is the default behavior.

trigger_name

Name of a single trigger to disable or enable.

ALL

Disable or enable all triggers belonging to the foreign table. (This requires superuser privilege if any of the triggers are internally generated triggers. The core system does not add such triggers to foreign tables, but add-on code could do so.)

USER

Disable or enable all triggers belonging to the foreign table except for internally generated triggers.

parent_table

A parent table to associate or de-associate with this foreign table.

new_owner

The user name of the new owner of the table.

new_schema

The name of the schema to which the table will be moved.

Notes

The key word COLUMN is noise and can be omitted.

Consistency with the foreign server is not checked when a column is added or removed with ADD COLUMN or DROP COLUMN, a NOT NULL or CHECK constraint is added, or a column type is changed with SET DATA TYPE. It is the user's responsibility to ensure that the table definition matches the remote side.

Refer to CREATE FOREIGN TABLE for a further description of valid parameters.

Examples

To mark a column as not-null:

```
ALTER FOREIGN TABLE distributors ALTER COLUMN street SET NOT NULL;
```

To change options of a foreign table:

```
ALTER FOREIGN TABLE myschema.distributors OPTIONS (ADD opt1 'value', SET opt2 'value2',
 DROP opt3);
```

Compatibility

The forms ADD, DROP, and SET DATA TYPE conform with the SQL standard. The other forms are Postgres Pro extensions of the SQL standard. Also, the ability to specify more than one manipulation in a single ALTER FOREIGN TABLE command is an extension.

`ALTER FOREIGN TABLE DROP COLUMN` can be used to drop the only column of a foreign table, leaving a zero-column table. This is an extension of SQL, which disallows zero-column foreign tables.

See Also

CREATE FOREIGN TABLE, DROP FOREIGN TABLE

ALTER FUNCTION

ALTER FUNCTION — change the definition of a function

Synopsis

```
ALTER FUNCTION name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    action [ ... ] [ RESTRICT ]
ALTER FUNCTION name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    RENAME TO new_name
ALTER FUNCTION name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
ALTER FUNCTION name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    SET SCHEMA new_schema
ALTER FUNCTION name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    [ NO ] DEPENDS ON EXTENSION extension_name

where action is one of:

    CALLED ON NULL INPUT | RETURNS NULL ON NULL INPUT | STRICT
    IMMUTABLE | STABLE | VOLATILE
    [ NOT ] LEAKPROOF
    [ EXTERNAL ] SECURITY INVOKER | [ EXTERNAL ] SECURITY DEFINER
    PARALLEL { UNSAFE | RESTRICTED | SAFE }
    COST execution_cost
    ROWS result_rows
    SUPPORT support_function
    SET configuration_parameter { TO | = } { value | DEFAULT }
    SET configuration_parameter FROM CURRENT
    RESET configuration_parameter
    RESET ALL
```

Description

`ALTER FUNCTION` changes the definition of a function.

You must own the function to use `ALTER FUNCTION`. To change a function's schema, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the function's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the function. However, a superuser can alter ownership of any function anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing function. If no argument list is specified, the name must be unique in its schema.

argmode

The mode of an argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN`. Note that `ALTER FUNCTION` does not actually pay any attention to `OUT` arguments, since only the input arguments are needed to determine the function's identity. So it is sufficient to list the `IN`, `INOUT`, and `VARIADIC` arguments.

argname

The name of an argument. Note that `ALTER FUNCTION` does not actually pay any attention to argument names, since only the argument data types are needed to determine the function's identity.

argtype

The data type(s) of the function's arguments (optionally schema-qualified), if any.

new_name

The new name of the function.

new_owner

The new owner of the function. Note that if the function is marked SECURITY DEFINER, it will subsequently execute as the new owner.

new_schema

The new schema for the function.

DEPENDS ON EXTENSION *extension_name*
NO DEPENDS ON EXTENSION *extension_name*

This form marks the function as dependent on the extension, or no longer dependent on that extension if NO is specified. A function that's marked as dependent on an extension is dropped when the extension is dropped, even if CASCADE is not specified. A function can depend upon multiple extensions, and will be dropped when any one of those extensions is dropped.

CALLED ON NULL INPUT
RETURNS NULL ON NULL INPUT
STRICT

CALLED ON NULL INPUT changes the function so that it will be invoked when some or all of its arguments are null. RETURNS NULL ON NULL INPUT or STRICT changes the function so that it is not invoked if any of its arguments are null; instead, a null result is assumed automatically. See CREATE FUNCTION for more information.

IMMUTABLE
STABLE
VOLATILE

Change the volatility of the function to the specified setting. See CREATE FUNCTION for details.

[EXTERNAL] SECURITY INVOKER
[EXTERNAL] SECURITY DEFINER

Change whether the function is a security definer or not. The key word EXTERNAL is ignored for SQL conformance. See CREATE FUNCTION for more information about this capability.

PARALLEL

Change whether the function is deemed safe for parallelism. See CREATE FUNCTION for details.

LEAKPROOF

Change whether the function is considered leakproof or not. See CREATE FUNCTION for more information about this capability.

COST *execution_cost*

Change the estimated execution cost of the function. See CREATE FUNCTION for more information.

ROWS *result_rows*

Change the estimated number of rows returned by a set-returning function. See CREATE FUNCTION for more information.

SUPPORT *support_function*

Set or change the planner support function to use for this function. See Section 40.11 for details. You must be superuser to use this option.

This option cannot be used to remove the support function altogether, since it must name a new support function. Use `CREATE OR REPLACE FUNCTION` if you need to do that.

configuration_parameter
value

Add or change the assignment to be made to a configuration parameter when the function is called. If *value* is `DEFAULT` or, equivalently, `RESET` is used, the function-local setting is removed, so that the function executes with the value present in its environment. Use `RESET ALL` to clear all function-local settings. `SET FROM CURRENT` saves the value of the parameter that is current when `ALTER FUNCTION` is executed as the value to be applied when the function is entered.

See SET and Chapter 19 for more information about allowed parameter names and values.

`RESTRICT`

Ignored for conformance with the SQL standard.

Examples

To rename the function `sqrt` for type `integer` to `square_root`:

```
ALTER FUNCTION sqrt(integer) RENAME TO square_root;
```

To change the owner of the function `sqrt` for type `integer` to `joe`:

```
ALTER FUNCTION sqrt(integer) OWNER TO joe;
```

To change the schema of the function `sqrt` for type `integer` to `maths`:

```
ALTER FUNCTION sqrt(integer) SET SCHEMA maths;
```

To mark the function `sqrt` for type `integer` as being dependent on the extension `mathlib`:

```
ALTER FUNCTION sqrt(integer) DEPENDS ON EXTENSION mathlib;
```

To adjust the search path that is automatically set for a function:

```
ALTER FUNCTION check_password(text) SET search_path = admin, pg_temp;
```

To disable automatic setting of `search_path` for a function:

```
ALTER FUNCTION check_password(text) RESET search_path;
```

The function will now execute with whatever search path is used by its caller.

Compatibility

This statement is partially compatible with the `ALTER FUNCTION` statement in the SQL standard. The standard allows more properties of a function to be modified, but does not provide the ability to rename a function, make a function a security definer, attach configuration parameter values to a function, or change the owner, schema, or volatility of a function. The standard also requires the `RESTRICT` key word, which is optional in Postgres Pro.

See Also

CREATE FUNCTION, DROP FUNCTION, ALTER PROCEDURE, ALTER ROUTINE

ALTER GROUP

ALTER GROUP — change role name or membership

Synopsis

```
ALTER GROUP role_specification ADD USER user_name [, ... ]
ALTER GROUP role_specification DROP USER user_name [, ... ]

where role_specification can be:

    role_name
  | CURRENT_ROLE
  | CURRENT_USER
  | SESSION_USER

ALTER GROUP group_name RENAME TO new_name
```

Description

`ALTER GROUP` changes the attributes of a user group. This is an obsolete command, though still accepted for backwards compatibility, because groups (and users too) have been superseded by the more general concept of roles.

The first two variants add users to a group or remove them from a group. (Any role can play the part of either a "user" or a "group" for this purpose.) These variants are effectively equivalent to granting or revoking membership in the role named as the "group"; so the preferred way to do this is to use `GRANT` or `REVOKE`.

The third variant changes the name of the group. This is exactly equivalent to renaming the role with `ALTER ROLE`.

Parameters

group_name

The name of the group (role) to modify.

user_name

Users (roles) that are to be added to or removed from the group. The users must already exist; `ALTER GROUP` does not create or drop users.

new_name

The new name of the group.

Examples

Add users to a group:

```
ALTER GROUP staff ADD USER karl, john;
```

Remove a user from a group:

```
ALTER GROUP workers DROP USER beth;
```

Compatibility

There is no `ALTER GROUP` statement in the SQL standard.

See Also

GRANT, REVOKE, ALTER ROLE

ALTER INDEX

ALTER INDEX — change the definition of an index

Synopsis

```
ALTER INDEX [ IF EXISTS ] name RENAME TO new_name
ALTER INDEX [ IF EXISTS ] name SET TABLESPACE tablespace_name
ALTER INDEX name ATTACH PARTITION index_name
ALTER INDEX name [ NO ] DEPENDS ON EXTENSION extension_name
ALTER INDEX [ IF EXISTS ] name SET ( storage_parameter [= value] [, ... ] )
ALTER INDEX [ IF EXISTS ] name RESET ( storage_parameter [, ... ] )
ALTER INDEX [ IF EXISTS ] name ALTER [ COLUMN ] column_number
    SET STATISTICS integer
ALTER INDEX ALL IN TABLESPACE name [ OWNED BY role_name [, ... ] ]
    SET TABLESPACE new_tablespace [ NOWAIT ]
```

Description

`ALTER INDEX` changes the definition of an existing index. There are several subforms described below. Note that the lock level required may differ for each subform. An `ACCESS EXCLUSIVE` lock is held unless explicitly noted. When multiple subcommands are listed, the lock held will be the strictest one required from any subcommand.

`RENAME`

The `RENAME` form changes the name of the index. If the index is associated with a table constraint (either `UNIQUE`, `PRIMARY KEY`, or `EXCLUDE`), the constraint is renamed as well. There is no effect on the stored data.

Renaming an index acquires a `SHARE UPDATE EXCLUSIVE` lock.

`SET TABLESPACE`

This form changes the index's tablespace to the specified tablespace and moves the data file(s) associated with the index to the new tablespace. To change the tablespace of an index, you must own the index and have `CREATE` privilege on the new tablespace. All indexes in the current database in a tablespace can be moved by using the `ALL IN TABLESPACE` form, which will lock all indexes to be moved and then move each one. This form also supports `OWNED BY`, which will only move indexes owned by the roles specified. If the `NOWAIT` option is specified then the command will fail if it is unable to acquire all of the locks required immediately. Note that system catalogs will not be moved by this command, use `ALTER DATABASE` or explicit `ALTER INDEX` invocations instead if desired. See also `CREATE TABLESPACE`.

`ATTACH PARTITION` *index_name*

Causes the named index (possibly schema-qualified) to become attached to the altered index. The named index must be on a partition of the table containing the index being altered, and have an equivalent definition. An attached index cannot be dropped by itself, and will automatically be dropped if its parent index is dropped.

`DEPENDS ON EXTENSION` *extension_name*
`NO DEPENDS ON EXTENSION` *extension_name*

This form marks the index as dependent on the extension, or no longer dependent on that extension if `NO` is specified. An index that's marked as dependent on an extension is automatically dropped when the extension is dropped.

`SET (` *storage_parameter* `[= value] [, ... ] )`

This form changes one or more index-method-specific storage parameters for the index. See `CREATE INDEX` for details on the available parameters. Note that the index contents will not be modified

immediately by this command; depending on the parameter you might need to rebuild the index with REINDEX to get the desired effects.

`RESET ( storage_parameter [, ... ] )`

This form resets one or more index-method-specific storage parameters to their defaults. As with SET, a REINDEX might be needed to update the index entirely.

`ALTER [ COLUMN ] column_number SET STATISTICS integer`

This form sets the per-column statistics-gathering target for subsequent ANALYZE operations, though can be used only on index columns that are defined as an expression. Since expressions lack a unique name, we refer to them using the ordinal number of the index column. The target can be set in the range 0 to 10000; alternatively, set it to -1 to revert to using the system default statistics target (default_statistics_target). For more information on the use of statistics by the Postgres Pro query planner, refer to Section 14.2.

Parameters

`IF EXISTS`

Do not throw an error if the index does not exist. A notice is issued in this case.

column_number

The ordinal number refers to the ordinal (left-to-right) position of the index column.

name

The name (possibly schema-qualified) of an existing index to alter.

new_name

The new name for the index.

tablespace_name

The tablespace to which the index will be moved.

extension_name

The name of the extension that the index is to depend on.

storage_parameter

The name of an index-method-specific storage parameter.

value

The new value for an index-method-specific storage parameter. This might be a number or a word depending on the parameter.

Notes

These operations are also possible using ALTER TABLE. ALTER INDEX is in fact just an alias for the forms of ALTER TABLE that apply to indexes.

There was formerly an ALTER INDEX OWNER variant, but this is now ignored (with a warning). An index cannot have an owner different from its table's owner. Changing the table's owner automatically changes the index as well.

Changing any part of a system catalog index is not permitted.

Examples

To rename an existing index:

```
ALTER INDEX distributors RENAME TO suppliers;
```

To move an index to a different tablespace:

```
ALTER INDEX distributors SET TABLESPACE fasttablespace;
```

To change an index's fill factor (assuming that the index method supports it):

```
ALTER INDEX distributors SET (fillfactor = 75);
REINDEX INDEX distributors;
```

Set the statistics-gathering target for an expression index:

```
CREATE INDEX coord_idx ON measured (x, y, (z + t));
ALTER INDEX coord_idx ALTER COLUMN 3 SET STATISTICS 1000;
```

Compatibility

`ALTER INDEX` is a Postgres Pro extension.

See Also

CREATE INDEX, REINDEX

ALTER LANGUAGE

ALTER LANGUAGE — change the definition of a procedural language

Synopsis

```
ALTER [ PROCEDURAL ] LANGUAGE name RENAME TO new_name
ALTER [ PROCEDURAL ] LANGUAGE name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
```

Description

`ALTER LANGUAGE` changes the definition of a procedural language. The only functionality is to rename the language or assign a new owner. You must be superuser or owner of the language to use `ALTER LANGUAGE`.

Parameters

name

Name of a language

new_name

The new name of the language

new_owner

The new owner of the language

Compatibility

There is no `ALTER LANGUAGE` statement in the SQL standard.

See Also

CREATE LANGUAGE, DROP LANGUAGE

ALTER LARGE OBJECT

ALTER LARGE OBJECT — change the definition of a large object

Synopsis

```
ALTER LARGE OBJECT large_object_oid OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER
 | SESSION_USER }
```

Description

`ALTER LARGE OBJECT` changes the definition of a large object.

You must own the large object to use `ALTER LARGE OBJECT`. To alter the owner, you must also be a direct or indirect member of the new owning role. (However, a superuser can alter any large object anyway.) Currently, the only functionality is to assign a new owner, so both restrictions always apply.

Parameters

large_object_oid

OID of the large object to be altered

new_owner

The new owner of the large object

Compatibility

There is no `ALTER LARGE OBJECT` statement in the SQL standard.

See Also

Chapter 37

ALTER MATERIALIZED VIEW

ALTER MATERIALIZED VIEW — change the definition of a materialized view

Synopsis

```
ALTER MATERIALIZED VIEW [ IF EXISTS ] name
    action [, ... ]
ALTER MATERIALIZED VIEW name
    [ NO ] DEPENDS ON EXTENSION extension_name
ALTER MATERIALIZED VIEW [ IF EXISTS ] name
    RENAME [ COLUMN ] column_name TO new_column_name
ALTER MATERIALIZED VIEW [ IF EXISTS ] name
    RENAME TO new_name
ALTER MATERIALIZED VIEW [ IF EXISTS ] name
    SET SCHEMA new_schema
ALTER MATERIALIZED VIEW ALL IN TABLESPACE name [ OWNED BY role_name [, ... ] ]
    SET TABLESPACE new_tablespace [ NOWAIT ]

where action is one of:

    ALTER [ COLUMN ] column_name SET STATISTICS integer
    ALTER [ COLUMN ] column_name SET ( attribute_option = value [, ... ] )
    ALTER [ COLUMN ] column_name RESET ( attribute_option [, ... ] )
    ALTER [ COLUMN ] column_name SET STORAGE { PLAIN | EXTERNAL | EXTENDED | MAIN }
    ALTER [ COLUMN ] column_name SET COMPRESSION compression_method
    CLUSTER ON index_name
    SET WITHOUT CLUSTER
    SET TABLESPACE new_tablespace
    SET ( storage_parameter [= value] [, ... ] )
    RESET ( storage_parameter [, ... ] )
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
```

Description

`ALTER MATERIALIZED VIEW` changes various auxiliary properties of an existing materialized view.

You must own the materialized view to use `ALTER MATERIALIZED VIEW`. To change a materialized view's schema, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the materialized view's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the materialized view. However, a superuser can alter ownership of any view anyway.)

The statement subforms and actions available for `ALTER MATERIALIZED VIEW` are a subset of those available for `ALTER TABLE`, and have the same meaning when used for materialized views. See the descriptions for `ALTER TABLE` for details.

Parameters

name

The name (optionally schema-qualified) of an existing materialized view.

column_name

Name of an existing column.

extension_name

The name of the extension that the materialized view is to depend on (or no longer dependent on, if `NO` is specified). A materialized view that's marked as dependent on an extension is automatically dropped when the extension is dropped.

new_column_name

New name for an existing column.

new_owner

The user name of the new owner of the materialized view.

new_name

The new name for the materialized view.

new_schema

The new schema for the materialized view.

Examples

To rename the materialized view `foo` to `bar`:

```
ALTER MATERIALIZED VIEW foo RENAME TO bar;
```

Compatibility

`ALTER MATERIALIZED VIEW` is a Postgres Pro extension.

See Also

CREATE MATERIALIZED VIEW, DROP MATERIALIZED VIEW, REFRESH MATERIALIZED VIEW

ALTER OPERATOR

ALTER OPERATOR — change the definition of an operator

Synopsis

```
ALTER OPERATOR name ( { left_type | NONE } , right_type )
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }

ALTER OPERATOR name ( { left_type | NONE } , right_type )
    SET SCHEMA new_schema

ALTER OPERATOR name ( { left_type | NONE } , right_type )
    SET ( {  RESTRICT = { res_proc | NONE }
           | JOIN = { join_proc | NONE }
         } [, ... ] )
```

Description

`ALTER OPERATOR` changes the definition of an operator.

You must own the operator to use `ALTER OPERATOR`. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the operator's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the operator. However, a superuser can alter ownership of any operator anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing operator.

left_type

The data type of the operator's left operand; write `NONE` if the operator has no left operand.

right_type

The data type of the operator's right operand.

new_owner

The new owner of the operator.

new_schema

The new schema for the operator.

res_proc

The restriction selectivity estimator function for this operator; write NONE to remove existing selectivity estimator.

join_proc

The join selectivity estimator function for this operator; write NONE to remove existing selectivity estimator.

Examples

Change the owner of a custom operator `a @@ b` for type `text`:

```
ALTER OPERATOR @@ (text, text) OWNER TO joe;
```

Change the restriction and join selectivity estimator functions of a custom operator `a && b` for type `int[]`:

```
ALTER OPERATOR && (_int4, _int4) SET (RESTRICT = _int_contsel, JOIN =
 _int_contjoinsel);
```

Compatibility

There is no `ALTER OPERATOR` statement in the SQL standard.

See Also

CREATE OPERATOR, DROP OPERATOR

ALTER OPERATOR CLASS

ALTER OPERATOR CLASS — change the definition of an operator class

Synopsis

```
ALTER OPERATOR CLASS name USING index_method
    RENAME TO new_name

ALTER OPERATOR CLASS name USING index_method
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }

ALTER OPERATOR CLASS name USING index_method
    SET SCHEMA new_schema
```

Description

`ALTER OPERATOR CLASS` changes the definition of an operator class.

You must own the operator class to use `ALTER OPERATOR CLASS`. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the operator class's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the operator class. However, a superuser can alter ownership of any operator class anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing operator class.

index_method

The name of the index method this operator class is for.

new_name

The new name of the operator class.

new_owner

The new owner of the operator class.

new_schema

The new schema for the operator class.

Compatibility

There is no `ALTER OPERATOR CLASS` statement in the SQL standard.

See Also

CREATE OPERATOR CLASS, DROP OPERATOR CLASS, ALTER OPERATOR FAMILY

ALTER OPERATOR FAMILY

ALTER OPERATOR FAMILY — change the definition of an operator family

Synopsis

```
ALTER OPERATOR FAMILY name USING index_method ADD
  {  OPERATOR strategy_number operator_name ( op_type, op_type )
             [ FOR SEARCH | FOR ORDER BY sort_family_name ]
   | FUNCTION support_number [ ( op_type [ , op_type ] ) ]
             function_name [ ( argument_type [, ...] ) ]
  } [, ... ]

ALTER OPERATOR FAMILY name USING index_method DROP
  {  OPERATOR strategy_number ( op_type [ , op_type ] )
   | FUNCTION support_number ( op_type [ , op_type ] )
  } [, ... ]

ALTER OPERATOR FAMILY name USING index_method
    RENAME TO new_name

ALTER OPERATOR FAMILY name USING index_method
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }

ALTER OPERATOR FAMILY name USING index_method
    SET SCHEMA new_schema
```

Description

`ALTER OPERATOR FAMILY` changes the definition of an operator family. You can add operators and support functions to the family, remove them from the family, or change the family's name or owner.

When operators and support functions are added to a family with `ALTER OPERATOR FAMILY`, they are not part of any specific operator class within the family, but are just “loose” within the family. This indicates that these operators and functions are compatible with the family's semantics, but are not required for correct functioning of any specific index. (Operators and functions that are so required should be declared as part of an operator class, instead; see CREATE OPERATOR CLASS.) Postgres Pro will allow loose members of a family to be dropped from the family at any time, but members of an operator class cannot be dropped without dropping the whole class and any indexes that depend on it. Typically, single-data-type operators and functions are part of operator classes because they are needed to support an index on that specific data type, while cross-data-type operators and functions are made loose members of the family.

You must be a superuser to use `ALTER OPERATOR FAMILY`. (This restriction is made because an erroneous operator family definition could confuse or even crash the server.)

`ALTER OPERATOR FAMILY` does not presently check whether the operator family definition includes all the operators and functions required by the index method, nor whether the operators and functions form a self-consistent set. It is the user's responsibility to define a valid operator family.

Refer to Section 40.16 for further information.

Parameters

name

The name (optionally schema-qualified) of an existing operator family.

index_method

The name of the index method this operator family is for.

strategy_number

The index method's strategy number for an operator associated with the operator family.

operator_name

The name (optionally schema-qualified) of an operator associated with the operator family.

op_type

In an OPERATOR clause, the operand data type(s) of the operator, or NONE to signify a prefix operator. Unlike the comparable syntax in CREATE OPERATOR CLASS, the operand data types must always be specified.

In an ADD FUNCTION clause, the operand data type(s) the function is intended to support, if different from the input data type(s) of the function. For B-tree comparison functions and hash functions it is not necessary to specify *op_type* since the function's input data type(s) are always the correct ones to use. For B-tree sort support functions, B-Tree equal image functions, and all functions in GiST, SP-GiST and GIN operator classes, it is necessary to specify the operand data type(s) the function is to be used with.

In a DROP FUNCTION clause, the operand data type(s) the function is intended to support must be specified.

sort_family_name

The name (optionally schema-qualified) of an existing btree operator family that describes the sort ordering associated with an ordering operator.

If neither FOR SEARCH nor FOR ORDER BY is specified, FOR SEARCH is the default.

support_number

The index method's support function number for a function associated with the operator family.

function_name

The name (optionally schema-qualified) of a function that is an index method support function for the operator family. If no argument list is specified, the name must be unique in its schema.

argument_type

The parameter data type(s) of the function.

new_name

The new name of the operator family.

new_owner

The new owner of the operator family.

new_schema

The new schema for the operator family.

The OPERATOR and FUNCTION clauses can appear in any order.

Notes

Notice that the DROP syntax only specifies the “slot” in the operator family, by strategy or support number and input data type(s). The name of the operator or function occupying the slot is not mentioned. Also, for DROP FUNCTION the type(s) to specify are the input data type(s) the function is intended to support;

for GiST, SP-GiST and GIN indexes this might have nothing to do with the actual input argument types of the function.

Because the index machinery does not check access permissions on functions before using them, including a function or operator in an operator family is tantamount to granting public execute permission on it. This is usually not an issue for the sorts of functions that are useful in an operator family.

The operators should not be defined by SQL functions. An SQL function is likely to be inlined into the calling query, which will prevent the optimizer from recognizing that the query matches an index.

Before PostgreSQL 8.4, the `OPERATOR` clause could include a `RECHECK` option. This is no longer supported because whether an index operator is "lossy" is now determined on-the-fly at run time. This allows efficient handling of cases where an operator might or might not be lossy.

Examples

The following example command adds cross-data-type operators and support functions to an operator family that already contains B-tree operator classes for data types `int4` and `int2`.

```
ALTER OPERATOR FAMILY integer_ops USING btree ADD

  -- int4 vs int2
  OPERATOR 1 < (int4, int2) ,
  OPERATOR 2 <= (int4, int2) ,
  OPERATOR 3 = (int4, int2) ,
  OPERATOR 4 >= (int4, int2) ,
  OPERATOR 5 > (int4, int2) ,
  FUNCTION 1 btint42cmp(int4, int2) ,

  -- int2 vs int4
  OPERATOR 1 < (int2, int4) ,
  OPERATOR 2 <= (int2, int4) ,
  OPERATOR 3 = (int2, int4) ,
  OPERATOR 4 >= (int2, int4) ,
  OPERATOR 5 > (int2, int4) ,
  FUNCTION 1 btint24cmp(int2, int4) ;
```

To remove these entries again:

```
ALTER OPERATOR FAMILY integer_ops USING btree DROP

  -- int4 vs int2
  OPERATOR 1 (int4, int2) ,
  OPERATOR 2 (int4, int2) ,
  OPERATOR 3 (int4, int2) ,
  OPERATOR 4 (int4, int2) ,
  OPERATOR 5 (int4, int2) ,
  FUNCTION 1 (int4, int2) ,

  -- int2 vs int4
  OPERATOR 1 (int2, int4) ,
  OPERATOR 2 (int2, int4) ,
  OPERATOR 3 (int2, int4) ,
  OPERATOR 4 (int2, int4) ,
  OPERATOR 5 (int2, int4) ,
  FUNCTION 1 (int2, int4) ;
```

Compatibility

There is no `ALTER OPERATOR FAMILY` statement in the SQL standard.

See Also

CREATE OPERATOR FAMILY, DROP OPERATOR FAMILY, CREATE OPERATOR CLASS, ALTER OPERATOR CLASS, DROP OPERATOR CLASS

ALTER POLICY

ALTER POLICY — change the definition of a row-level security policy

Synopsis

```
ALTER POLICY name ON table_name RENAME TO new_name

ALTER POLICY name ON table_name
    [ TO { role_name | PUBLIC | CURRENT_ROLE | CURRENT_USER | SESSION_USER } [, ...] ]
    [ USING ( using_expression ) ]
    [ WITH CHECK ( check_expression ) ]
```

Description

`ALTER POLICY` changes the definition of an existing row-level security policy. Note that `ALTER POLICY` only allows the set of roles to which the policy applies and the `USING` and `WITH CHECK` expressions to be modified. To change other properties of a policy, such as the command to which it applies or whether it is permissive or restrictive, the policy must be dropped and recreated.

To use `ALTER POLICY`, you must own the table that the policy applies to.

In the second form of `ALTER POLICY`, the role list, *using_expression*, and *check_expression* are replaced independently if specified. When one of those clauses is omitted, the corresponding part of the policy is unchanged.

Parameters

name

The name of an existing policy to alter.

table_name

The name (optionally schema-qualified) of the table that the policy is on.

new_name

The new name for the policy.

role_name

The role(s) to which the policy applies. Multiple roles can be specified at one time. To apply the policy to all roles, use `PUBLIC`.

using_expression

The `USING` expression for the policy. See CREATE POLICY for details.

check_expression

The `WITH CHECK` expression for the policy. See CREATE POLICY for details.

Compatibility

`ALTER POLICY` is a Postgres Pro extension.

See Also

CREATE POLICY, DROP POLICY

ALTER PROCEDURE

ALTER PROCEDURE — change the definition of a procedure

Synopsis

```
ALTER PROCEDURE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    action [ ... ] [ RESTRICT ]
ALTER PROCEDURE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    RENAME TO new_name
ALTER PROCEDURE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
ALTER PROCEDURE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    SET SCHEMA new_schema
ALTER PROCEDURE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    [ NO ] DEPENDS ON EXTENSION extension_name

where action is one of:

    [ EXTERNAL ] SECURITY INVOKER | [ EXTERNAL ] SECURITY DEFINER
    SET configuration_parameter { TO | = } { value | DEFAULT }
    SET configuration_parameter FROM CURRENT
    RESET configuration_parameter
    RESET ALL
```

Description

`ALTER PROCEDURE` changes the definition of a procedure.

You must own the procedure to use `ALTER PROCEDURE`. To change a procedure's schema, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the procedure's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the procedure. However, a superuser can alter ownership of any procedure anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing procedure. If no argument list is specified, the name must be unique in its schema.

argmode

The mode of an argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN`.

argname

The name of an argument. Note that `ALTER PROCEDURE` does not actually pay any attention to argument names, since only the argument data types are used to determine the procedure's identity.

argtype

The data type(s) of the procedure's arguments (optionally schema-qualified), if any. See DROP PROCEDURE for the details of how the procedure is looked up using the argument data type(s).

new_name

The new name of the procedure.

new_owner

The new owner of the procedure. Note that if the procedure is marked `SECURITY DEFINER`, it will subsequently execute as the new owner.

new_schema

The new schema for the procedure.

extension_name

This form marks the procedure as dependent on the extension, or no longer dependent on the extension if `NO` is specified. A procedure that's marked as dependent on an extension is dropped when the extension is dropped, even if cascade is not specified. A procedure can depend upon multiple extensions, and will be dropped when any one of those extensions is dropped.

```
[ EXTERNAL ] SECURITY INVOKER
[ EXTERNAL ] SECURITY DEFINER
```

Change whether the procedure is a security definer or not. The key word `EXTERNAL` is ignored for SQL conformance. See CREATE PROCEDURE for more information about this capability.

configuration_parameter
value

Add or change the assignment to be made to a configuration parameter when the procedure is called. If *value* is `DEFAULT` or, equivalently, `RESET` is used, the procedure-local setting is removed, so that the procedure executes with the value present in its environment. Use `RESET ALL` to clear all procedure-local settings. `SET FROM CURRENT` saves the value of the parameter that is current when `ALTER PROCEDURE` is executed as the value to be applied when the procedure is entered.

See SET and Chapter 19 for more information about allowed parameter names and values.

`RESTRICT`

Ignored for conformance with the SQL standard.

Examples

To rename the procedure `insert_data` with two arguments of type `integer` to `insert_record`:

```
ALTER PROCEDURE insert_data(integer, integer) RENAME TO insert_record;
```

To change the owner of the procedure `insert_data` with two arguments of type `integer` to `joe`:

```
ALTER PROCEDURE insert_data(integer, integer) OWNER TO joe;
```

To change the schema of the procedure `insert_data` with two arguments of type `integer` to `accounting`:

```
ALTER PROCEDURE insert_data(integer, integer) SET SCHEMA accounting;
```

To mark the procedure `insert_data(integer, integer)` as being dependent on the extension `myext`:

```
ALTER PROCEDURE insert_data(integer, integer) DEPENDS ON EXTENSION myext;
```

To adjust the search path that is automatically set for a procedure:

```
ALTER PROCEDURE check_password(text) SET search_path = admin, pg_temp;
```

To disable automatic setting of `search_path` for a procedure:

```
ALTER PROCEDURE check_password(text) RESET search_path;
```

The procedure will now execute with whatever search path is used by its caller.

Compatibility

This statement is partially compatible with the `ALTER PROCEDURE` statement in the SQL standard. The standard allows more properties of a procedure to be modified, but does not provide the ability to rename a procedure, make a procedure a security definer, attach configuration parameter values to a procedure, or change the owner, schema, or volatility of a procedure. The standard also requires the `RESTRICT` key word, which is optional in Postgres Pro.

See Also

CREATE PROCEDURE, DROP PROCEDURE, ALTER FUNCTION, ALTER ROUTINE

ALTER PROFILE

ALTER PROFILE — change an authentication profile

Synopsis

```
ALTER PROFILE name [ LIMIT parameter value [ ... ] ]

where parameter can be:

      FAILED_LOGIN_ATTEMPTS
    | PASSWORD_REUSE_TIME
    | PASSWORD_REUSE_MAX
    | PASSWORD_LIFE_TIME
    | PASSWORD_GRACE_TIME
    | USER_INACTIVE_TIME
    | FAILED_AUTH_KEEP_TIME
    | PASSWORD_MIN_UNIQUE_CHARS
    | PASSWORD_MIN_LEN
    | PASSWORD_REQUIRE_COMPLEX

ALTER PROFILE name RENAME TO new_name
```

Description

The `ALTER PROFILE` command changes parameters of a Postgres Pro profile. You must be a database superuser to use this command.

Parameters

name

The name of the profile for which to alter parameters.

`FAILED_LOGIN_ATTEMPTS` *value*
`PASSWORD_REUSE_TIME` *value*
`PASSWORD_REUSE_MAX` *value*
`PASSWORD_LIFE_TIME` *value*
`PASSWORD_GRACE_TIME` *value*
`USER_INACTIVE_TIME` *value*
`FAILED_AUTH_KEEP_TIME` *value*
`PASSWORD_MIN_UNIQUE_CHARS` *value*
`PASSWORD_MIN_LEN` *value*
`PASSWORD_REQUIRE_COMPLEX` *value*

These clauses alter parameters originally set by CREATE PROFILE. For more information, see the `CREATE PROFILE` reference page.

new_name

The new name of the profile.

Notes

Use CREATE PROFILE to add new profiles, and DROP PROFILE to remove a profile.

Examples

Change `PASSWORD_LIFE_TIME` and `PASSWORD_GRACE_TIME` parameters of a profile:

```
ALTER PROFILE admin_profile
    LIMIT PASSWORD_LIFE_TIME 90
          PASSWORD_GRACE_TIME 3;
```

See Also

CREATE PROFILE, DROP PROFILE, CREATE ROLE

ALTER PUBLICATION

ALTER PUBLICATION — change the definition of a publication

Synopsis

```
ALTER PUBLICATION name ADD TABLE [ ONLY ] table_name [ * ] [, ...]
ALTER PUBLICATION name SET TABLE [ ONLY ] table_name [ * ] [, ...]
ALTER PUBLICATION name DROP TABLE [ ONLY ] table_name [ * ] [, ...]
ALTER PUBLICATION name SET ( publication_parameter [= value] [, ... ] )
ALTER PUBLICATION name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER PUBLICATION name RENAME TO new_name
```

Description

The command `ALTER PUBLICATION` can change the attributes of a publication.

The first three variants change which tables are part of the publication. The `SET TABLE` clause will replace the list of tables in the publication with the specified one. The `ADD TABLE` and `DROP TABLE` clauses will add and remove one or more tables from the publication. Note that adding tables to a publication that is already subscribed to will require a `ALTER SUBSCRIPTION ... REFRESH PUBLICATION` action on the subscribing side in order to become effective.

The fourth variant of this command listed in the synopsis can change all of the publication properties specified in CREATE PUBLICATION. Properties not mentioned in the command retain their previous settings.

The remaining variants change the owner and the name of the publication.

You must own the publication to use `ALTER PUBLICATION`. Adding a table to a publication additionally requires owning that table. To alter the owner, you must also be a direct or indirect member of the new owning role. The new owner must have `CREATE` privilege on the database. Also, the new owner of a `FOR ALL TABLES` publication must be a superuser. However, a superuser can change the ownership of a publication regardless of these restrictions.

Parameters

name

The name of an existing publication whose definition is to be altered.

table_name

Name of an existing table. If `ONLY` is specified before the table name, only that table is affected. If `ONLY` is not specified, the table and all its descendant tables (if any) are affected. Optionally, `*` can be specified after the table name to explicitly indicate that descendant tables are included.

`SET ( publication_parameter [= value] [, ... ] )`

This clause alters publication parameters originally set by CREATE PUBLICATION. See there for more information.

new_owner

The user name of the new owner of the publication.

new_name

The new name for the publication.

Examples

Change the publication to publish only deletes and updates:

```
ALTER PUBLICATION noinsert SET (publish = 'update, delete');
```

Add some tables to the publication:

```
ALTER PUBLICATION mypublication ADD TABLE users, departments;
```

Compatibility

`ALTER PUBLICATION` is a Postgres Pro extension.

See Also

CREATE PUBLICATION, DROP PUBLICATION, CREATE SUBSCRIPTION, ALTER SUBSCRIPTION

ALTER ROLE

ALTER ROLE — change a database role

Synopsis

```
ALTER ROLE role_specification [ WITH ] option [ ... ]

where option can be:

      SUPERUSER | NOSUPERUSER
    | CREATEDB | NOCREATEDB
    | CREATEROLE | NOCREATEROLE
    | INHERIT | NOINHERIT
    | LOGIN | NOLOGIN
    | REPLICATION | NOREPLICATION
    | BYPASSRLS | NOBYPASSRLS
    | CONNECTION LIMIT connlimit
    | [ ENCRYPTED ] PASSWORD 'password' | PASSWORD NULL
    | VALID UNTIL 'timestamp'
    | PROFILE profile_name
    | ACCOUNT UNLOCK | ACCOUNT LOCK

ALTER ROLE name RENAME TO new_name

ALTER ROLE { role_specification | ALL } [ IN DATABASE database_name ]
 SET configuration_parameter { TO | = } { value | DEFAULT }
ALTER ROLE { role_specification | ALL } [ IN DATABASE database_name ]
 SET configuration_parameter FROM CURRENT
ALTER ROLE { role_specification | ALL } [ IN DATABASE database_name ]
 RESET configuration_parameter
ALTER ROLE { role_specification | ALL } [ IN DATABASE database_name ] RESET ALL

where role_specification can be:

    role_name
  | CURRENT_ROLE
  | CURRENT_USER
  | SESSION_USER
```

Description

`ALTER ROLE` changes the attributes of a Postgres Pro role.

The first variant of this command listed in the synopsis can change many of the role attributes that can be specified in `CREATE ROLE`. (All the possible attributes are covered, except that there are no options for adding or removing memberships; use `GRANT` and `REVOKE` for that.) Attributes not mentioned in the command retain their previous settings. Database superusers can change any of these settings for any role. Non-superuser roles having `CREATEROLE` privilege can change most of these properties, but only for non-superuser and non-replication roles for which they have been granted `ADMIN OPTION`. Non-superusers cannot change the `SUPERUSER` property and can change the `CREATEDB`, `REPLICATION`, and `BYPASSRLS` properties only if they possess the corresponding property themselves. Ordinary roles can only change their own password.

The second variant changes the name of the role. Database superusers can rename any role. Roles having `CREATEROLE` privilege can rename non-superuser roles for which they have been granted `ADMIN OPTION`. The current session user cannot be renamed. (Connect as a different user if you need to do that.)

Because MD5-encrypted passwords use the role name as cryptographic salt, renaming a role clears its password if the password is MD5-encrypted.

The remaining variants change a role's session default for a configuration variable, either for all databases or, when the IN DATABASE clause is specified, only for sessions in the named database. If ALL is specified instead of a role name, this changes the setting for all roles. Using ALL with IN DATABASE is effectively the same as using the command ALTER DATABASE ... SET ....

Whenever the role subsequently starts a new session, the specified value becomes the session default, overriding whatever setting is present in postgresql.conf or has been received from the postgres command line. This only happens at login time; executing SET ROLE or SET SESSION AUTHORIZATION does not cause new configuration values to be set. Settings set for all databases are overridden by database-specific settings attached to a role. Settings for specific databases or specific roles override settings for all roles.

Superusers can change anyone's session defaults. Roles having CREATEROLE privilege can change defaults for non-superuser roles for which they have been granted ADMIN OPTION. Ordinary roles can only set defaults for themselves. Certain configuration variables cannot be set this way, or can only be set if a superuser issues the command. Only superusers can change a setting for all roles in all databases.

Parameters

name

The name of the role whose attributes are to be altered.

CURRENT_ROLE
CURRENT_USER

Alter the current user instead of an explicitly identified role.

SESSION_USER

Alter the current session user instead of an explicitly identified role.

SUPERUSER
NOSUPERUSER
CREATEDB
NOCREATEDB
CREATEROLE
NOCREATEROLE
INHERIT
NOINHERIT
LOGIN
NOLOGIN
REPLICATION
NOREPLICATION
BYPASSRLS
NOBYPASSRLS
CONNECTION LIMIT *connlimit*
[ENCRYPTED] PASSWORD '*password*'
PASSWORD NULL
VALID UNTIL '*timestamp*'
PROFILE *profile_name*

These clauses alter attributes originally set by CREATE ROLE. For more information, see the CREATE ROLE reference page.

ACCOUNT UNLOCK

Unlock the role. A role can be locked if the allowed number of failed login attempts has been exceeded (see CREATE PROFILE for details).

`ACCOUNT LOCK`

Explicitly lock the role.

`new_name`

The new name of the role.

`database_name`

The name of the database the configuration variable should be set in.

`configuration_parameter`
`value`

Set this role's session default for the specified configuration parameter to the given value. If *`value`* is `DEFAULT` or, equivalently, `RESET` is used, the role-specific variable setting is removed, so the role will inherit the system-wide default setting in new sessions. Use `RESET ALL` to clear all role-specific settings. `SET FROM CURRENT` saves the session's current value of the parameter as the role-specific value. If `IN DATABASE` is specified, the configuration parameter is set or removed for the given role and database only.

Role-specific variable settings take effect only at login; `SET ROLE` and `SET SESSION AUTHORIZATION` do not process role-specific variable settings.

See SET and Chapter 19 for more information about allowed parameter names and values.

Notes

Use `CREATE ROLE` to add new roles, and `DROP ROLE` to remove a role.

`ALTER ROLE` cannot change a role's memberships. Use `GRANT` and `REVOKE` to do that.

Caution must be exercised when specifying an unencrypted password with this command. The password will be transmitted to the server in cleartext, and it might also be logged in the client's command history or the server log. psql contains a command `\password` that can be used to change a role's password without exposing the cleartext password.

It is also possible to tie a session default to a specific database rather than to a role; see ALTER DATABASE. If there is a conflict, database-role-specific settings override role-specific ones, which in turn override database-specific ones.

Examples

Change a role's password:

```
ALTER ROLE davide WITH PASSWORD 'hu8jmn3';
```

Remove a role's password:

```
ALTER ROLE davide WITH PASSWORD NULL;
```

Change a password expiration date, specifying that the password should expire at midday on 4th May 2015 using the time zone which is one hour ahead of UTC:

```
ALTER ROLE chris VALID UNTIL 'May 4 12:00:00 2015 +1';
```

Make a password valid forever:

```
ALTER ROLE fred VALID UNTIL 'infinity';
```

Give a role the ability to manage other roles and create new databases:

```
ALTER ROLE miriam CREATEROLE CREATEDB;
```

Give a role a non-default setting of the maintenance_work_mem parameter:

```
ALTER ROLE worker_bee SET maintenance_work_mem = 100000;
```

Give a role a non-default, database-specific setting of the client_min_messages parameter:

```
ALTER ROLE fred IN DATABASE devel SET client_min_messages = DEBUG;
```

Compatibility

The `ALTER ROLE` statement is a Postgres Pro extension.

See Also

CREATE ROLE, DROP ROLE, ALTER DATABASE, SET, CREATE PROFILE

ALTER ROUTINE

ALTER ROUTINE — change the definition of a routine

Synopsis

```
ALTER ROUTINE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    action [ ... ] [ RESTRICT ]
ALTER ROUTINE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    RENAME TO new_name
ALTER ROUTINE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
ALTER ROUTINE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    SET SCHEMA new_schema
ALTER ROUTINE name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
    [ NO ] DEPENDS ON EXTENSION extension_name

where action is one of:

    IMMUTABLE | STABLE | VOLATILE
    [ NOT ] LEAKPROOF
    [ EXTERNAL ] SECURITY INVOKER | [ EXTERNAL ] SECURITY DEFINER
    PARALLEL { UNSAFE | RESTRICTED | SAFE }
    COST execution_cost
    ROWS result_rows
    SET configuration_parameter { TO | = } { value | DEFAULT }
    SET configuration_parameter FROM CURRENT
    RESET configuration_parameter
    RESET ALL
```

Description

`ALTER ROUTINE` changes the definition of a routine, which can be an aggregate function, a normal function, or a procedure. See under ALTER AGGREGATE, ALTER FUNCTION, and ALTER PROCEDURE for the description of the parameters, more examples, and further details.

Examples

To rename the routine `foo` for type `integer` to `foobar`:

```
ALTER ROUTINE foo(integer) RENAME TO foobar;
```

This command will work independent of whether `foo` is an aggregate, function, or procedure.

Compatibility

This statement is partially compatible with the `ALTER ROUTINE` statement in the SQL standard. See under ALTER FUNCTION and ALTER PROCEDURE for more details. Allowing routine names to refer to aggregate functions is a Postgres Pro extension.

See Also

ALTER AGGREGATE, ALTER FUNCTION, ALTER PROCEDURE, DROP ROUTINE

Note that there is no `CREATE ROUTINE` command.

ALTER RULE

ALTER RULE — change the definition of a rule

Synopsis

```
ALTER RULE name ON table_name RENAME TO new_name
```

Description

`ALTER RULE` changes properties of an existing rule. Currently, the only available action is to change the rule's name.

To use `ALTER RULE`, you must own the table or view that the rule applies to.

Parameters

name

The name of an existing rule to alter.

table_name

The name (optionally schema-qualified) of the table or view that the rule applies to.

new_name

The new name for the rule.

Examples

To rename an existing rule:

```
ALTER RULE notify_all ON emp RENAME TO notify_me;
```

Compatibility

`ALTER RULE` is a Postgres Pro language extension, as is the entire query rewrite system.

See Also

CREATE RULE, DROP RULE

ALTER SCHEMA

ALTER SCHEMA — change the definition of a schema

Synopsis

```
ALTER SCHEMA name RENAME TO new_name
ALTER SCHEMA name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
```

Description

`ALTER SCHEMA` changes the definition of a schema.

You must own the schema to use `ALTER SCHEMA`. To rename a schema you must also have the `CREATE` privilege for the database. To alter the owner, you must also be a direct or indirect member of the new owning role, and you must have the `CREATE` privilege for the database. (Note that superusers have all these privileges automatically.)

Parameters

name

The name of an existing schema.

new_name

The new name of the schema. The new name cannot begin with `pg_`, as such names are reserved for system schemas.

new_owner

The new owner of the schema.

Compatibility

There is no `ALTER SCHEMA` statement in the SQL standard.

See Also

CREATE SCHEMA, DROP SCHEMA

ALTER SEQUENCE

ALTER SEQUENCE — change the definition of a sequence generator

Synopsis

```
ALTER SEQUENCE [ IF EXISTS ] name
    [ AS data_type ]
    [ INCREMENT [ BY ] increment ]
    [ MINVALUE minvalue | NO MINVALUE ] [ MAXVALUE maxvalue | NO MAXVALUE ]
    [ START [ WITH ] start ]
    [ RESTART [ [ WITH ] restart ] ]
    [ CACHE cache ] [ [ NO ] CYCLE ]
    [ OWNED BY { table_name.column_name | NONE } ]
ALTER SEQUENCE [ IF EXISTS ] name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER SEQUENCE [ IF EXISTS ] name RENAME TO new_name
ALTER SEQUENCE [ IF EXISTS ] name SET SCHEMA new_schema
```

Description

`ALTER SEQUENCE` changes the parameters of an existing sequence generator. Any parameters not specifically set in the `ALTER SEQUENCE` command retain their prior settings.

You must own the sequence to use `ALTER SEQUENCE`. To change a sequence's schema, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the sequence's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the sequence. However, a superuser can alter ownership of any sequence anyway.)

Parameters

name

The name (optionally schema-qualified) of a sequence to be altered.

`IF EXISTS`

Do not throw an error if the sequence does not exist. A notice is issued in this case.

data_type

The optional clause `AS` *data_type* changes the data type of the sequence. Valid types are `smallint`, `integer`, and `bigint`.

Changing the data type automatically changes the minimum and maximum values of the sequence if and only if the previous minimum and maximum values were the minimum or maximum value of the old data type (in other words, if the sequence had been created using `NO MINVALUE` or `NO MAXVALUE`, implicitly or explicitly). Otherwise, the minimum and maximum values are preserved, unless new values are given as part of the same command. If the minimum and maximum values do not fit into the new data type, an error will be generated.

increment

The clause `INCREMENT BY` *increment* is optional. A positive value will make an ascending sequence, a negative one a descending sequence. If unspecified, the old increment value will be maintained.

minvalue
`NO MINVALUE`

The optional clause `MINVALUE` *minvalue* determines the minimum value a sequence can generate. If `NO MINVALUE` is specified, the defaults of 1 and the minimum value of the data type for ascending and

descending sequences, respectively, will be used. If neither option is specified, the current minimum value will be maintained.

maxvalue
NO MAXVALUE

The optional clause MAXVALUE *maxvalue* determines the maximum value for the sequence. If NO MAXVALUE is specified, the defaults of the maximum value of the data type and -1 for ascending and descending sequences, respectively, will be used. If neither option is specified, the current maximum value will be maintained.

start

The optional clause START WITH *start* changes the recorded start value of the sequence. This has no effect on the *current* sequence value; it simply sets the value that future ALTER SEQUENCE RESTART commands will use.

restart

The optional clause RESTART [WITH *restart*] changes the current value of the sequence. This is similar to calling the setval function with is_called = false: the specified value will be returned by the *next* call of nextval. Writing RESTART with no *restart* value is equivalent to supplying the start value that was recorded by CREATE SEQUENCE or last set by ALTER SEQUENCE START WITH.

In contrast to a setval call, a RESTART operation on a sequence is transactional and blocks concurrent transactions from obtaining numbers from the same sequence. If that's not the desired mode of operation, setval should be used.

cache

The clause CACHE *cache* enables sequence numbers to be preallocated and stored in memory for faster access. The minimum value is 1 (only one value can be generated at a time, i.e., no cache). If unspecified, the old cache value will be maintained.

CYCLE

The optional CYCLE key word can be used to enable the sequence to wrap around when the *maxvalue* or *minvalue* has been reached by an ascending or descending sequence respectively. If the limit is reached, the next number generated will be the *minvalue* or *maxvalue*, respectively.

NO CYCLE

If the optional NO CYCLE key word is specified, any calls to nextval after the sequence has reached its maximum value will return an error. If neither CYCLE or NO CYCLE are specified, the old cycle behavior will be maintained.

OWNED BY *table_name*.*column_name*
OWNED BY NONE

The OWNED BY option causes the sequence to be associated with a specific table column, such that if that column (or its whole table) is dropped, the sequence will be automatically dropped as well. If specified, this association replaces any previously specified association for the sequence. The specified table must have the same owner and be in the same schema as the sequence. Specifying OWNED BY NONE removes any existing association, making the sequence “free-standing”.

new_owner

The user name of the new owner of the sequence.

new_name

The new name for the sequence.

new_schema

The new schema for the sequence.

Notes

`ALTER SEQUENCE` will not immediately affect `nextval` results in backends, other than the current one, that have preallocated (cached) sequence values. They will use up all cached values prior to noticing the changed sequence generation parameters. The current backend will be affected immediately.

`ALTER SEQUENCE` does not affect the `currval` status for the sequence. (Before PostgreSQL 8.3, it sometimes did.)

`ALTER SEQUENCE` blocks concurrent `nextval`, `currval`, `lastval`, and `setval` calls.

For historical reasons, `ALTER TABLE` can be used with sequences too; but the only variants of `ALTER TABLE` that are allowed with sequences are equivalent to the forms shown above.

Examples

Restart a sequence called `serial`, at 105:

```
ALTER SEQUENCE serial RESTART WITH 105;
```

Compatibility

`ALTER SEQUENCE` conforms to the SQL standard, except for the `AS`, `START WITH`, `OWNED BY`, `OWNER TO`, `RENAME TO`, and `SET SCHEMA` clauses, which are Postgres Pro extensions.

See Also

CREATE SEQUENCE, DROP SEQUENCE

ALTER SERVER

ALTER SERVER — change the definition of a foreign server

Synopsis

```
ALTER SERVER name [ VERSION 'new_version' ]
    [ OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ] ) ]
ALTER SERVER name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
ALTER SERVER name RENAME TO new_name
```

Description

`ALTER SERVER` changes the definition of a foreign server. The first form changes the server version string or the generic options of the server (at least one clause is required). The second form changes the owner of the server.

To alter the server you must be the owner of the server. Additionally to alter the owner, you must own the server and also be a direct or indirect member of the new owning role, and you must have `USAGE` privilege on the server's foreign-data wrapper. (Note that superusers satisfy all these criteria automatically.)

Parameters

name

The name of an existing server.

new_version

New server version.

`OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ] )`

Change options for the server. `ADD`, `SET`, and `DROP` specify the action to be performed. `ADD` is assumed if no operation is explicitly specified. Option names must be unique; names and values are also validated using the server's foreign-data wrapper library.

new_owner

The user name of the new owner of the foreign server.

new_name

The new name for the foreign server.

Examples

Alter server `foo`, add connection options:

```
ALTER SERVER foo OPTIONS (host 'foo', dbname 'foodb');
```

Alter server `foo`, change version, change `host` option:

```
ALTER SERVER foo VERSION '8.4' OPTIONS (SET host 'baz');
```

Compatibility

`ALTER SERVER` conforms to ISO/IEC 9075-9 (SQL/MED). The `OWNER TO` and `RENAME` forms are Postgres Pro extensions.

See Also

CREATE SERVER, DROP SERVER

ALTER STATISTICS

ALTER STATISTICS — change the definition of an extended statistics object

Synopsis

```
ALTER STATISTICS name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER STATISTICS name RENAME TO new_name
ALTER STATISTICS name SET SCHEMA new_schema
ALTER STATISTICS name SET STATISTICS new_target
```

Description

`ALTER STATISTICS` changes the parameters of an existing extended statistics object. Any parameters not specifically set in the `ALTER STATISTICS` command retain their prior settings.

You must own the statistics object to use `ALTER STATISTICS`. To change a statistics object's schema, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the statistics object's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the statistics object. However, a superuser can alter ownership of any statistics object anyway.)

Parameters

name

The name (optionally schema-qualified) of the statistics object to be altered.

new_owner

The user name of the new owner of the statistics object.

new_name

The new name for the statistics object.

new_schema

The new schema for the statistics object.

new_target

The statistic-gathering target for this statistics object for subsequent `ANALYZE` operations. The target can be set in the range 0 to 10000; alternatively, set it to -1 to revert to using the maximum of the statistics target of the referenced columns, if set, or the system default statistics target (default_statistics_target). For more information on the use of statistics by the PostgreSQL query planner, refer to Section 14.2.

Compatibility

There is no `ALTER STATISTICS` command in the SQL standard.

See Also

CREATE STATISTICS, DROP STATISTICS

ALTER SUBSCRIPTION

ALTER SUBSCRIPTION — change the definition of a subscription

Synopsis

```
ALTER SUBSCRIPTION name CONNECTION 'conninfo'
ALTER SUBSCRIPTION name SET PUBLICATION publication_name [, ...] [ WITH
 ( publication_option [= value] [, ... ] ) ]
ALTER SUBSCRIPTION name ADD PUBLICATION publication_name [, ...] [ WITH
 ( publication_option [= value] [, ... ] ) ]
ALTER SUBSCRIPTION name DROP PUBLICATION publication_name [, ...] [ WITH
 ( publication_option [= value] [, ... ] ) ]
ALTER SUBSCRIPTION name REFRESH PUBLICATION [ WITH ( refresh_option [= value]
 [, ... ] ) ]
ALTER SUBSCRIPTION name ENABLE
ALTER SUBSCRIPTION name DISABLE
ALTER SUBSCRIPTION name SET ( subscription_parameter [= value] [, ... ] )
ALTER SUBSCRIPTION name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER SUBSCRIPTION name RENAME TO new_name
```

Description

`ALTER SUBSCRIPTION` can change most of the subscription properties that can be specified in CREATE SUBSCRIPTION.

You must own the subscription to use `ALTER SUBSCRIPTION`. To alter the owner, you must also be a direct or indirect member of the new owning role. The new owner has to be a superuser. (Currently, all subscription owners must be superusers, so the owner checks will be bypassed in practice. But this might change in the future.)

When refreshing a publication we remove the relations that are no longer part of the publication and we also remove the table synchronization slots if there are any. It is necessary to remove these slots so that the resources allocated for the subscription on the remote host are released. If due to network breakdown or some other error, Postgres Pro is unable to remove the slots, an ERROR will be reported. To proceed in this situation, the user either needs to retry the operation or disassociate the slot from the subscription and drop the subscription as explained in DROP SUBSCRIPTION.

Commands `ALTER SUBSCRIPTION ... REFRESH PUBLICATION` and `ALTER SUBSCRIPTION ... {SET|ADD|DROP} PUBLICATION ...` with `refresh` option as `true` cannot be executed inside a transaction block.

Parameters

name

The name of a subscription whose properties are to be altered.

`CONNECTION '`*conninfo*`'`

This clause alters the connection property originally set by CREATE SUBSCRIPTION. See there for more information.

`SET PUBLICATION` *publication_name*
`ADD PUBLICATION` *publication_name*
`DROP PUBLICATION` *publication_name*

Changes the list of subscribed publications. `SET` replaces the entire list of publications with a new list, `ADD` adds additional publications to the list of publications, and `DROP` removes the publications

from the list of publications. See CREATE SUBSCRIPTION for more information. By default, this command will also act like REFRESH PUBLICATION.

publication_option specifies additional options for this operation. The supported options are:

refresh (boolean)

When false, the command will not try to refresh table information. REFRESH PUBLICATION should then be executed separately. The default is true.

Additionally, the options described under REFRESH PUBLICATION may be specified, to control the implicit refresh operation.

REFRESH PUBLICATION

Fetch missing table information from publisher. This will start replication of tables that were added to the subscribed-to publications since the last invocation of REFRESH PUBLICATION or since CREATE SUBSCRIPTION.

refresh_option specifies additional options for the refresh operation. The supported options are:

copy_data (boolean)

Specifies whether the existing data in the publications that are being subscribed to should be copied once the replication starts. The default is true. (Previously subscribed tables are not copied.)

ENABLE

Enables the previously disabled subscription, starting the logical replication worker at the end of transaction.

DISABLE

Disables the running subscription, stopping the logical replication worker at the end of transaction.

SET (*subscription_parameter* [= *value*] [, ...])

This clause alters parameters originally set by CREATE SUBSCRIPTION. See there for more information. The parameters that can be altered are slot_name, synchronous_commit, binary, and streaming.

new_owner

The user name of the new owner of the subscription.

new_name

The new name for the subscription.

Examples

Change the publication subscribed by a subscription to insert_only:

```
ALTER SUBSCRIPTION mysub SET PUBLICATION insert_only;
```

Disable (stop) the subscription:

```
ALTER SUBSCRIPTION mysub DISABLE;
```

Compatibility

ALTER SUBSCRIPTION is a Postgres Pro extension.

See Also

CREATE SUBSCRIPTION, DROP SUBSCRIPTION, CREATE PUBLICATION, ALTER PUBLICATION

ALTER SYSTEM

ALTER SYSTEM — change a server configuration parameter

Synopsis

```
ALTER SYSTEM SET configuration_parameter { TO | = } { value [, ...] | DEFAULT }

ALTER SYSTEM RESET configuration_parameter
ALTER SYSTEM RESET ALL
```

Description

`ALTER SYSTEM` is used for changing server configuration parameters across the entire database cluster. It can be more convenient than the traditional method of manually editing the `postgresql.conf` file. `ALTER SYSTEM` writes the given parameter setting to the `postgresql.auto.conf` file, which is read in addition to `postgresql.conf`. Setting a parameter to `DEFAULT`, or using the `RESET` variant, removes that configuration entry from the `postgresql.auto.conf` file. Use `RESET ALL` to remove all such configuration entries.

Values set with `ALTER SYSTEM` will be effective after the next server configuration reload, or after the next server restart in the case of parameters that can only be changed at server start. A server configuration reload can be commanded by calling the SQL function `pg_reload_conf()`, running `pg_ctl reload`, or sending a SIGHUP signal to the main server process.

Only superusers can use `ALTER SYSTEM`. Also, since this command acts directly on the file system and cannot be rolled back, it is not allowed inside a transaction block or function.

Parameters

configuration_parameter

Name of a settable configuration parameter. Available parameters are documented in Chapter 19.

value

New value of the parameter. Values can be specified as string constants, identifiers, numbers, or comma-separated lists of these, as appropriate for the particular parameter. Values that are neither numbers nor valid identifiers must be quoted. `DEFAULT` can be written to specify removing the parameter and its value from `postgresql.auto.conf`.

For some list-accepting parameters, quoted values will produce double-quoted output to preserve whitespace and commas; for others, double-quotes must be used inside single-quoted strings to get this effect.

Notes

This command can't be used to set data_directory, nor parameters that are not allowed in `postgresql.conf` (e.g., preset options).

See Section 19.1 for other ways to set the parameters.

Examples

Set the `wal_level`:

```
ALTER SYSTEM SET wal_level = replica;
```

Undo that, restoring whatever setting was effective in `postgresql.conf`:

```
ALTER SYSTEM RESET wal_level;
```

Compatibility

The `ALTER SYSTEM` statement is a Postgres Pro extension.

See Also

SET, SHOW

ALTER TABLE

ALTER TABLE — change the definition of a table

Synopsis

```
ALTER TABLE [ IF EXISTS ] [ ONLY ] name [ * ]
    action [, ... ]
ALTER TABLE [ IF EXISTS ] [ ONLY ] name [ * ]
    RENAME [ COLUMN ] column_name TO new_column_name
ALTER TABLE [ IF EXISTS ] [ ONLY ] name [ * ]
    RENAME CONSTRAINT constraint_name TO new_constraint_name
ALTER TABLE [ IF EXISTS ] name
    RENAME TO new_name
ALTER TABLE [ IF EXISTS ] name
    SET SCHEMA new_schema
ALTER TABLE ALL IN TABLESPACE name [ OWNED BY role_name [, ... ] ]
    SET TABLESPACE new_tablespace [ NOWAIT ]
ALTER TABLE [ IF EXISTS ] name
    ATTACH PARTITION partition_name { FOR VALUES partition_bound_spec | DEFAULT }
ALTER TABLE [ IF EXISTS ] name
    DETACH PARTITION partition_name [ CONCURRENTLY | FINALIZE ]
ALTER TABLE [ IF EXISTS ] name
    pg_pathman_action

where action is one of:

    ADD [ COLUMN ] [ IF NOT EXISTS ] column_name data_type [ COLLATE collation ]
 [ column_constraint [ ... ] ]
    DROP [ COLUMN ] [ IF EXISTS ] column_name [ RESTRICT | CASCADE ]
    ALTER [ COLUMN ] column_name [ SET DATA ] TYPE data_type [ COLLATE collation ]
 [ USING expression ]
    ALTER [ COLUMN ] column_name SET DEFAULT expression
    ALTER [ COLUMN ] column_name DROP DEFAULT
    ALTER [ COLUMN ] column_name { SET | DROP } NOT NULL
    ALTER [ COLUMN ] column_name DROP EXPRESSION [ IF EXISTS ]
    ALTER [ COLUMN ] column_name ADD GENERATED { ALWAYS | BY DEFAULT } AS IDENTITY
 [ ( sequence_options ) ]
    ALTER [ COLUMN ] column_name { SET GENERATED { ALWAYS | BY DEFAULT } |
 SET sequence_option | RESTART [ [ WITH ] restart ] } [...]
    ALTER [ COLUMN ] column_name DROP IDENTITY [ IF EXISTS ]
    ALTER [ COLUMN ] column_name SET STATISTICS integer
    ALTER [ COLUMN ] column_name SET ( attribute_option = value [, ... ] )
    ALTER [ COLUMN ] column_name RESET ( attribute_option [, ... ] )
    ALTER [ COLUMN ] column_name SET STORAGE { PLAIN | EXTERNAL | EXTENDED | MAIN }
    ALTER [ COLUMN ] column_name SET COMPRESSION compression_method
    ADD table_constraint [ NOT VALID ]
    ADD table_constraint_using_index
    ALTER CONSTRAINT constraint_name [ DEFERRABLE | NOT DEFERRABLE ] [ INITIALLY
 DEFERRED | INITIALLY IMMEDIATE ]
    VALIDATE CONSTRAINT constraint_name
    DROP CONSTRAINT [ IF EXISTS ]  constraint_name [ RESTRICT | CASCADE ]
    DISABLE TRIGGER [ trigger_name | ALL | USER ]
    ENABLE TRIGGER [ trigger_name | ALL | USER ]
    ENABLE REPLICA TRIGGER trigger_name
    ENABLE ALWAYS TRIGGER trigger_name
    DISABLE RULE rewrite_rule_name
```

```
    ENABLE RULE rewrite_rule_name
    ENABLE REPLICA RULE rewrite_rule_name
    ENABLE ALWAYS RULE rewrite_rule_name
    DISABLE ROW LEVEL SECURITY
    ENABLE ROW LEVEL SECURITY
    FORCE ROW LEVEL SECURITY
    NO FORCE ROW LEVEL SECURITY
    CLUSTER ON index_name
    SET WITHOUT CLUSTER
    SET WITHOUT OIDS
    SET TABLESPACE new_tablespace
    SET { LOGGED | UNLOGGED }
    SET CONSTANT
    SET ( storage_parameter [= value] [, ... ] )
    RESET ( storage_parameter [, ... ] )
    INHERIT parent_table
    NO INHERIT parent_table
    OF type_name
    NOT OF
    OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
    REPLICA IDENTITY { DEFAULT | USING INDEX index_name | FULL | NOTHING }

and partition_bound_spec is:

IN ( partition_bound_expr [, ...] ) |
FROM ( { partition_bound_expr | MINVALUE | MAXVALUE } [, ...] )
  TO ( { partition_bound_expr | MINVALUE | MAXVALUE } [, ...] ) |
WITH ( MODULUS numeric_literal, REMAINDER numeric_literal )

pg_pathman_action is:

    PARTITION BY HASH ( partition_key ) PARTITIONS ( partition_count ) [ CONCURRENTLY ]
    PARTITION BY RANGE ( partition_key ) START FROM ( start_value ) INTERVAL ( value )
 [ CONCURRENTLY ]
    ADD PARTITION partition_name VALUES LESS THAN ( value )
 [ TABLESPACE tablespace_name ]
    DROP PARTITION partition_name
    MERGE PARTITIONS partition_name [, ... ] INTO PARTITION partition_name
 [ TABLESPACE tablespace_name ]
    MOVE PARTITION partition_name [ TABLESPACE tablespace_name ]
    RENAME PARTITION partition_name TO new_partition_name
    SET INTERVAL ( value )
    SPLIT PARTITION partition_name AT ( value ) [ INTO ( PARTITION left_partition
 [ TABLESPACE tablespace_name1 ], PARTITION right_partition
 [ TABLESPACE tablespace_name2 ] ) ]

and column_constraint is:

[ CONSTRAINT constraint_name ]
{ NOT NULL |
  NULL |
  CHECK ( expression ) [ NO INHERIT ] |
  DEFAULT default_expr |
  GENERATED ALWAYS AS ( generation_expr ) STORED |
  GENERATED { ALWAYS | BY DEFAULT } AS IDENTITY [ ( sequence_options ) ] |
  UNIQUE index_parameters |
  PRIMARY KEY index_parameters |
  REFERENCES reftable [ ( refcolumn ) ] [ MATCH FULL | MATCH PARTIAL | MATCH SIMPLE ]
```

```
    [ ON DELETE referential_action ] [ ON UPDATE referential_action ] }
[ DEFERRABLE | NOT DEFERRABLE ] [ INITIALLY DEFERRED | INITIALLY IMMEDIATE ]

and table_constraint is:

[ CONSTRAINT constraint_name ]
{ CHECK ( expression ) [ NO INHERIT ] |
  UNIQUE ( column_name [, ... ] ) index_parameters |
  PRIMARY KEY ( column_name [, ... ] ) index_parameters |
  EXCLUDE [ USING index_method ] ( exclude_element WITH operator
 [, ... ] ) index_parameters [ WHERE ( predicate ) ] |
  FOREIGN KEY ( column_name [, ... ] ) REFERENCES reftable [ ( refcolumn [, ... ] ) ]
    [ MATCH FULL | MATCH PARTIAL | MATCH SIMPLE ] [ ON DELETE referential_action ] [ ON
 UPDATE referential_action ] }
[ DEFERRABLE | NOT DEFERRABLE ] [ INITIALLY DEFERRED | INITIALLY IMMEDIATE ]

and table_constraint_using_index is:

    [ CONSTRAINT constraint_name ]
    { UNIQUE | PRIMARY KEY } USING INDEX index_name
    [ DEFERRABLE | NOT DEFERRABLE ] [ INITIALLY DEFERRED | INITIALLY IMMEDIATE ]

index_parameters in UNIQUE, PRIMARY KEY, and EXCLUDE constraints are:

[ INCLUDE ( column_name [, ... ] ) ]
[ WITH ( storage_parameter [= value] [, ... ] ) ]
[ USING INDEX TABLESPACE tablespace_name ]

exclude_element in an EXCLUDE constraint is:

{ column_name | ( expression ) } [ COLLATE collation ] [ opclass [ ( opclass_parameter
 = value [, ... ] ) ] ] [ ASC | DESC ] [ NULLS { FIRST | LAST } ]
```

Description

`ALTER TABLE` changes the definition of an existing table. There are several subforms described below. Note that the lock level required may differ for each subform. An `ACCESS EXCLUSIVE` lock is acquired unless explicitly noted. When multiple subcommands are given, the lock acquired will be the strictest one required by any subcommand.

`ADD COLUMN [ IF NOT EXISTS ]`

This form adds a new column to the table, using the same syntax as `CREATE TABLE`. If `IF NOT EXISTS` is specified and a column already exists with this name, no error is thrown.

`DROP COLUMN [ IF EXISTS ]`

This form drops a column from a table. Indexes and table constraints involving the column will be automatically dropped as well. Multivariate statistics referencing the dropped column will also be removed if the removal of the column would cause the statistics to contain data for only a single column. You will need to say `CASCADE` if anything outside the table depends on the column, for example, foreign key references or views. If `IF EXISTS` is specified and the column does not exist, no error is thrown. In this case a notice is issued instead.

`SET DATA TYPE`

This form changes the type of a column of a table. Indexes and simple table constraints involving the column will be automatically converted to use the new column type by reparsing the originally supplied expression. The optional `COLLATE` clause specifies a collation for the new column; if omitted, the collation is the default for the new column type. The optional `USING` clause specifies how to compute the new column value from the old; if omitted, the default conversion is the same as an

assignment cast from old data type to new. A USING clause must be provided if there is no implicit or assignment cast from old to new type.

SET/DROP DEFAULT

These forms set or remove the default value for a column (where removal is equivalent to setting the default value to NULL). The new default value will only apply in subsequent INSERT or UPDATE commands; it does not cause rows already in the table to change.

SET/DROP NOT NULL

These forms change whether a column is marked to allow null values or to reject null values.

SET NOT NULL may only be applied to a column provided none of the records in the table contain a NULL value for the column. Ordinarily this is checked during the ALTER TABLE by scanning the entire table; however, if a valid CHECK constraint is found which proves no NULL can exist, then the table scan is skipped.

If this table is a partition, one cannot perform DROP NOT NULL on a column if it is marked NOT NULL in the parent table. To drop the NOT NULL constraint from all the partitions, perform DROP NOT NULL on the parent table. Even if there is no NOT NULL constraint on the parent, such a constraint can still be added to individual partitions, if desired; that is, the children can disallow nulls even if the parent allows them, but not the other way around.

DROP EXPRESSION [IF EXISTS]

This form turns a stored generated column into a normal base column. Existing data in the columns is retained, but future changes will no longer apply the generation expression.

If DROP EXPRESSION IF EXISTS is specified and the column is not a stored generated column, no error is thrown. In this case a notice is issued instead.

ADD GENERATED { ALWAYS | BY DEFAULT } AS IDENTITY
SET GENERATED { ALWAYS | BY DEFAULT }
DROP IDENTITY [IF EXISTS]

These forms change whether a column is an identity column or change the generation attribute of an existing identity column. See CREATE TABLE for details. Like SET DEFAULT, these forms only affect the behavior of subsequent INSERT and UPDATE commands; they do not cause rows already in the table to change.

If DROP IDENTITY IF EXISTS is specified and the column is not an identity column, no error is thrown. In this case a notice is issued instead.

SET *sequence_option*
RESTART

These forms alter the sequence that underlies an existing identity column. *sequence_option* is an option supported by ALTER SEQUENCE such as INCREMENT BY.

SET STATISTICS

This form sets the per-column statistics-gathering target for subsequent ANALYZE operations. The target can be set in the range 0 to 10000; alternatively, set it to -1 to revert to using the system default statistics target (default_statistics_target). For more information on the use of statistics by the Postgres Pro query planner, refer to Section 14.2.

SET STATISTICS acquires a SHARE UPDATE EXCLUSIVE lock.

SET (*attribute_option* = *value* [, ...])
RESET (*attribute_option* [, ...])

This form sets or resets per-attribute options. Currently, the only defined per-attribute options are n_distinct and n_distinct_inherited, which override the number-of-distinct-values estimates

made by subsequent ANALYZE operations. n_distinct affects the statistics for the table itself, while n_distinct_inherited affects the statistics gathered for the table plus its inheritance children. When set to a positive value, ANALYZE will assume that the column contains exactly the specified number of distinct nonnull values. When set to a negative value, which must be greater than or equal to -1, ANALYZE will assume that the number of distinct nonnull values in the column is linear in the size of the table; the exact count is to be computed by multiplying the estimated table size by the absolute value of the given number. For example, a value of -1 implies that all values in the column are distinct, while a value of -0.5 implies that each value appears twice on the average. This can be useful when the size of the table changes over time, since the multiplication by the number of rows in the table is not performed until query planning time. Specify a value of 0 to revert to estimating the number of distinct values normally. For more information on the use of statistics by the Postgres Pro query planner, refer to Section 14.2.

Changing per-attribute options acquires a SHARE UPDATE EXCLUSIVE lock.

SET STORAGE

This form sets the storage mode for a column. This controls whether this column is held inline or in a secondary TOAST table, and whether the data should be compressed or not. PLAIN must be used for fixed-length values such as integer and is inline, uncompressed. MAIN is for inline, compressible data. EXTERNAL is for external, uncompressed data, and EXTENDED is for external, compressed data. EXTENDED is the default for most data types that support non-PLAIN storage. Use of EXTERNAL will make substring operations on very large text and bytea values run faster, at the penalty of increased storage space. Note that SET STORAGE doesn't itself change anything in the table, it just sets the strategy to be pursued during future table updates. See Section 70.2 for more information.

SET COMPRESSION *compression_method*

This form sets the compression method for a column, determining how values inserted in future will be compressed (if the storage mode permits compression at all). This does not cause the table to be rewritten, so existing data may still be compressed with other compression methods. If the table is restored with pg_restore, then all values are rewritten with the configured compression method. However, when data is inserted from another relation (for example, by INSERT ... SELECT), values from the source table are not necessarily detoasted, so any previously compressed data may retain its existing compression method, rather than being recompressed with the compression method of the target column. The supported compression methods are pglz and lz4. (lz4 is available only if --with-lz4 was used when building Postgres Pro.) In addition, *compression_method* can be default, which selects the default behavior of consulting the default_toast_compression setting at the time of data insertion to determine the method to use.

ADD *table_constraint* [NOT VALID]

This form adds a new constraint to a table using the same constraint syntax as CREATE TABLE, plus the option NOT VALID, which is currently only allowed for foreign key and CHECK constraints.

Normally, this form will cause a scan of the table to verify that all existing rows in the table satisfy the new constraint. But if the NOT VALID option is used, this potentially-lengthy scan is skipped. The constraint will still be enforced against subsequent inserts or updates (that is, they'll fail unless there is a matching row in the referenced table, in the case of foreign keys, or they'll fail unless the new row matches the specified check condition). But the database will not assume that the constraint holds for all rows in the table, until it is validated by using the VALIDATE CONSTRAINT option. See Notes below for more information about using the NOT VALID option.

Although most forms of ADD *table_constraint* require an ACCESS EXCLUSIVE lock, ADD FOREIGN KEY requires only a SHARE ROW EXCLUSIVE lock. Note that ADD FOREIGN KEY also acquires a SHARE ROW EXCLUSIVE lock on the referenced table, in addition to the lock on the table on which the constraint is declared.

Additional restrictions apply when unique or primary key constraints are added to partitioned tables; see CREATE TABLE. Also, foreign key constraints on partitioned tables may not be declared NOT VALID at present.

`ADD` *`table_constraint_using_index`*

This form adds a new `PRIMARY KEY` or `UNIQUE` constraint to a table based on an existing unique index. All the columns of the index will be included in the constraint.

The index cannot have expression columns nor be a partial index. Also, it must be a b-tree index with default sort ordering. These restrictions ensure that the index is equivalent to one that would be built by a regular `ADD PRIMARY KEY` or `ADD UNIQUE` command.

If `PRIMARY KEY` is specified, and the index's columns are not already marked `NOT NULL`, then this command will attempt to do `ALTER COLUMN SET NOT NULL` against each such column. That requires a full table scan to verify the column(s) contain no nulls. In all other cases, this is a fast operation.

If a constraint name is provided then the index will be renamed to match the constraint name. Otherwise the constraint will be named the same as the index.

After this command is executed, the index is “owned” by the constraint, in the same way as if the index had been built by a regular `ADD PRIMARY KEY` or `ADD UNIQUE` command. In particular, dropping the constraint will make the index disappear too.

This form is not currently supported on partitioned tables.

> **Note**
>
> Adding a constraint using an existing index can be helpful in situations where a new constraint needs to be added without blocking table updates for a long time. To do that, create the index using `CREATE INDEX CONCURRENTLY`, and then install it as an official constraint using this syntax. See the example below.

`ALTER CONSTRAINT`

This form alters the attributes of a constraint that was previously created. Currently only foreign key constraints may be altered.

`VALIDATE CONSTRAINT`

This form validates a foreign key or check constraint that was previously created as `NOT VALID`, by scanning the table to ensure there are no rows for which the constraint is not satisfied. Nothing happens if the constraint is already marked valid. (See Notes below for an explanation of the usefulness of this command.)

This command acquires a `SHARE UPDATE EXCLUSIVE` lock.

`DROP CONSTRAINT [ IF EXISTS ]`

This form drops the specified constraint on a table, along with any index underlying the constraint. If `IF EXISTS` is specified and the constraint does not exist, no error is thrown. In this case a notice is issued instead.

`DISABLE/ENABLE [ REPLICA | ALWAYS ] TRIGGER`

These forms configure the firing of trigger(s) belonging to the table. A disabled trigger is still known to the system, but is not executed when its triggering event occurs. For a deferred trigger, the enable status is checked when the event occurs, not when the trigger function is actually executed. One can disable or enable a single trigger specified by name, or all triggers on the table, or only user triggers (this option excludes internally generated constraint triggers such as those that are used to implement foreign key constraints or deferrable uniqueness and exclusion constraints). Disabling or enabling internally generated constraint triggers requires superuser privileges; it should be done with caution since of course the integrity of the constraint cannot be guaranteed if the triggers are not executed.

The trigger firing mechanism is also affected by the configuration variable session_replication_role. Simply enabled triggers (the default) will fire when the replication role is "origin" (the default) or "local". Triggers configured as `ENABLE REPLICA` will only fire if the session is in "replica" mode, and triggers configured as `ENABLE ALWAYS` will fire regardless of the current replication role.

The effect of this mechanism is that in the default configuration, triggers do not fire on replicas. This is useful because if a trigger is used on the origin to propagate data between tables, then the replication system will also replicate the propagated data, and the trigger should not fire a second time on the replica, because that would lead to duplication. However, if a trigger is used for another purpose such as creating external alerts, then it might be appropriate to set it to `ENABLE ALWAYS` so that it is also fired on replicas.

This command acquires a `SHARE ROW EXCLUSIVE` lock.

`DISABLE/ENABLE [ REPLICA | ALWAYS ] RULE`

These forms configure the firing of rewrite rules belonging to the table. A disabled rule is still known to the system, but is not applied during query rewriting. The semantics are as for disabled/enabled triggers. This configuration is ignored for `ON SELECT` rules, which are always applied in order to keep views working even if the current session is in a non-default replication role.

The rule firing mechanism is also affected by the configuration variable session_replication_role, analogous to triggers as described above.

`DISABLE/ENABLE ROW LEVEL SECURITY`

These forms control the application of row security policies belonging to the table. If enabled and no policies exist for the table, then a default-deny policy is applied. Note that policies can exist for a table even if row-level security is disabled. In this case, the policies will *not* be applied and the policies will be ignored. See also `CREATE POLICY`.

`NO FORCE/FORCE ROW LEVEL SECURITY`

These forms control the application of row security policies belonging to the table when the user is the table owner. If enabled, row-level security policies will be applied when the user is the table owner. If disabled (the default) then row-level security will not be applied when the user is the table owner. See also `CREATE POLICY`.

`CLUSTER ON`

This form selects the default index for future `CLUSTER` operations. It does not actually re-cluster the table.

Changing cluster options acquires a `SHARE UPDATE EXCLUSIVE` lock.

`SET WITHOUT CLUSTER`

This form removes the most recently used `CLUSTER` index specification from the table. This affects future cluster operations that don't specify an index.

Changing cluster options acquires a `SHARE UPDATE EXCLUSIVE` lock.

`SET WITHOUT OIDS`

Backward-compatible syntax for removing the `oid` system column. As `oid` system columns cannot be added anymore, this never has an effect.

`SET TABLESPACE`

This form changes the table's tablespace to the specified tablespace and moves the data file(s) associated with the table to the new tablespace. Indexes on the table, if any, are not moved; but they can be moved separately with additional `SET TABLESPACE` commands. When applied to a partitioned

table, nothing is moved, but any partitions created afterwards with CREATE TABLE PARTITION OF will use that tablespace, unless overridden by a TABLESPACE clause.

All tables in the current database in a tablespace can be moved by using the ALL IN TABLESPACE form, which will lock all tables to be moved first and then move each one. This form also supports OWNED BY, which will only move tables owned by the roles specified. If the NOWAIT option is specified then the command will fail if it is unable to acquire all of the locks required immediately. Note that system catalogs are not moved by this command; use ALTER DATABASE or explicit ALTER TABLE invocations instead if desired. The information_schema relations are not considered part of the system catalogs and will be moved. See also CREATE TABLESPACE.

SET { LOGGED | UNLOGGED }

This form changes the table from unlogged to logged or vice-versa (see UNLOGGED). It cannot be applied to a temporary table.

SET CONSTANT

This form changes the table into read-only mode. No data can be modified or added to constant tables, and they are not processed by autovacuum. Constant tables cannot be changed back to read-write mode.

SET (*storage_parameter* [= *value*] [, ...])

This form changes one or more storage parameters for the table. See Storage Parameters in the CREATE TABLE documentation for details on the available parameters. Note that the table contents will not be modified immediately by this command; depending on the parameter you might need to rewrite the table to get the desired effects. That can be done with VACUUM FULL, CLUSTER or one of the forms of ALTER TABLE that forces a table rewrite. For planner related parameters, changes will take effect from the next time the table is locked so currently executing queries will not be affected.

SHARE UPDATE EXCLUSIVE lock will be taken for fillfactor, toast and autovacuum storage parameters, as well as the planner parameter parallel_workers.

RESET (*storage_parameter* [, ...])

This form resets one or more storage parameters to their defaults. As with SET, a table rewrite might be needed to update the table entirely.

INHERIT *parent_table*

This form adds the target table as a new child of the specified parent table. Subsequently, queries against the parent will include records of the target table. To be added as a child, the target table must already contain all the same columns as the parent (it could have additional columns, too). The columns must have matching data types, and if they have NOT NULL constraints in the parent then they must also have NOT NULL constraints in the child.

There must also be matching child-table constraints for all CHECK constraints of the parent, except those marked non-inheritable (that is, created with ALTER TABLE ... ADD CONSTRAINT ... NO INHERIT) in the parent, which are ignored; all child-table constraints matched must not be marked non-inheritable. Currently UNIQUE, PRIMARY KEY, and FOREIGN KEY constraints are not considered, but this might change in the future.

NO INHERIT *parent_table*

This form removes the target table from the list of children of the specified parent table. Queries against the parent table will no longer include records drawn from the target table.

OF *type_name*

This form links the table to a composite type as though CREATE TABLE OF had formed it. The table's list of column names and types must precisely match that of the composite type. The table must

not inherit from any other table. These restrictions ensure that `CREATE TABLE OF` would permit an equivalent table definition.

`NOT OF`

This form dissociates a typed table from its type.

`OWNER TO`

This form changes the owner of the table, sequence, view, materialized view, or foreign table to the specified user.

`REPLICA IDENTITY`

This form changes the information which is written to the write-ahead log to identify rows which are updated or deleted. In most cases, the old value of each column is only logged if it differs from the new value; however, if the old value is stored externally, it is always logged regardless of whether it changed. This option has no effect except when logical replication is in use.

`DEFAULT`

Records the old values of the columns of the primary key, if any. This is the default for non-system tables.

`USING INDEX` *`index_name`*

Records the old values of the columns covered by the named index, that must be unique, not partial, not deferrable, and include only columns marked `NOT NULL`. If this index is dropped, the behavior is the same as `NOTHING`.

`FULL`

Records the old values of all columns in the row.

`NOTHING`

Records no information about the old row. This is the default for system tables.

`RENAME`

The `RENAME` forms change the name of a table (or an index, sequence, view, materialized view, or foreign table), the name of an individual column in a table, or the name of a constraint of the table. When renaming a constraint that has an underlying index, the index is renamed as well. There is no effect on the stored data.

`SET SCHEMA`

This form moves the table into another schema. Associated indexes, constraints, and sequences owned by table columns are moved as well.

`ATTACH PARTITION` *`partition_name`* `{ FOR VALUES` *`partition_bound_spec`* `| DEFAULT }`

This form attaches an existing table (which might itself be partitioned) as a partition of the target table. The table can be attached as a partition for specific values using `FOR VALUES` or as a default partition by using `DEFAULT`. For each index in the target table, a corresponding one will be created in the attached table; or, if an equivalent index already exists, it will be attached to the target table's index, as if `ALTER INDEX ATTACH PARTITION` had been executed. Note that if the existing table is a foreign table, it is currently not allowed to attach the table as a partition of the target table if there are `UNIQUE` indexes on the target table. (See also CREATE FOREIGN TABLE.) For each user-defined row-level trigger that exists in the target table, a corresponding one is created in the attached table.

A partition using `FOR VALUES` uses same syntax for *`partition_bound_spec`* as `CREATE TABLE`. The partition bound specification must correspond to the partitioning strategy and partition key of the target table. The table to be attached must have all the same columns as the target table and no

more; moreover, the column types must also match. Also, it must have all the NOT NULL and CHECK constraints of the target table, not marked NO INHERIT. Currently FOREIGN KEY constraints are not considered. UNIQUE and PRIMARY KEY constraints from the parent table will be created in the partition, if they don't already exist.

If the new partition is a regular table, a full table scan is performed to check that existing rows in the table do not violate the partition constraint. It is possible to avoid this scan by adding a valid CHECK constraint to the table that allows only rows satisfying the desired partition constraint before running this command. The CHECK constraint will be used to determine that the table need not be scanned to validate the partition constraint. This does not work, however, if any of the partition keys is an expression and the partition does not accept NULL values. If attaching a list partition that will not accept NULL values, also add a NOT NULL constraint to the partition key column, unless it's an expression.

If the new partition is a foreign table, nothing is done to verify that all the rows in the foreign table obey the partition constraint. (See the discussion in CREATE FOREIGN TABLE about constraints on the foreign table.)

When a table has a default partition, defining a new partition changes the partition constraint for the default partition. The default partition can't contain any rows that would need to be moved to the new partition, and will be scanned to verify that none are present. This scan, like the scan of the new partition, can be avoided if an appropriate CHECK constraint is present. Also like the scan of the new partition, it is always skipped when the default partition is a foreign table.

Attaching a partition acquires a SHARE UPDATE EXCLUSIVE lock on the parent table, in addition to the ACCESS EXCLUSIVE locks on the table being attached and on the default partition (if any).

Further locks must also be held on all sub-partitions if the table being attached is itself a partitioned table. Likewise if the default partition is itself a partitioned table. The locking of the sub-partitions can be avoided by adding a CHECK constraint as described in Section 5.11.2.2.

This form is not supported by pg_pathman.

DETACH PARTITION *partition_name* [CONCURRENTLY | FINALIZE]

This form detaches the specified partition of the target table. The detached partition continues to exist as a standalone table, but no longer has any ties to the table from which it was detached. Any indexes that were attached to the target table's indexes are detached. Any triggers that were created as clones of those in the target table are removed. SHARE lock is obtained on any tables that reference this partitioned table in foreign key constraints.

If CONCURRENTLY is specified, it runs using a reduced lock level to avoid blocking other sessions that might be accessing the partitioned table. In this mode, two transactions are used internally. During the first transaction, a SHARE UPDATE EXCLUSIVE lock is taken on both parent table and partition, and the partition is marked as undergoing detach; at that point, the transaction is committed and all other transactions using the partitioned table are waited for. Once all those transactions have completed, the second transaction acquires SHARE UPDATE EXCLUSIVE on the partitioned table and ACCESS EXCLUSIVE on the partition, and the detach process completes. A CHECK constraint that duplicates the partition constraint is added to the partition. CONCURRENTLY cannot be run in a transaction block and is not allowed if the partitioned table contains a default partition.

If FINALIZE is specified, a previous DETACH CONCURRENTLY invocation that was canceled or interrupted is completed. At most one partition in a partitioned table can be pending detach at a time.

This form is not supported by pg_pathman.

pg_pathman Actions

The pg_pathman extension of Postgres Pro Enterprise provides several forms for creating and managing table partitions. These forms will not work for tables partitioned using the core partitioning functionality.

For tables that are not yet partitioned, you can use the PARTITION BY form if the partition_backend parameter is set to pg_pathman. Other forms can only be used for tables already partitioned by pg_pathman and do not depend on the partition_backend setting.

Starting from Postgres Pro 12, using pg_pathman is not recommended.

PARTITION BY *pg_pathman_partitioning_clause*

This form splits the created table into partitions based on the specified partitioning clause. You can also apply this form to partitions created by pg_pathman to perform multilevel partitioning. The *pg_pathman_partitioning_clause* can be one of the following:

HASH (*partition_key*) PARTITIONS (*partition_count*) [CONCURRENTLY]

Split the table into the specified number of partitions based on the hash function. You can specify a column name or an expression to use as the *partition_key*.

RANGE (*partition_key*) START FROM (*start_value*) INTERVAL (*value*) [CONCURRENTLY]

Split the table into partitions by range. You can specify a column name or an expression to use as the *partition_key*. The START FROM clause specifies the lower bound of the first partition, and the INTERVAL clause sets the interval at which to create new partitions. The *start_value* must not be greater than the smallest value in the partition key column and must match the partition key by type. The value defining the interval must also be of the same type.

If you specify the optional CONCURRENTLY clause, pg_pathman first creates empty partitions and then migrates the data to partitions in batches of 1000 rows to avoid locks.

ADD PARTITION *partition_name* VALUES LESS THAN (*value*)

This form adds a new partition to a range-partitioned table. The VALUES LESS THAN clause specifies the range of values to include into a single partition. The specified *value* is excluded from the created partition.

DROP PARTITION *partition_name*

This form deletes the specified partition.

MERGE PARTITIONS *partition_name* [, ...] INTO PARTITION *partition_name* [TABLESPACE *tablespace_name*]

This form merges two or more adjacent range partitions into one.

MOVE PARTITION *partition_name* TABLESPACE *tablespace_name*

This form moves the partition to the specified tablespace.

RENAME PARTITION *partition_name* TO *new_partition_name*

This form renames a partition.

SET INTERVAL (*value*)

This form specifies the partitioning interval to use when creating new range partitions. This form only works for already partitioned tables.

SPLIT PARTITION *partition_name* AT (*value*) [INTO (PARTITION *left_partition* [TABLESPACE *tablespace_name1*], PARTITION *right_partition* [TABLESPACE *tablespace_name2*])]

This form splits the specified range partition into two based on the value provided in the AT clause. This value serves as the lower bound of the right partition. If you omit the INTO clause when splitting partitions, the left partition will use the parent name, and the right partition name will be generated automatically.

All the forms of ALTER TABLE that act on a single table, except RENAME, SET SCHEMA, ATTACH PARTITION, DETACH PARTITION, and all the pg_pathman forms can be combined into a list of multiple alterations to be applied together. For example, it is possible to add several columns and/or alter the type of several columns in a single command. This is particularly useful with large tables, since only one pass over the table need be made.

You must own the table to use ALTER TABLE. To change the schema or tablespace of a table, you must also have CREATE privilege on the new schema or tablespace. To add the table as a new child of a parent table, you must own the parent table as well. Also, to attach a table as a new partition of the table, you must own the table being attached. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have CREATE privilege on the table's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the table. However, a superuser can alter ownership of any table anyway.) To add a column or alter a column type or use the OF clause, you must also have USAGE privilege on the data type.

Parameters

IF EXISTS

Do not throw an error if the table does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an existing table to alter. If ONLY is specified before the table name, only that table is altered. If ONLY is not specified, the table and all its descendant tables (if any) are altered. Optionally, * can be specified after the table name to explicitly indicate that descendant tables are included.

column_name

Name of a new or existing column.

new_column_name

New name for an existing column.

new_name

New name for the table.

data_type

Data type of the new column, or new data type for an existing column.

table_constraint

New table constraint for the table.

constraint_name

Name of a new or existing constraint.

CASCADE

Automatically drop objects that depend on the dropped column or constraint (for example, views referencing the column), and in turn all objects that depend on those objects (see Section 5.14).

RESTRICT

Refuse to drop the column or constraint if there are any dependent objects. This is the default behavior.

trigger_name

Name of a single trigger to disable or enable.

`ALL`

Disable or enable all triggers belonging to the table. (This requires superuser privilege if any of the triggers are internally generated constraint triggers such as those that are used to implement foreign key constraints or deferrable uniqueness and exclusion constraints.)

`USER`

Disable or enable all triggers belonging to the table except for internally generated constraint triggers such as those that are used to implement foreign key constraints or deferrable uniqueness and exclusion constraints.

`index_name`

The name of an existing index.

`storage_parameter`

The name of a table storage parameter.

`value`

The new value for a table storage parameter. This might be a number or a word depending on the parameter.

`parent_table`

A parent table to associate or de-associate with this table.

`new_owner`

The user name of the new owner of the table.

`new_tablespace`

The name of the tablespace to which the table will be moved.

`new_schema`

The name of the schema to which the table will be moved.

`partition_name`

The name of the table to attach as a new partition or to detach from this table.

`partition_bound_spec`

The partition bound specification for a new partition. Refer to CREATE TABLE for more details on the syntax of the same.

Notes

The key word `COLUMN` is noise and can be omitted.

When a column is added with `ADD COLUMN` and a non-volatile `DEFAULT` is specified, the default is evaluated at the time of the statement and the result stored in the table's metadata. That value will be used for the column for all existing rows. If no `DEFAULT` is specified, NULL is used. In neither case is a rewrite of the table required.

Adding a column with a volatile `DEFAULT` or changing the type of an existing column will require the entire table and its indexes to be rewritten. As an exception, when changing the type of an existing column, if the `USING` clause does not change the column contents and the old type is either binary coercible to the new type or an unconstrained domain over the new type, a table rewrite is not needed; but any indexes on the affected columns must still be rebuilt. Table and/or index rebuilds may take a significant amount of time for a large table; and will temporarily require as much as double the disk space.

Adding a CHECK or NOT NULL constraint requires scanning the table to verify that existing rows meet the constraint, but does not require a table rewrite.

Similarly, when attaching a new partition it may be scanned to verify that existing rows meet the partition constraint.

The main reason for providing the option to specify multiple changes in a single ALTER TABLE is that multiple table scans or rewrites can thereby be combined into a single pass over the table.

Scanning a large table to verify a new foreign key or check constraint can take a long time, and other updates to the table are locked out until the ALTER TABLE ADD CONSTRAINT command is committed. The main purpose of the NOT VALID constraint option is to reduce the impact of adding a constraint on concurrent updates. With NOT VALID, the ADD CONSTRAINT command does not scan the table and can be committed immediately. After that, a VALIDATE CONSTRAINT command can be issued to verify that existing rows satisfy the constraint. The validation step does not need to lock out concurrent updates, since it knows that other transactions will be enforcing the constraint for rows that they insert or update; only pre-existing rows need to be checked. Hence, validation acquires only a SHARE UPDATE EXCLUSIVE lock on the table being altered. (If the constraint is a foreign key then a ROW SHARE lock is also required on the table referenced by the constraint.) In addition to improving concurrency, it can be useful to use NOT VALID and VALIDATE CONSTRAINT in cases where the table is known to contain pre-existing violations. Once the constraint is in place, no new violations can be inserted, and the existing problems can be corrected at leisure until VALIDATE CONSTRAINT finally succeeds.

The DROP COLUMN form does not physically remove the column, but simply makes it invisible to SQL operations. Subsequent insert and update operations in the table will store a null value for the column. Thus, dropping a column is quick but it will not immediately reduce the on-disk size of your table, as the space occupied by the dropped column is not reclaimed. The space will be reclaimed over time as existing rows are updated.

To force immediate reclamation of space occupied by a dropped column, you can execute one of the forms of ALTER TABLE that performs a rewrite of the whole table. This results in reconstructing each row with the dropped column replaced by a null value.

The rewriting forms of ALTER TABLE are not MVCC-safe. After a table rewrite, the table will appear empty to concurrent transactions, if they are using a snapshot taken before the rewrite occurred. See Section 13.5 for more details.

The USING option of SET DATA TYPE can actually specify any expression involving the old values of the row; that is, it can refer to other columns as well as the one being converted. This allows very general conversions to be done with the SET DATA TYPE syntax. Because of this flexibility, the USING expression is not applied to the column's default value (if any); the result might not be a constant expression as required for a default. This means that when there is no implicit or assignment cast from old to new type, SET DATA TYPE might fail to convert the default even though a USING clause is supplied. In such cases, drop the default with DROP DEFAULT, perform the ALTER TYPE, and then use SET DEFAULT to add a suitable new default. Similar considerations apply to indexes and constraints involving the column.

If a table has any descendant tables, it is not permitted to add, rename, or change the type of a column in the parent table without doing the same to the descendants. This ensures that the descendants always have columns matching the parent. Similarly, a CHECK constraint cannot be renamed in the parent without also renaming it in all descendants, so that CHECK constraints also match between the parent and its descendants. (That restriction does not apply to index-based constraints, however.) Also, because selecting from the parent also selects from its descendants, a constraint on the parent cannot be marked valid unless it is also marked valid for those descendants. In all of these cases, ALTER TABLE ONLY will be rejected.

A recursive DROP COLUMN operation will remove a descendant table's column only if the descendant does not inherit that column from any other parents and never had an independent definition of the column. A nonrecursive DROP COLUMN (i.e., ALTER TABLE ONLY ... DROP COLUMN) never removes any descendant columns, but instead marks them as independently defined rather than inherited. A nonrecursive DROP

`COLUMN` command will fail for a partitioned table, because all partitions of a table must have the same columns as the partitioning root.

The actions for identity columns (`ADD GENERATED`, `SET` etc., `DROP IDENTITY`), as well as the actions `TRIGGER`, `CLUSTER`, `OWNER`, and `TABLESPACE` never recurse to descendant tables; that is, they always act as though `ONLY` were specified. Adding a constraint recurses only for `CHECK` constraints that are not marked `NO INHERIT`.

Changing any part of a system catalog table is not permitted.

Refer to CREATE TABLE for a further description of valid parameters. Chapter 5 has further information on inheritance.

Examples

To add a column of type `varchar` to a table:

```
ALTER TABLE distributors ADD COLUMN address varchar(30);
```

That will cause all existing rows in the table to be filled with null values for the new column.

To add a column with a non-null default:

```
ALTER TABLE measurements
  ADD COLUMN mtime timestamp with time zone DEFAULT now();
```

Existing rows will be filled with the current time as the value of the new column, and then new rows will receive the time of their insertion.

To add a column and fill it with a value different from the default to be used later:

```
ALTER TABLE transactions
  ADD COLUMN status varchar(30) DEFAULT 'old',
  ALTER COLUMN status SET default 'current';
```

Existing rows will be filled with `old`, but then the default for subsequent commands will be `current`. The effects are the same as if the two sub-commands had been issued in separate `ALTER TABLE` commands.

To drop a column from a table:

```
ALTER TABLE distributors DROP COLUMN address RESTRICT;
```

To change the types of two existing columns in one operation:

```
ALTER TABLE distributors
    ALTER COLUMN address TYPE varchar(80),
    ALTER COLUMN name TYPE varchar(100);
```

To change an integer column containing Unix timestamps to `timestamp with time zone` via a `USING` clause:

```
ALTER TABLE foo
    ALTER COLUMN foo_timestamp SET DATA TYPE timestamp with time zone
    USING
        timestamp with time zone 'epoch' + foo_timestamp * interval '1 second';
```

The same, when the column has a default expression that won't automatically cast to the new data type:

```
ALTER TABLE foo
    ALTER COLUMN foo_timestamp DROP DEFAULT,
    ALTER COLUMN foo_timestamp TYPE timestamp with time zone
    USING
        timestamp with time zone 'epoch' + foo_timestamp * interval '1 second',
    ALTER COLUMN foo_timestamp SET DEFAULT now();
```

To rename an existing column:

```
ALTER TABLE distributors RENAME COLUMN address TO city;
```

To rename an existing table:

```
ALTER TABLE distributors RENAME TO suppliers;
```

To rename an existing constraint:

```
ALTER TABLE distributors RENAME CONSTRAINT zipchk TO zip_check;
```

To add a not-null constraint to a column:

```
ALTER TABLE distributors ALTER COLUMN street SET NOT NULL;
```

To remove a not-null constraint from a column:

```
ALTER TABLE distributors ALTER COLUMN street DROP NOT NULL;
```

To add a check constraint to a table and all its children:

```
ALTER TABLE distributors ADD CONSTRAINT zipchk CHECK (char_length(zipcode) = 5);
```

To add a check constraint only to a table and not to its children:

```
ALTER TABLE distributors ADD CONSTRAINT zipchk CHECK (char_length(zipcode) = 5) NO
 INHERIT;
```

(The check constraint will not be inherited by future children, either.)

To remove a check constraint from a table and all its children:

```
ALTER TABLE distributors DROP CONSTRAINT zipchk;
```

To remove a check constraint from one table only:

```
ALTER TABLE ONLY distributors DROP CONSTRAINT zipchk;
```

(The check constraint remains in place for any child tables.)

To add a foreign key constraint to a table:

```
ALTER TABLE distributors ADD CONSTRAINT distfk FOREIGN KEY (address) REFERENCES
 addresses (address);
```

To add a foreign key constraint to a table with the least impact on other work:

```
ALTER TABLE distributors ADD CONSTRAINT distfk FOREIGN KEY (address) REFERENCES
 addresses (address) NOT VALID;
ALTER TABLE distributors VALIDATE CONSTRAINT distfk;
```

To add a (multicolumn) unique constraint to a table:

```
ALTER TABLE distributors ADD CONSTRAINT dist_id_zipcode_key UNIQUE (dist_id, zipcode);
```

To add an automatically named primary key constraint to a table, noting that a table can only ever have one primary key:

```
ALTER TABLE distributors ADD PRIMARY KEY (dist_id);
```

To move a table to a different tablespace:

```
ALTER TABLE distributors SET TABLESPACE fasttablespace;
```

To move a table to a different schema:

```
ALTER TABLE myschema.distributors SET SCHEMA yourschema;
```

To recreate a primary key constraint, without blocking updates while the index is rebuilt:

```
CREATE UNIQUE INDEX CONCURRENTLY dist_id_temp_idx ON distributors (dist_id);
ALTER TABLE distributors DROP CONSTRAINT distributors_pkey,
    ADD CONSTRAINT distributors_pkey PRIMARY KEY USING INDEX dist_id_temp_idx;
```

To attach a partition to a range-partitioned table:

```
ALTER TABLE measurement
    ATTACH PARTITION measurement_y2016m07 FOR VALUES FROM ('2016-07-01') TO
 ('2016-08-01');
```

To attach a partition to a list-partitioned table:

```
ALTER TABLE cities
    ATTACH PARTITION cities_ab FOR VALUES IN ('a', 'b');
```

To attach a partition to a hash-partitioned table:

```
ALTER TABLE orders
    ATTACH PARTITION orders_p4 FOR VALUES WITH (MODULUS 4, REMAINDER 3);
```

To attach a default partition to a partitioned table:

```
ALTER TABLE cities
    ATTACH PARTITION cities_partdef DEFAULT;
```

To detach a partition from a partitioned table:

```
ALTER TABLE measurement
    DETACH PARTITION measurement_y2015m12;
```

Partition an existing table by range with interval 100 using `pg_pathman`, and then split the `journal_1` partition into two:

```
ALTER TABLE journal
    PARTITION BY RANGE(id)
    START FROM (0)
    INTERVAL (100);
```

```
ALTER TABLE journal
    SPLIT PARTITION journal_1
    AT (50)
    INTO (PARTITION journal_050, PARTITION journal_100);
```

Add a new partition to the `journal` table partitioned by range using `pg_pathman`:

```
ALTER TABLE journal
    ADD PARTITION journal_300
    VALUES LESS THAN (300);
```

Merge two adjacent partitions of the `journal` table into one:

```
ALTER TABLE journal
    MERGE PARTITIONS journal_050 INTO PARTITION journal_100;
```

Partition an existing table by hash using `pg_pathman`:

```
ALTER TABLE journal
    PARTITION BY HASH PARTITIONS (3);
```

Compatibility

The forms `ADD` (without `USING INDEX`), `DROP [COLUMN]`, `DROP IDENTITY`, `RESTART`, `SET DEFAULT`, `SET DATA TYPE` (without `USING`), `SET GENERATED`, and `SET` *`sequence_option`* conform with the SQL standard. The other forms are Postgres Pro extensions of the SQL standard. Also, the ability to specify more than one manipulation in a single `ALTER TABLE` command is an extension.

`ALTER TABLE DROP COLUMN` can be used to drop the only column of a table, leaving a zero-column table. This is an extension of SQL, which disallows zero-column tables.

See Also

CREATE TABLE

ALTER TABLESPACE

ALTER TABLESPACE — change the definition of a tablespace

Synopsis

```
ALTER TABLESPACE name RENAME TO new_name
ALTER TABLESPACE name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER TABLESPACE name SET ( tablespace_option = value [, ... ] )
ALTER TABLESPACE name RESET ( tablespace_option [, ... ] )
```

Description

`ALTER TABLESPACE` can be used to change the definition of a tablespace.

You must own the tablespace to change the definition of a tablespace. To alter the owner, you must also be a direct or indirect member of the new owning role. (Note that superusers have these privileges automatically.)

Parameters

name

The name of an existing tablespace.

new_name

The new name of the tablespace. The new name cannot begin with `pg_`, as such names are reserved for system tablespaces.

new_owner

The new owner of the tablespace.

tablespace_option

A tablespace parameter to be set or reset. Currently, the only available parameters are `seq_page_cost`, `random_page_cost`, `effective_io_concurrency` and `maintenance_io_concurrency`. Setting these values for a particular tablespace will override the planner's usual estimate of the cost of reading pages from tables in that tablespace, and the executor's prefetching behavior, as established by the configuration parameters of the same name (see seq_page_cost, random_page_cost, effective_io_concurrency, maintenance_io_concurrency). This may be useful if one tablespace is located on a disk which is faster or slower than the remainder of the I/O subsystem.

Examples

Rename tablespace `index_space` to `fast_raid`:

```
ALTER TABLESPACE index_space RENAME TO fast_raid;
```

Change the owner of tablespace `index_space`:

```
ALTER TABLESPACE index_space OWNER TO mary;
```

Compatibility

There is no `ALTER TABLESPACE` statement in the SQL standard.

See Also

CREATE TABLESPACE, DROP TABLESPACE

ALTER TEXT SEARCH CONFIGURATION

ALTER TEXT SEARCH CONFIGURATION — change the definition of a text search configuration

Synopsis

```
ALTER TEXT SEARCH CONFIGURATION name
    ADD MAPPING FOR token_type [, ... ] WITH dictionary_name [, ... ]
ALTER TEXT SEARCH CONFIGURATION name
    ALTER MAPPING FOR token_type [, ... ] WITH dictionary_name [, ... ]
ALTER TEXT SEARCH CONFIGURATION name
    ALTER MAPPING REPLACE old_dictionary WITH new_dictionary
ALTER TEXT SEARCH CONFIGURATION name
    ALTER MAPPING FOR token_type [, ... ] REPLACE old_dictionary WITH new_dictionary
ALTER TEXT SEARCH CONFIGURATION name
    DROP MAPPING [ IF EXISTS ] FOR token_type [, ... ]
ALTER TEXT SEARCH CONFIGURATION name RENAME TO new_name
ALTER TEXT SEARCH CONFIGURATION name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER
 | SESSION_USER }
ALTER TEXT SEARCH CONFIGURATION name SET SCHEMA new_schema
```

Description

`ALTER TEXT SEARCH CONFIGURATION` changes the definition of a text search configuration. You can modify its mappings from token types to dictionaries, or change the configuration's name or owner.

You must be the owner of the configuration to use `ALTER TEXT SEARCH CONFIGURATION`.

Parameters

name

The name (optionally schema-qualified) of an existing text search configuration.

token_type

The name of a token type that is emitted by the configuration's parser.

dictionary_name

The name of a text search dictionary to be consulted for the specified token type(s). If multiple dictionaries are listed, they are consulted in the specified order.

old_dictionary

The name of a text search dictionary to be replaced in the mapping.

new_dictionary

The name of a text search dictionary to be substituted for *old_dictionary*.

new_name

The new name of the text search configuration.

new_owner

The new owner of the text search configuration.

new_schema

The new schema for the text search configuration.

The ADD MAPPING FOR form installs a list of dictionaries to be consulted for the specified token type(s); it is an error if there is already a mapping for any of the token types. The ALTER MAPPING FOR form does the same, but first removing any existing mapping for those token types. The ALTER MAPPING REPLACE forms substitute *new_dictionary* for *old_dictionary* anywhere the latter appears. This is done for only the specified token types when FOR appears, or for all mappings of the configuration when it doesn't. The DROP MAPPING form removes all dictionaries for the specified token type(s), causing tokens of those types to be ignored by the text search configuration. It is an error if there is no mapping for the token types, unless IF EXISTS appears.

Examples

The following example replaces the english dictionary with the swedish dictionary anywhere that english is used within my_config.

```
ALTER TEXT SEARCH CONFIGURATION my_config
  ALTER MAPPING REPLACE english WITH swedish;
```

Compatibility

There is no ALTER TEXT SEARCH CONFIGURATION statement in the SQL standard.

See Also

CREATE TEXT SEARCH CONFIGURATION, DROP TEXT SEARCH CONFIGURATION

ALTER TEXT SEARCH DICTIONARY

ALTER TEXT SEARCH DICTIONARY — change the definition of a text search dictionary

Synopsis

```
ALTER TEXT SEARCH DICTIONARY name (
    option [ = value ] [, ... ]
)
ALTER TEXT SEARCH DICTIONARY name RENAME TO new_name
ALTER TEXT SEARCH DICTIONARY name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER TEXT SEARCH DICTIONARY name SET SCHEMA new_schema
```

Description

`ALTER TEXT SEARCH DICTIONARY` changes the definition of a text search dictionary. You can change the dictionary's template-specific options, or change the dictionary's name or owner.

You must be the owner of the dictionary to use `ALTER TEXT SEARCH DICTIONARY`.

Parameters

name

The name (optionally schema-qualified) of an existing text search dictionary.

option

The name of a template-specific option to be set for this dictionary.

value

The new value to use for a template-specific option. If the equal sign and value are omitted, then any previous setting for the option is removed from the dictionary, allowing the default to be used.

new_name

The new name of the text search dictionary.

new_owner

The new owner of the text search dictionary.

new_schema

The new schema for the text search dictionary.

Template-specific options can appear in any order.

Examples

The following example command changes the stopword list for a Snowball-based dictionary. Other parameters remain unchanged.

```
ALTER TEXT SEARCH DICTIONARY my_dict ( StopWords = newrussian );
```

The following example command changes the language option to `dutch`, and removes the stopword option entirely.

```
ALTER TEXT SEARCH DICTIONARY my_dict ( language = dutch, StopWords );
```

The following example command “updates” the dictionary's definition without actually changing anything.

```
ALTER TEXT SEARCH DICTIONARY my_dict ( dummy );
```

(The reason this works is that the option removal code doesn't complain if there is no such option.) This trick is useful when changing configuration files for the dictionary: the `ALTER` will force existing database sessions to re-read the configuration files, which otherwise they would never do if they had read them earlier.

Compatibility

There is no `ALTER TEXT SEARCH DICTIONARY` statement in the SQL standard.

See Also

CREATE TEXT SEARCH DICTIONARY, DROP TEXT SEARCH DICTIONARY

ALTER TEXT SEARCH PARSER

ALTER TEXT SEARCH PARSER — change the definition of a text search parser

Synopsis

```
ALTER TEXT SEARCH PARSER name RENAME TO new_name
ALTER TEXT SEARCH PARSER name SET SCHEMA new_schema
```

Description

`ALTER TEXT SEARCH PARSER` changes the definition of a text search parser. Currently, the only supported functionality is to change the parser's name.

You must be a superuser to use `ALTER TEXT SEARCH PARSER`.

Parameters

name

The name (optionally schema-qualified) of an existing text search parser.

new_name

The new name of the text search parser.

new_schema

The new schema for the text search parser.

Compatibility

There is no `ALTER TEXT SEARCH PARSER` statement in the SQL standard.

See Also

CREATE TEXT SEARCH PARSER, DROP TEXT SEARCH PARSER

ALTER TEXT SEARCH TEMPLATE

ALTER TEXT SEARCH TEMPLATE — change the definition of a text search template

Synopsis

```
ALTER TEXT SEARCH TEMPLATE name RENAME TO new_name
ALTER TEXT SEARCH TEMPLATE name SET SCHEMA new_schema
```

Description

`ALTER TEXT SEARCH TEMPLATE` changes the definition of a text search template. Currently, the only supported functionality is to change the template's name.

You must be a superuser to use `ALTER TEXT SEARCH TEMPLATE`.

Parameters

name

The name (optionally schema-qualified) of an existing text search template.

new_name

The new name of the text search template.

new_schema

The new schema for the text search template.

Compatibility

There is no `ALTER TEXT SEARCH TEMPLATE` statement in the SQL standard.

See Also

CREATE TEXT SEARCH TEMPLATE, DROP TEXT SEARCH TEMPLATE

ALTER TRIGGER

ALTER TRIGGER — change the definition of a trigger

Synopsis

```
ALTER TRIGGER name ON table_name RENAME TO new_name
ALTER TRIGGER name ON table_name [ NO ] DEPENDS ON EXTENSION extension_name
```

Description

`ALTER TRIGGER` changes properties of an existing trigger. The `RENAME` clause changes the name of the given trigger without otherwise changing the trigger definition. The `DEPENDS ON EXTENSION` clause marks the trigger as dependent on an extension, such that if the extension is dropped, the trigger will automatically be dropped as well.

You must own the table on which the trigger acts to be allowed to change its properties.

Parameters

name

The name of an existing trigger to alter.

table_name

The name of the table on which this trigger acts.

new_name

The new name for the trigger.

extension_name

The name of the extension that the trigger is to depend on (or no longer dependent on, if `NO` is specified). A trigger that's marked as dependent on an extension is automatically dropped when the extension is dropped.

Notes

The ability to temporarily enable or disable a trigger is provided by `ALTER TABLE`, not by `ALTER TRIGGER`, because `ALTER TRIGGER` has no convenient way to express the option of enabling or disabling all of a table's triggers at once.

Examples

To rename an existing trigger:

```
ALTER TRIGGER emp_stamp ON emp RENAME TO emp_track_chgs;
```

To mark a trigger as being dependent on an extension:

```
ALTER TRIGGER emp_stamp ON emp DEPENDS ON EXTENSION emplib;
```

Compatibility

`ALTER TRIGGER` is a Postgres Pro extension of the SQL standard.

See Also

ALTER TABLE

ALTER TYPE

ALTER TYPE — change the definition of a type

Synopsis

```
ALTER TYPE name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
ALTER TYPE name RENAME TO new_name
ALTER TYPE name SET SCHEMA new_schema
ALTER TYPE name RENAME ATTRIBUTE attribute_name TO new_attribute_name [ CASCADE |
 RESTRICT ]
ALTER TYPE name action [, ... ]
ALTER TYPE name ADD VALUE [ IF NOT EXISTS ] new_enum_value [ { BEFORE |
 AFTER } neighbor_enum_value ]
ALTER TYPE name RENAME VALUE existing_enum_value TO new_enum_value
ALTER TYPE name SET ( property = value [, ... ] )

where action is one of:

    ADD ATTRIBUTE attribute_name data_type [ COLLATE collation ] [ CASCADE | RESTRICT ]
    DROP ATTRIBUTE [ IF EXISTS ] attribute_name [ CASCADE | RESTRICT ]
    ALTER ATTRIBUTE attribute_name [ SET DATA ] TYPE data_type [ COLLATE collation ]
 [ CASCADE | RESTRICT ]
```

Description

`ALTER TYPE` changes the definition of an existing type. There are several subforms:

`OWNER`

This form changes the owner of the type.

`RENAME`

This form changes the name of the type.

`SET SCHEMA`

This form moves the type into another schema.

`RENAME ATTRIBUTE`

This form is only usable with composite types. It changes the name of an individual attribute of the type.

`ADD ATTRIBUTE`

This form adds a new attribute to a composite type, using the same syntax as `CREATE TYPE`.

`DROP ATTRIBUTE [ IF EXISTS ]`

This form drops an attribute from a composite type. If `IF EXISTS` is specified and the attribute does not exist, no error is thrown. In this case a notice is issued instead.

`ALTER ATTRIBUTE ... SET DATA TYPE`

This form changes the type of an attribute of a composite type.

`ADD VALUE [ IF NOT EXISTS ] [ BEFORE | AFTER ]`

This form adds a new value to an enum type. The new value's place in the enum's ordering can be specified as being `BEFORE` or `AFTER` one of the existing values. Otherwise, the new item is added at the end of the list of values.

If IF NOT EXISTS is specified, it is not an error if the type already contains the new value: a notice is issued but no other action is taken. Otherwise, an error will occur if the new value is already present.

RENAME VALUE

This form renames a value of an enum type. The value's place in the enum's ordering is not affected. An error will occur if the specified value is not present or the new name is already present.

SET (*property* = *value* [, ...])

This form is only applicable to base types. It allows adjustment of a subset of the base-type properties that can be set in CREATE TYPE. Specifically, these properties can be changed:

- RECEIVE can be set to the name of a binary input function, or NONE to remove the type's binary input function. Using this option requires superuser privilege.
- SEND can be set to the name of a binary output function, or NONE to remove the type's binary output function. Using this option requires superuser privilege.
- TYPMOD_IN can be set to the name of a type modifier input function, or NONE to remove the type's type modifier input function. Using this option requires superuser privilege.
- TYPMOD_OUT can be set to the name of a type modifier output function, or NONE to remove the type's type modifier output function. Using this option requires superuser privilege.
- ANALYZE can be set to the name of a type-specific statistics collection function, or NONE to remove the type's statistics collection function. Using this option requires superuser privilege.
- SUBSCRIPT can be set to the name of a type-specific subscripting handler function, or NONE to remove the type's subscripting handler function. Using this option requires superuser privilege.
- STORAGEcan be set to plain, extended, external, or main (see Section 70.2 for more information about what these mean). However, changing from plain to another setting requires superuser privilege (because it requires that the type's C functions all be TOAST-ready), and changing to plain from another setting is not allowed at all (since the type may already have TOASTed values present in the database). Note that changing this option doesn't by itself change any stored data, it just sets the default TOAST strategy to be used for table columns created in the future. See ALTER TABLE to change the TOAST strategy for existing table columns.

See CREATE TYPE for more details about these type properties. Note that where appropriate, a change in these properties for a base type will be propagated automatically to domains based on that type.

The ADD ATTRIBUTE, DROP ATTRIBUTE, and ALTER ATTRIBUTE actions can be combined into a list of multiple alterations to apply in parallel. For example, it is possible to add several attributes and/or alter the type of several attributes in a single command.

You must own the type to use ALTER TYPE. To change the schema of a type, you must also have CREATE privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have CREATE privilege on the type's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the type. However, a superuser can alter ownership of any type anyway.) To add an attribute or alter an attribute type, you must also have USAGE privilege on the attribute's data type.

Parameters

name

The name (possibly schema-qualified) of an existing type to alter.

new_name

The new name for the type.

new_owner

The user name of the new owner of the type.

new_schema

The new schema for the type.

attribute_name

The name of the attribute to add, alter, or drop.

new_attribute_name

The new name of the attribute to be renamed.

data_type

The data type of the attribute to add, or the new type of the attribute to alter.

new_enum_value

The new value to be added to an enum type's list of values, or the new name to be given to an existing value. Like all enum literals, it needs to be quoted.

neighbor_enum_value

The existing enum value that the new value should be added immediately before or after in the enum type's sort ordering. Like all enum literals, it needs to be quoted.

existing_enum_value

The existing enum value that should be renamed. Like all enum literals, it needs to be quoted.

property

The name of a base-type property to be modified; see above for possible values.

CASCADE

Automatically propagate the operation to typed tables of the type being altered, and their descendants.

RESTRICT

Refuse the operation if the type being altered is the type of a typed table. This is the default.

Notes

If `ALTER TYPE ... ADD VALUE` (the form that adds a new value to an enum type) is executed inside a transaction block, the new value cannot be used until after the transaction has been committed.

Comparisons involving an added enum value will sometimes be slower than comparisons involving only original members of the enum type. This will usually only occur if `BEFORE` or `AFTER` is used to set the new value's sort position somewhere other than at the end of the list. However, sometimes it will happen even though the new value is added at the end (this occurs if the OID counter “wrapped around” since the original creation of the enum type). The slowdown is usually insignificant; but if it matters, optimal performance can be regained by dropping and recreating the enum type, or by dumping and restoring the database.

Examples

To rename a data type:

```
ALTER TYPE electronic_mail RENAME TO email;
```

To change the owner of the type `email` to `joe`:

```
ALTER TYPE email OWNER TO joe;
```

To change the schema of the type `email` to `customers`:

```
ALTER TYPE email SET SCHEMA customers;
```

To add a new attribute to a composite type:

```
ALTER TYPE compfoo ADD ATTRIBUTE f3 int;
```

To add a new value to an enum type in a particular sort position:

```
ALTER TYPE colors ADD VALUE 'orange' AFTER 'red';
```

To rename an enum value:

```
ALTER TYPE colors RENAME VALUE 'purple' TO 'mauve';
```

To create binary I/O functions for an existing base type:

```
CREATE FUNCTION mytypesend(mytype) RETURNS bytea ...;
CREATE FUNCTION mytyperecv(internal, oid, integer) RETURNS mytype ...;
ALTER TYPE mytype SET (
    SEND = mytypesend,
    RECEIVE = mytyperecv
);
```

Compatibility

The variants to add and drop attributes are part of the SQL standard; the other variants are Postgres Pro extensions.

See Also

CREATE TYPE, DROP TYPE

ALTER USER

ALTER USER — change a database role

Synopsis

```
ALTER USER role_specification [ WITH ] option [ ... ]

where option can be:

      SUPERUSER | NOSUPERUSER
    | CREATEDB | NOCREATEDB
    | CREATEROLE | NOCREATEROLE
    | INHERIT | NOINHERIT
    | LOGIN | NOLOGIN
    | REPLICATION | NOREPLICATION
    | BYPASSRLS | NOBYPASSRLS
    | CONNECTION LIMIT connlimit
    | [ ENCRYPTED ] PASSWORD 'password' | PASSWORD NULL
    | VALID UNTIL 'timestamp'
    | PROFILE profile_name
    | ACCOUNT UNLOCK | ACCOUNT LOCK

ALTER USER name RENAME TO new_name

ALTER USER { role_specification | ALL } [ IN DATABASE database_name ]
 SET configuration_parameter { TO | = } { value | DEFAULT }
ALTER USER { role_specification | ALL } [ IN DATABASE database_name ]
 SET configuration_parameter FROM CURRENT
ALTER USER { role_specification | ALL } [ IN DATABASE database_name ]
 RESET configuration_parameter
ALTER USER { role_specification | ALL } [ IN DATABASE database_name ] RESET ALL

where role_specification can be:

    role_name
  | CURRENT_ROLE
  | CURRENT_USER
  | SESSION_USER
```

Description

`ALTER USER` is now an alias for `ALTER ROLE`.

Compatibility

The `ALTER USER` statement is a Postgres Pro extension. The SQL standard leaves the definition of users to the implementation.

See Also

ALTER ROLE

ALTER USER MAPPING

ALTER USER MAPPING — change the definition of a user mapping

Synopsis

```
ALTER USER MAPPING FOR { user_name | USER | CURRENT_ROLE | CURRENT_USER | SESSION_USER
 | PUBLIC }
    SERVER server_name
    OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ] )
```

Description

`ALTER USER MAPPING` changes the definition of a user mapping.

The owner of a foreign server can alter user mappings for that server for any user. Also, a user can alter a user mapping for their own user name if `USAGE` privilege on the server has been granted to the user.

Parameters

user_name

User name of the mapping. `CURRENT_ROLE`, `CURRENT_USER`, and `USER` match the name of the current user. `PUBLIC` is used to match all present and future user names in the system.

server_name

Server name of the user mapping.

`OPTIONS ( [ ADD | SET | DROP ] option ['value'] [, ... ] )`

Change options for the user mapping. The new options override any previously specified options. `ADD`, `SET`, and `DROP` specify the action to be performed. `ADD` is assumed if no operation is explicitly specified. Option names must be unique; options are also validated by the server's foreign-data wrapper.

Examples

Change the password for user mapping `bob`, server `foo`:

```
ALTER USER MAPPING FOR bob SERVER foo OPTIONS (SET password 'public');
```

Compatibility

`ALTER USER MAPPING` conforms to ISO/IEC 9075-9 (SQL/MED). There is a subtle syntax issue: The standard omits the `FOR` key word. Since both `CREATE USER MAPPING` and `DROP USER MAPPING` use `FOR` in analogous positions, and IBM DB2 (being the other major SQL/MED implementation) also requires it for `ALTER USER MAPPING`, Postgres Pro diverges from the standard here in the interest of consistency and interoperability.

See Also

CREATE USER MAPPING, DROP USER MAPPING

ALTER VIEW

ALTER VIEW — change the definition of a view

Synopsis

```
ALTER VIEW [ IF EXISTS ] name ALTER [ COLUMN ] column_name SET DEFAULT expression
ALTER VIEW [ IF EXISTS ] name ALTER [ COLUMN ] column_name DROP DEFAULT
ALTER VIEW [ IF EXISTS ] name OWNER TO { new_owner | CURRENT_ROLE | CURRENT_USER |
 SESSION_USER }
ALTER VIEW [ IF EXISTS ] name RENAME [ COLUMN ] column_name TO new_column_name
ALTER VIEW [ IF EXISTS ] name RENAME TO new_name
ALTER VIEW [ IF EXISTS ] name SET SCHEMA new_schema
ALTER VIEW [ IF EXISTS ] name SET ( view_option_name [= view_option_value] [, ... ] )
ALTER VIEW [ IF EXISTS ] name RESET ( view_option_name [, ... ] )
```

Description

`ALTER VIEW` changes various auxiliary properties of a view. (If you want to modify the view's defining query, use `CREATE OR REPLACE VIEW`.)

You must own the view to use `ALTER VIEW`. To change a view's schema, you must also have `CREATE` privilege on the new schema. To alter the owner, you must also be a direct or indirect member of the new owning role, and that role must have `CREATE` privilege on the view's schema. (These restrictions enforce that altering the owner doesn't do anything you couldn't do by dropping and recreating the view. However, a superuser can alter ownership of any view anyway.)

Parameters

name

The name (optionally schema-qualified) of an existing view.

column_name

Name of an existing column.

new_column_name

New name for an existing column.

`IF EXISTS`

Do not throw an error if the view does not exist. A notice is issued in this case.

`SET`/`DROP DEFAULT`

These forms set or remove the default value for a column. A view column's default value is substituted into any `INSERT` or `UPDATE` command whose target is the view, before applying any rules or triggers for the view. The view's default will therefore take precedence over any default values from underlying relations.

new_owner

The user name of the new owner of the view.

new_name

The new name for the view.

new_schema

The new schema for the view.

```
SET ( view_option_name [= view_option_value] [, ... ] )
RESET ( view_option_name [, ... ] )
```

Sets or resets a view option. Currently supported options are:

`check_option` (`enum`)

Changes the check option of the view. The value must be `local` or `cascaded`.

`security_barrier` (`boolean`)

Changes the security-barrier property of the view. The value must be Boolean value, such as `true` or `false`.

Notes

For historical reasons, `ALTER TABLE` can be used with views too; but the only variants of `ALTER TABLE` that are allowed with views are equivalent to the ones shown above.

Examples

To rename the view `foo` to `bar`:

```
ALTER VIEW foo RENAME TO bar;
```

To attach a default column value to an updatable view:

```
CREATE TABLE base_table (id int, ts timestamptz);
CREATE VIEW a_view AS SELECT * FROM base_table;
ALTER VIEW a_view ALTER COLUMN ts SET DEFAULT now();
INSERT INTO base_table(id) VALUES(1);  -- ts will receive a NULL
INSERT INTO a_view(id) VALUES(2);  -- ts will receive the current time
```

Compatibility

`ALTER VIEW` is a Postgres Pro extension of the SQL standard.

See Also

CREATE VIEW, DROP VIEW

ANALYZE

ANALYZE — collect statistics about a database

Synopsis

```
ANALYZE [ ( option [, ...] ) ] [ table_and_columns [, ...] ]
ANALYZE [ VERBOSE ] [ table_and_columns [, ...] ]

where option can be one of:

    VERBOSE [ boolean ]
    SKIP_LOCKED [ boolean ]

and table_and_columns is:

    table_name [ ( column_name [, ...] ) ]
```

Description

`ANALYZE` collects statistics about the contents of tables in the database, and stores the results in the `pg_statistic` system catalog. Subsequently, the query planner uses these statistics to help determine the most efficient execution plans for queries.

Without a *`table_and_columns`* list, `ANALYZE` processes every table and materialized view in the current database that the current user has permission to analyze. With a list, `ANALYZE` processes only those table(s). It is further possible to give a list of column names for a table, in which case only the statistics for those columns are collected.

When the option list is surrounded by parentheses, the options can be written in any order. The parenthesized syntax was added in PostgreSQL 11; the unparenthesized syntax is deprecated.

Parameters

`VERBOSE`

Enables display of progress messages.

`SKIP_LOCKED`

Specifies that `ANALYZE` should not wait for any conflicting locks to be released when beginning work on a relation: if a relation cannot be locked immediately without waiting, the relation is skipped. Note that even with this option, `ANALYZE` may still block when opening the relation's indexes or when acquiring sample rows from partitions, table inheritance children, and some types of foreign tables. Also, while `ANALYZE` ordinarily processes all partitions of specified partitioned tables, this option will cause `ANALYZE` to skip all partitions if there is a conflicting lock on the partitioned table.

`boolean`

Specifies whether the selected option should be turned on or off. You can write `TRUE`, `ON`, or `1` to enable the option, and `FALSE`, `OFF`, or `0` to disable it. The *`boolean`* value can also be omitted, in which case `TRUE` is assumed.

`table_name`

The name (possibly schema-qualified) of a specific table to analyze. If omitted, all regular tables, partitioned tables, and materialized views in the current database are analyzed (but not foreign tables). If the specified table is a partitioned table, both the inheritance statistics of the partitioned table as a whole and statistics of the individual partitions are updated.

column_name

The name of a specific column to analyze. Defaults to all columns.

Outputs

When VERBOSE is specified, ANALYZE emits progress messages to indicate which table is currently being processed. Various statistics about the tables are printed as well.

Notes

To analyze a table, one must ordinarily be the table's owner or a superuser. However, database owners are allowed to analyze all tables in their databases, except shared catalogs. (The restriction for shared catalogs means that a true database-wide ANALYZE can only be performed by a superuser.) ANALYZE will skip over any tables that the calling user does not have permission to analyze.

Foreign tables are analyzed only when explicitly selected. Not all foreign data wrappers support ANALYZE. If the table's wrapper does not support ANALYZE, the command prints a warning and does nothing.

In the default Postgres Pro configuration, the autovacuum daemon (see Section 24.1.6) takes care of automatic analyzing of tables when they are first loaded with data, and as they change throughout regular operation. When autovacuum is disabled, it is a good idea to run ANALYZE periodically, or just after making major changes in the contents of a table. Accurate statistics will help the planner to choose the most appropriate query plan, and thereby improve the speed of query processing. A common strategy for read-mostly databases is to run VACUUM and ANALYZE once a day during a low-usage time of day. (This will not be sufficient if there is heavy update activity.)

ANALYZE requires only a read lock on the target table, so it can run in parallel with other activity on the table.

The statistics collected by ANALYZE usually include a list of some of the most common values in each column and a histogram showing the approximate data distribution in each column. One or both of these can be omitted if ANALYZE deems them uninteresting (for example, in a unique-key column, there are no common values) or if the column data type does not support the appropriate operators. There is more information about the statistics in Chapter 24.

For large tables, ANALYZE takes a random sample of the table contents, rather than examining every row. This allows even very large tables to be analyzed in a small amount of time. Note, however, that the statistics are only approximate, and will change slightly each time ANALYZE is run, even if the actual table contents did not change. This might result in small changes in the planner's estimated costs shown by EXPLAIN. In rare situations, this non-determinism will cause the planner's choices of query plans to change after ANALYZE is run. To avoid this, raise the amount of statistics collected by ANALYZE, as described below.

The extent of analysis can be controlled by adjusting the default_statistics_target configuration variable, or on a column-by-column basis by setting the per-column statistics target with ALTER TABLE ... ALTER COLUMN ... SET STATISTICS. The target value sets the maximum number of entries in the most-common-value list and the maximum number of bins in the histogram. The default target value is 100, but this can be adjusted up or down to trade off accuracy of planner estimates against the time taken for ANALYZE and the amount of space occupied in pg_statistic. In particular, setting the statistics target to zero disables collection of statistics for that column. It might be useful to do that for columns that are never used as part of the WHERE, GROUP BY, or ORDER BY clauses of queries, since the planner will have no use for statistics on such columns.

The largest statistics target among the columns being analyzed determines the number of table rows sampled to prepare the statistics. Increasing the target causes a proportional increase in the time and space needed to do ANALYZE.

One of the values estimated by ANALYZE is the number of distinct values that appear in each column. Because only a subset of the rows are examined, this estimate can sometimes be quite inaccurate, even

with the largest possible statistics target. If this inaccuracy leads to bad query plans, a more accurate value can be determined manually and then installed with `ALTER TABLE ... ALTER COLUMN ... SET (n_distinct = ...)`.

If the table being analyzed has inheritance children, `ANALYZE` gathers two sets of statistics: one on the rows of the parent table only, and a second including rows of both the parent table and all of its children. This second set of statistics is needed when planning queries that process the inheritance tree as a whole. The child tables themselves are not individually analyzed in this case. The autovacuum daemon, however, will only consider inserts or updates on the parent table itself when deciding whether to trigger an automatic analyze for that table. If that table is rarely inserted into or updated, the inheritance statistics will not be up to date unless you run `ANALYZE` manually.

For partitioned tables, `ANALYZE` gathers statistics by sampling rows from all partitions; in addition, it will recurse into each partition and update its statistics. Each leaf partition is analyzed only once, even with multi-level partitioning. No statistics are collected for only the parent table (without data from its partitions), because with partitioning it's guaranteed to be empty.

The autovacuum daemon does not process partitioned tables, nor does it process inheritance parents if only the children are ever modified. It is usually necessary to periodically run a manual `ANALYZE` to keep the statistics of the table hierarchy up to date.

If any child tables or partitions are foreign tables whose foreign data wrappers do not support `ANALYZE`, those tables are ignored while gathering inheritance statistics.

If the table being analyzed is completely empty, `ANALYZE` will not record new statistics for that table. Any existing statistics will be retained.

Each backend running `ANALYZE` will report its progress in the `pg_stat_progress_analyze` view. See Section 27.4.1 for details.

Compatibility

There is no `ANALYZE` statement in the SQL standard.

See Also

VACUUM, vacuumdb, Section 19.4.4, Section 24.1.6, Section 27.4.1

BEGIN

BEGIN — start a transaction block

Synopsis

```
BEGIN [ AUTONOMOUS ] [ WORK | TRANSACTION ] [ transaction_mode [, ...] ]

where transaction_mode is one of:

    ISOLATION LEVEL { SERIALIZABLE | REPEATABLE READ | READ COMMITTED | READ
 UNCOMMITTED }
    READ WRITE | READ ONLY
    [ NOT ] DEFERRABLE
```

Description

`BEGIN` initiates a transaction block, that is, all statements after a `BEGIN` command will be executed in a single transaction until an explicit `COMMIT` or `ROLLBACK` is given. By default (without `BEGIN`), Postgres Pro executes transactions in "autocommit" mode, that is, each statement is executed in its own transaction and a commit is implicitly performed at the end of the statement (if execution was successful, otherwise a rollback is done).

Statements are executed more quickly in a transaction block, because transaction start/commit requires significant CPU and disk activity. Execution of multiple statements inside a transaction is also useful to ensure consistency when making several related changes: other sessions will be unable to see the intermediate states wherein not all the related updates have been done.

If the isolation level, read/write mode, or deferrable mode is specified, the new transaction has those characteristics, as if `SET TRANSACTION` was executed.

If you specify an optional `AUTONOMOUS` keyword, an autonomous transaction is started. Autonomous transactions can be started only within another transaction. For details, see Chapter 16.

Parameters

`AUTONOMOUS`

Starts an autonomous transaction within another transaction.

`WORK`
`TRANSACTION`

Optional key words. They have no effect.

Refer to SET TRANSACTION for information on the meaning of the other parameters to this statement.

Notes

`START TRANSACTION` has the same functionality as `BEGIN`.

Use `COMMIT` or `ROLLBACK` to terminate a transaction block.

Issuing `BEGIN` when already inside a transaction block will provoke a warning message. The state of the transaction is not affected. To nest transactions within a transaction block, use savepoints (see SAVEPOINT).

For reasons of backwards compatibility, the commas between successive *transaction_modes* can be omitted.

Examples

To begin a transaction block:

```
BEGIN;
```

Compatibility

`BEGIN` is a Postgres Pro language extension. It is equivalent to the SQL-standard command `START TRANSACTION`, whose reference page contains additional compatibility information.

The `DEFERRABLE` *`transaction_mode`* is a Postgres Pro language extension.

Incidentally, the `BEGIN` key word is used for a different purpose in embedded SQL. You are advised to be careful about the transaction semantics when porting database applications.

See Also

COMMIT, ROLLBACK, START TRANSACTION, SAVEPOINT

CALL

CALL — invoke a procedure

Synopsis

```
CALL name ( [ argument ] [, ...] )
```

Description

`CALL` executes a procedure.

If the procedure has any output parameters, then a result row will be returned, containing the values of those parameters.

Parameters

name

The name (optionally schema-qualified) of the procedure.

argument

An argument expression for the procedure call.

Arguments can include parameter names, using the syntax *name* `=>` *value*. This works the same as in ordinary function calls; see Section 4.3 for details.

Arguments must be supplied for all procedure parameters that lack defaults, including `OUT` parameters. However, arguments matching `OUT` parameters are not evaluated, so it's customary to just write `NULL` for them. (Writing something else for an `OUT` parameter might cause compatibility problems with future PostgreSQL versions.)

Notes

The user must have `EXECUTE` privilege on the procedure in order to be allowed to invoke it.

To call a function (not a procedure), use `SELECT` instead.

If `CALL` is executed in a transaction block, then the called procedure cannot execute transaction control statements. Transaction control statements are only allowed if `CALL` is executed in its own transaction.

PL/pgSQL handles output parameters in `CALL` commands differently; see Section 45.6.3.

Examples

```
CALL do_db_maintenance();
```

Compatibility

`CALL` conforms to the SQL standard, except for the handling of output parameters. The standard says that users should write variables to receive the values of output parameters.

See Also

CREATE PROCEDURE

CHECKPOINT

CHECKPOINT — force a write-ahead log checkpoint

Synopsis

```
CHECKPOINT
```

Description

A checkpoint is a point in the write-ahead log sequence at which all data files have been updated to reflect the information in the log. All data files will be flushed to disk. Refer to Section 29.5 for more details about what happens during a checkpoint.

The `CHECKPOINT` command forces an immediate checkpoint when the command is issued, without waiting for a regular checkpoint scheduled by the system (controlled by the settings in Section 19.5.2). `CHECKPOINT` is not intended for use during normal operation.

If executed during recovery, the `CHECKPOINT` command will force a restartpoint (see Section 29.5) rather than writing a new checkpoint.

Only superusers can call `CHECKPOINT`.

Compatibility

The `CHECKPOINT` command is a Postgres Pro language extension.

CLOSE

CLOSE — close a cursor

Synopsis

```
CLOSE { name | ALL }
```

Description

`CLOSE` frees the resources associated with an open cursor. After the cursor is closed, no subsequent operations are allowed on it. A cursor should be closed when it is no longer needed.

Every non-holdable open cursor is implicitly closed when a transaction is terminated by `COMMIT` or `ROLLBACK`. A holdable cursor is implicitly closed if the transaction that created it aborts via `ROLLBACK`. If the creating transaction successfully commits, the holdable cursor remains open until an explicit `CLOSE` is executed, or the client disconnects.

Parameters

name

The name of an open cursor to close.

`ALL`

Close all open cursors.

Notes

Postgres Pro does not have an explicit `OPEN` cursor statement; a cursor is considered open when it is declared. Use the `DECLARE` statement to declare a cursor.

You can see all available cursors by querying the `pg_cursors` system view.

If a cursor is closed after a savepoint which is later rolled back, the `CLOSE` is not rolled back; that is, the cursor remains closed.

Examples

Close the cursor `liahona`:

```
CLOSE liahona;
```

Compatibility

`CLOSE` is fully conforming with the SQL standard. `CLOSE ALL` is a Postgres Pro extension.

See Also

DECLARE, FETCH, MOVE

CLUSTER

CLUSTER — cluster a table according to an index

Synopsis

```
CLUSTER [VERBOSE] table_name [ USING index_name ]
CLUSTER ( option [, ...] ) table_name [ USING index_name ]
CLUSTER [VERBOSE]

where option can be one of:

    VERBOSE [ boolean ]
```

Description

`CLUSTER` instructs Postgres Pro to cluster the table specified by *table_name* based on the index specified by *index_name*. The index must already have been defined on *table_name*.

When a table is clustered, it is physically reordered based on the index information. Clustering is a one-time operation: when the table is subsequently updated, the changes are not clustered. That is, no attempt is made to store new or updated rows according to their index order. (If one wishes, one can periodically recluster by issuing the command again. Also, setting the table's `fillfactor` storage parameter to less than 100% can aid in preserving cluster ordering during updates, since updated rows are kept on the same page if enough space is available there.)

When a table is clustered, Postgres Pro remembers which index it was clustered by. The form `CLUSTER` *table_name* reclusters the table using the same index as before. You can also use the `CLUSTER` or `SET WITHOUT CLUSTER` forms of `ALTER TABLE` to set the index to be used for future cluster operations, or to clear any previous setting.

`CLUSTER` without any parameter reclusters all the previously-clustered tables in the current database that the calling user owns, or all such tables if called by a superuser. This form of `CLUSTER` cannot be executed inside a transaction block.

When a table is being clustered, an `ACCESS EXCLUSIVE` lock is acquired on it. This prevents any other database operations (both reads and writes) from operating on the table until the `CLUSTER` is finished.

Parameters

table_name

The name (possibly schema-qualified) of a table.

index_name

The name of an index.

VERBOSE

Prints a progress report as each table is clustered.

boolean

Specifies whether the selected option should be turned on or off. You can write `TRUE`, `ON`, or `1` to enable the option, and `FALSE`, `OFF`, or `0` to disable it. The *boolean* value can also be omitted, in which case `TRUE` is assumed.

Notes

In cases where you are accessing single rows randomly within a table, the actual order of the data in the table is unimportant. However, if you tend to access some data more than others, and there is an index

that groups them together, you will benefit from using CLUSTER. If you are requesting a range of indexed values from a table, or a single indexed value that has multiple rows that match, CLUSTER will help because once the index identifies the table page for the first row that matches, all other rows that match are probably already on the same table page, and so you save disk accesses and speed up the query.

CLUSTER can re-sort the table using either an index scan on the specified index, or (if the index is a b-tree) a sequential scan followed by sorting. It will attempt to choose the method that will be faster, based on planner cost parameters and available statistical information.

When an index scan is used, a temporary copy of the table is created that contains the table data in the index order. Temporary copies of each index on the table are created as well. Therefore, you need free space on disk at least equal to the sum of the table size and the index sizes.

When a sequential scan and sort is used, a temporary sort file is also created, so that the peak temporary space requirement is as much as double the table size, plus the index sizes. This method is often faster than the index scan method, but if the disk space requirement is intolerable, you can disable this choice by temporarily setting enable_sort to off.

It is advisable to set maintenance_work_mem to a reasonably large value (but not more than the amount of RAM you can dedicate to the CLUSTER operation) before clustering.

Because the planner records statistics about the ordering of tables, it is advisable to run ANALYZE on the newly clustered table. Otherwise, the planner might make poor choices of query plans.

Because CLUSTER remembers which indexes are clustered, one can cluster the tables one wants clustered manually the first time, then set up a periodic maintenance script that executes CLUSTER without any parameters, so that the desired tables are periodically reclustered.

Each backend running CLUSTER will report its progress in the pg_stat_progress_cluster view. See Section 27.4.4 for details.

Examples

Cluster the table employees on the basis of its index employees_ind:

```
CLUSTER employees USING employees_ind;
```

Cluster the employees table using the same index that was used before:

```
CLUSTER employees;
```

Cluster all tables in the database that have previously been clustered:

```
CLUSTER;
```

Compatibility

There is no CLUSTER statement in the SQL standard.

The syntax

```
CLUSTER index_name ON table_name
```

is also supported for compatibility with pre-8.3 PostgreSQL versions.

See Also

clusterdb, Section 27.4.4

COMMENT

COMMENT — define or change the comment of an object

Synopsis

```
COMMENT ON
{
  ACCESS METHOD object_name |
  AGGREGATE aggregate_name ( aggregate_signature ) |
  CAST (source_type AS target_type) |
  COLLATION object_name |
  COLUMN relation_name.column_name |
  CONSTRAINT constraint_name ON table_name |
  CONSTRAINT constraint_name ON DOMAIN domain_name |
  CONVERSION object_name |
  DATABASE object_name |
  DOMAIN object_name |
  EXTENSION object_name |
  EVENT TRIGGER object_name |
  FOREIGN DATA WRAPPER object_name |
  FOREIGN TABLE object_name |
  FUNCTION function_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  INDEX object_name |
  LARGE OBJECT large_object_oid |
  MATERIALIZED VIEW object_name |
  OPERATOR operator_name (left_type, right_type) |
  OPERATOR CLASS object_name USING index_method |
  OPERATOR FAMILY object_name USING index_method |
  POLICY policy_name ON table_name |
  [ PROCEDURAL ] LANGUAGE object_name |
  PROCEDURE procedure_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  PROFILE object_name |
  PUBLICATION object_name |
  ROLE object_name |
  ROUTINE routine_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  RULE rule_name ON table_name |
  SCHEMA object_name |
  SEQUENCE object_name |
  SERVER object_name |
  STATISTICS object_name |
  SUBSCRIPTION object_name |
  TABLE object_name |
  TABLESPACE object_name |
  TEXT SEARCH CONFIGURATION object_name |
  TEXT SEARCH DICTIONARY object_name |
  TEXT SEARCH PARSER object_name |
  TEXT SEARCH TEMPLATE object_name |
  TRANSFORM FOR type_name LANGUAGE lang_name |
  TRIGGER trigger_name ON table_name |
  TYPE object_name |
  VIEW object_name
} IS { string_literal | NULL }

where aggregate_signature is:

* |
```

```
[ argmode ] [ argname ] argtype [ , ... ] |
[ [ argmode ] [ argname ] argtype [ , ... ] ] ORDER BY [ argmode ] [ argname ] argtype
 [ , ... ]
```

Description

`COMMENT` stores a comment about a database object.

Only one comment string is stored for each object, so to modify a comment, issue a new `COMMENT` command for the same object. To remove a comment, write `NULL` in place of the text string. Comments are automatically dropped when their object is dropped.

A `SHARE UPDATE EXCLUSIVE` lock is acquired on the object to be commented.

For most kinds of object, only the object's owner can set the comment. Roles don't have owners, so the rule for `COMMENT ON ROLE` is that you must be superuser to comment on a superuser role, or have the `CREATEROLE` privilege and have been granted `ADMIN OPTION` on the target role. Likewise, access methods don't have owners either; you must be superuser to comment on an access method. Of course, a superuser can comment on anything.

Comments can be viewed using psql's `\d` family of commands. Other user interfaces to retrieve comments can be built atop the same built-in functions that psql uses, namely `obj_description`, `col_description`, and `shobj_description` (see Table 9.75).

Parameters

object_name
relation_name.column_name
aggregate_name
constraint_name
function_name
operator_name
policy_name
procedure_name
routine_name
rule_name
trigger_name

The name of the object to be commented. Names of objects that reside in schemas (tables, functions, etc.) can be schema-qualified. When commenting on a column, *relation_name* must refer to a table, view, composite type, or foreign table.

table_name
domain_name

When creating a comment on a constraint, a trigger, a rule or a policy these parameters specify the name of the table or domain on which that object is defined.

source_type

The name of the source data type of the cast.

target_type

The name of the target data type of the cast.

argmode

The mode of a function, procedure, or aggregate argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN`. Note that `COMMENT` does not actually pay any attention to `OUT` arguments, since only the input arguments are needed to determine the function's identity. So it is sufficient to list the `IN`, `INOUT`, and `VARIADIC` arguments.

argname

The name of a function, procedure, or aggregate argument. Note that COMMENT does not actually pay any attention to argument names, since only the argument data types are needed to determine the function's identity.

argtype

The data type of a function, procedure, or aggregate argument.

large_object_oid

The OID of the large object.

left_type
right_type

The data type(s) of the operator's arguments (optionally schema-qualified). Write NONE for the missing argument of a prefix operator.

PROCEDURAL

This is a noise word.

type_name

The name of the data type of the transform.

lang_name

The name of the language of the transform.

string_literal

The new comment contents, written as a string literal.

NULL

Write NULL to drop the comment.

Notes

There is presently no security mechanism for viewing comments: any user connected to a database can see all the comments for objects in that database. For shared objects such as databases, roles, and tablespaces, comments are stored globally so any user connected to any database in the cluster can see all the comments for shared objects. Therefore, don't put security-critical information in comments.

Examples

Attach a comment to the table mytable:

```
COMMENT ON TABLE mytable IS 'This is my table.';
```

Remove it again:

```
COMMENT ON TABLE mytable IS NULL;
```

Some more examples:

```
COMMENT ON ACCESS METHOD gin IS 'GIN index access method';
COMMENT ON AGGREGATE my_aggregate (double precision) IS 'Computes sample variance';
COMMENT ON CAST (text AS int4) IS 'Allow casts from text to int4';
COMMENT ON COLLATION "fr_CA" IS 'Canadian French';
COMMENT ON COLUMN my_table.my_column IS 'Employee ID number';
COMMENT ON CONVERSION my_conv IS 'Conversion to UTF8';
COMMENT ON CONSTRAINT bar_col_cons ON bar IS 'Constrains column col';
```

```
COMMENT ON CONSTRAINT dom_col_constr ON DOMAIN dom IS 'Constrains col of domain';
COMMENT ON DATABASE my_database IS 'Development Database';
COMMENT ON DOMAIN my_domain IS 'Email Address Domain';
COMMENT ON EVENT TRIGGER abort_ddl IS 'Aborts all DDL commands';
COMMENT ON EXTENSION hstore IS 'implements the hstore data type';
COMMENT ON FOREIGN DATA WRAPPER mywrapper IS 'my foreign data wrapper';
COMMENT ON FOREIGN TABLE my_foreign_table IS 'Employee Information in other database';
COMMENT ON FUNCTION my_function (timestamp) IS 'Returns Roman Numeral';
COMMENT ON INDEX my_index IS 'Enforces uniqueness on employee ID';
COMMENT ON LANGUAGE plpython IS 'Python support for stored procedures';
COMMENT ON LARGE OBJECT 346344 IS 'Planning document';
COMMENT ON MATERIALIZED VIEW my_matview IS 'Summary of order history';
COMMENT ON OPERATOR ^ (text, text) IS 'Performs intersection of two texts';
COMMENT ON OPERATOR - (NONE, integer) IS 'Unary minus';
COMMENT ON OPERATOR CLASS int4ops USING btree IS '4 byte integer operators for btrees';
COMMENT ON OPERATOR FAMILY integer_ops USING btree IS 'all integer operators for
 btrees';
COMMENT ON POLICY my_policy ON mytable IS 'Filter rows by users';
COMMENT ON PROCEDURE my_proc (integer, integer) IS 'Runs a report';
COMMENT ON PUBLICATION alltables IS 'Publishes all operations on all tables';
COMMENT ON ROLE my_role IS 'Administration group for finance tables';
COMMENT ON ROUTINE my_routine (integer, integer) IS 'Runs a routine (which is a
 function or procedure)';
COMMENT ON RULE my_rule ON my_table IS 'Logs updates of employee records';
COMMENT ON SCHEMA my_schema IS 'Departmental data';
COMMENT ON SEQUENCE my_sequence IS 'Used to generate primary keys';
COMMENT ON SERVER myserver IS 'my foreign server';
COMMENT ON STATISTICS my_statistics IS 'Improves planner row estimations';
COMMENT ON SUBSCRIPTION alltables IS 'Subscription for all operations on all tables';
COMMENT ON TABLE my_schema.my_table IS 'Employee Information';
COMMENT ON TABLESPACE my_tablespace IS 'Tablespace for indexes';
COMMENT ON TEXT SEARCH CONFIGURATION my_config IS 'Special word filtering';
COMMENT ON TEXT SEARCH DICTIONARY swedish IS 'Snowball stemmer for Swedish language';
COMMENT ON TEXT SEARCH PARSER my_parser IS 'Splits text into words';
COMMENT ON TEXT SEARCH TEMPLATE snowball IS 'Snowball stemmer';
COMMENT ON TRANSFORM FOR hstore LANGUAGE plpythonu IS 'Transform between hstore and
 Python dict';
COMMENT ON TRIGGER my_trigger ON my_table IS 'Used for RI';
COMMENT ON TYPE complex IS 'Complex number data type';
COMMENT ON VIEW my_view IS 'View of departmental costs';
```

Compatibility

There is no `COMMENT` command in the SQL standard.

COMMIT

COMMIT — commit the current transaction

Synopsis

```
COMMIT [ AUTONOMOUS ] [ WORK | TRANSACTION ] [ AND [ NO ] CHAIN ]
```

Description

`COMMIT` commits the current transaction. All changes made by the transaction become visible to others and are guaranteed to be durable if a crash occurs.

Parameters

`AUTONOMOUS`

Optional key word that can be used when committing an autonomous transaction. For details on autonomous transactions, see Chapter 16.

`WORK`
`TRANSACTION`

Optional key words. They have no effect.

`AND CHAIN`

If `AND CHAIN` is specified, a new transaction is immediately started with the same transaction characteristics (see SET TRANSACTION) as the just finished one. Otherwise, no new transaction is started.

Notes

Use ROLLBACK to abort a transaction.

Issuing `COMMIT` when not inside a transaction does no harm, but it will provoke a warning message. `COMMIT AND CHAIN` when not inside a transaction is an error.

Examples

To commit the current transaction and make all changes permanent:

```
COMMIT;
```

Compatibility

The command `COMMIT` conforms to the SQL standard. The form `COMMIT TRANSACTION` is a Postgres Pro extension.

See Also

BEGIN, ROLLBACK

COMMIT PREPARED

COMMIT PREPARED — commit a transaction that was earlier prepared for two-phase commit

Synopsis

```
COMMIT PREPARED transaction_id
```

Description

`COMMIT PREPARED` commits a transaction that is in prepared state.

Parameters

transaction_id

The transaction identifier of the transaction that is to be committed.

Notes

To commit a prepared transaction, you must be either the same user that executed the transaction originally, or a superuser. But you do not have to be in the same session that executed the transaction.

This command cannot be executed inside a transaction block. The prepared transaction is committed immediately.

All currently available prepared transactions are listed in the `pg_prepared_xacts` system view.

Examples

Commit the transaction identified by the transaction identifier `foobar`:

```
COMMIT PREPARED 'foobar';
```

Compatibility

`COMMIT PREPARED` is a Postgres Pro extension. It is intended for use by external transaction management systems, some of which are covered by standards (such as X/Open XA), but the SQL side of those systems is not standardized.

See Also

PREPARE TRANSACTION, ROLLBACK PREPARED

COPY

COPY — copy data between a file and a table

Synopsis

```
COPY table_name [ ( column_name [, ...] ) ]
    FROM { 'filename' | PROGRAM 'command' | STDIN }
    [ [ WITH ] ( option [, ...] ) ]
    [ WHERE condition ]

COPY { table_name [ ( column_name [, ...] ) ] | ( query ) }
    TO { 'filename' | PROGRAM 'command' | STDOUT }
    [ [ WITH ] ( option [, ...] ) ]

where option can be one of:

    FORMAT format_name
    FREEZE [ boolean ]
    DELIMITER 'delimiter_character'
    NULL 'null_string'
    HEADER [ boolean ]
    QUOTE 'quote_character'
    ESCAPE 'escape_character'
    FORCE_QUOTE { ( column_name [, ...] ) | * }
    FORCE_NOT_NULL ( column_name [, ...] )
    FORCE_NULL ( column_name [, ...] )
    ENCODING 'encoding_name'
```

Description

`COPY` moves data between Postgres Pro tables and standard file-system files. `COPY TO` copies the contents of a table *to* a file, while `COPY FROM` copies data *from* a file to a table (appending the data to whatever is in the table already). `COPY TO` can also copy the results of a `SELECT` query.

If a column list is specified, `COPY TO` copies only the data in the specified columns to the file. For `COPY FROM`, each field in the file is inserted, in order, into the specified column. Table columns not specified in the `COPY FROM` column list will receive their default values.

`COPY` with a file name instructs the Postgres Pro server to directly read from or write to a file. The file must be accessible by the Postgres Pro user (the user ID the server runs as) and the name must be specified from the viewpoint of the server. When `PROGRAM` is specified, the server executes the given command and reads from the standard output of the program, or writes to the standard input of the program. The command must be specified from the viewpoint of the server, and be executable by the Postgres Pro user. When `STDIN` or `STDOUT` is specified, data is transmitted via the connection between the client and the server.

Each backend running `COPY` will report its progress in the `pg_stat_progress_copy` view. See Section 27.4.6 for details.

Parameters

table_name

The name (optionally schema-qualified) of an existing table.

column_name

An optional list of columns to be copied. If no column list is specified, all columns of the table except generated columns will be copied.

query

A SELECT, VALUES, INSERT, UPDATE, or DELETE command whose results are to be copied. Note that parentheses are required around the query.

For INSERT, UPDATE and DELETE queries a RETURNING clause must be provided, and the target relation must not have a conditional rule, nor an ALSO rule, nor an INSTEAD rule that expands to multiple statements.

filename

The path name of the input or output file. An input file name can be an absolute or relative path, but an output file name must be an absolute path. Windows users might need to use an E'' string and double any backslashes used in the path name.

PROGRAM

A command to execute. In COPY FROM, the input is read from standard output of the command, and in COPY TO, the output is written to the standard input of the command.

Note that the command is invoked by the shell, so if you need to pass any arguments to shell command that come from an untrusted source, you must be careful to strip or escape any special characters that might have a special meaning for the shell. For security reasons, it is best to use a fixed command string, or at least avoid passing any user input in it.

STDIN

Specifies that input comes from the client application.

STDOUT

Specifies that output goes to the client application.

boolean

Specifies whether the selected option should be turned on or off. You can write TRUE, ON, or 1 to enable the option, and FALSE, OFF, or 0 to disable it. The *boolean* value can also be omitted, in which case TRUE is assumed.

FORMAT

Selects the data format to be read or written: text, csv (Comma Separated Values), or binary. The default is text.

FREEZE

Requests copying the data with rows already frozen, just as they would be after running the VACUUM FREEZE command. This is intended as a performance option for initial data loading. Rows will be frozen only if the table being loaded has been created or truncated in the current subtransaction, there are no cursors open and there are no older snapshots held by this transaction. It is currently not possible to perform a COPY FREEZE on a partitioned table.

Note that all other sessions will immediately be able to see the data once it has been successfully loaded. This violates the normal rules of MVCC visibility and users specifying should be aware of the potential problems this might cause.

DELIMITER

Specifies the character that separates columns within each row (line) of the file. The default is a tab character in text format, a comma in CSV format. This must be a single one-byte character. This option is not allowed when using binary format.

NULL

Specifies the string that represents a null value. The default is \N (backslash-N) in text format, and an unquoted empty string in CSV format. You might prefer an empty string even in text format for

cases where you don't want to distinguish nulls from empty strings. This option is not allowed when using `binary` format.

> **Note**
>
> When using `COPY FROM`, any data item that matches this string will be stored as a null value, so you should make sure that you use the same string as you used with `COPY TO`.

`HEADER`

Specifies that the file contains a header line with the names of each column in the file. On output, the first line contains the column names from the table, and on input, the first line is ignored. This option is allowed only when using `CSV` format.

`QUOTE`

Specifies the quoting character to be used when a data value is quoted. The default is double-quote. This must be a single one-byte character. This option is allowed only when using `CSV` format.

`ESCAPE`

Specifies the character that should appear before a data character that matches the `QUOTE` value. The default is the same as the `QUOTE` value (so that the quoting character is doubled if it appears in the data). This must be a single one-byte character. This option is allowed only when using `CSV` format.

`FORCE_QUOTE`

Forces quoting to be used for all non-`NULL` values in each specified column. `NULL` output is never quoted. If `*` is specified, non-`NULL` values will be quoted in all columns. This option is allowed only in `COPY TO`, and only when using `CSV` format.

`FORCE_NOT_NULL`

Do not match the specified columns' values against the null string. In the default case where the null string is empty, this means that empty values will be read as zero-length strings rather than nulls, even when they are not quoted. This option is allowed only in `COPY FROM`, and only when using `CSV` format.

`FORCE_NULL`

Match the specified columns' values against the null string, even if it has been quoted, and if a match is found set the value to `NULL`. In the default case where the null string is empty, this converts a quoted empty string into NULL. This option is allowed only in `COPY FROM`, and only when using `CSV` format.

`ENCODING`

Specifies that the file is encoded in the *`encoding_name`*. If this option is omitted, the current client encoding is used. See the Notes below for more details.

`WHERE`

The optional `WHERE` clause has the general form

`WHERE` *`condition`*

where *`condition`* is any expression that evaluates to a result of type `boolean`. Any row that does not satisfy this condition will not be inserted to the table. A row satisfies the condition if it returns true when the actual row values are substituted for any variable references.

Currently, subqueries are not allowed in `WHERE` expressions, and the evaluation does not see any changes made by the `COPY` itself (this matters when the expression contains calls to `VOLATILE` functions).

Outputs

On successful completion, a COPY command returns a command tag of the form

```
COPY count
```

The *count* is the number of rows copied.

> **Note**
>
> psql will print this command tag only if the command was not COPY ... TO STDOUT, or the equivalent psql meta-command \copy ... to stdout. This is to prevent confusing the command tag with the data that was just printed.

Notes

COPY TO can be used only with plain tables, not views, and does not copy rows from child tables or child partitions. For example, COPY *table* TO copies the same rows as SELECT * FROM ONLY *table*. The syntax COPY (SELECT * FROM *table*) TO ... can be used to dump all of the rows in an inheritance hierarchy, partitioned table, or view.

COPY FROM can be used with plain, foreign, or partitioned tables or with views that have INSTEAD OF INSERT triggers.

You must have select privilege on the table whose values are read by COPY TO, and insert privilege on the table into which values are inserted by COPY FROM. It is sufficient to have column privileges on the column(s) listed in the command.

If row-level security is enabled for the table, the relevant SELECT policies will apply to COPY *table* TO statements. Currently, COPY FROM is not supported for tables with row-level security. Use equivalent INSERT statements instead.

Files named in a COPY command are read or written directly by the server, not by the client application. Therefore, they must reside on or be accessible to the database server machine, not the client. They must be accessible to and readable or writable by the Postgres Pro user (the user ID the server runs as), not the client. Similarly, the command specified with PROGRAM is executed directly by the server, not by the client application, must be executable by the Postgres Pro user. COPY naming a file or command is only allowed to database superusers or users who are granted one of the roles pg_read_server_files, pg_write_server_files, or pg_execute_server_program, since it allows reading or writing any file or running a program that the server has privileges to access.

Do not confuse COPY with the psql instruction \copy. \copy invokes COPY FROM STDIN or COPY TO STDOUT, and then fetches/stores the data in a file accessible to the psql client. Thus, file accessibility and access rights depend on the client rather than the server when \copy is used.

It is recommended that the file name used in COPY always be specified as an absolute path. This is enforced by the server in the case of COPY TO, but for COPY FROM you do have the option of reading from a file specified by a relative path. The path will be interpreted relative to the working directory of the server process (normally the cluster's data directory), not the client's working directory.

Executing a command with PROGRAM might be restricted by the operating system's access control mechanisms, such as SELinux.

COPY FROM will invoke any triggers and check constraints on the destination table. However, it will not invoke rules.

For identity columns, the COPY FROM command will always write the column values provided in the input data, like the INSERT option OVERRIDING SYSTEM VALUE.

COPY input and output is affected by DateStyle. To ensure portability to other Postgres Pro installations that might use non-default DateStyle settings, DateStyle should be set to ISO before using COPY TO. It is also a good idea to avoid dumping data with IntervalStyle set to sql_standard, because negative interval values might be misinterpreted by a server that has a different setting for IntervalStyle.

Input data is interpreted according to ENCODING option or the current client encoding, and output data is encoded in ENCODING or the current client encoding, even if the data does not pass through the client but is read from or written to a file directly by the server.

COPY stops operation at the first error. This should not lead to problems in the event of a COPY TO, but the target table will already have received earlier rows in a COPY FROM. These rows will not be visible or accessible, but they still occupy disk space. This might amount to a considerable amount of wasted disk space if the failure happened well into a large copy operation. You might wish to invoke VACUUM to recover the wasted space.

FORCE_NULL and FORCE_NOT_NULL can be used simultaneously on the same column. This results in converting quoted null strings to null values and unquoted null strings to empty strings.

Postgres Pro does not allow NUL bytes in data. If you are going to import such data using the COPY FROM command, you can specify an ASCII character in the nul_byte_replacement_on_import configuration parameter to replace NUL bytes on the fly.

File Formats

Text Format

When the text format is used, the data read or written is a text file with one line per table row. Columns in a row are separated by the delimiter character. The column values themselves are strings generated by the output function, or acceptable to the input function, of each attribute's data type. The specified null string is used in place of columns that are null. COPY FROM will raise an error if any line of the input file contains more or fewer columns than are expected.

End of data can be represented by a single line containing just backslash-period (\.). An end-of-data marker is not necessary when reading from a file, since the end of file serves perfectly well; it is needed only when copying data to or from client applications using pre-3.0 client protocol.

Backslash characters (\) can be used in the COPY data to quote data characters that might otherwise be taken as row or column delimiters. In particular, the following characters *must* be preceded by a backslash if they appear as part of a column value: backslash itself, newline, carriage return, and the current delimiter character.

The specified null string is sent by COPY TO without adding any backslashes; conversely, COPY FROM matches the input against the null string before removing backslashes. Therefore, a null string such as \N cannot be confused with the actual data value \N (which would be represented as \\N).

The following special backslash sequences are recognized by COPY FROM:

Sequence	Represents
\b	Backspace (ASCII 8)
\f	Form feed (ASCII 12)
\n	Newline (ASCII 10)
\r	Carriage return (ASCII 13)
\t	Tab (ASCII 9)
\v	Vertical tab (ASCII 11)
digits	Backslash followed by one to three octal digits specifies the byte with that numeric code

Sequence	Represents
\x*digits*	Backslash x followed by one or two hex digits specifies the byte with that numeric code

Presently, COPY TO will never emit an octal or hex-digits backslash sequence, but it does use the other sequences listed above for those control characters.

Any other backslashed character that is not mentioned in the above table will be taken to represent itself. However, beware of adding backslashes unnecessarily, since that might accidentally produce a string matching the end-of-data marker (\.) or the null string (\N by default). These strings will be recognized before any other backslash processing is done.

It is strongly recommended that applications generating COPY data convert data newlines and carriage returns to the \n and \r sequences respectively. At present it is possible to represent a data carriage return by a backslash and carriage return, and to represent a data newline by a backslash and newline. However, these representations might not be accepted in future releases. They are also highly vulnerable to corruption if the COPY file is transferred across different machines (for example, from Unix to Windows or vice versa).

All backslash sequences are interpreted after encoding conversion. The bytes specified with the octal and hex-digit backslash sequences must form valid characters in the database encoding.

COPY TO will terminate each row with a Unix-style newline ("\n"). Servers running on Microsoft Windows instead output carriage return/newline ("\r\n"), but only for COPY to a server file; for consistency across platforms, COPY TO STDOUT always sends "\n" regardless of server platform. COPY FROM can handle lines ending with newlines, carriage returns, or carriage return/newlines. To reduce the risk of error due to un-backslashed newlines or carriage returns that were meant as data, COPY FROM will complain if the line endings in the input are not all alike.

CSV Format

This format option is used for importing and exporting the Comma Separated Value (CSV) file format used by many other programs, such as spreadsheets. Instead of the escaping rules used by Postgres Pro's standard text format, it produces and recognizes the common CSV escaping mechanism.

The values in each record are separated by the DELIMITER character. If the value contains the delimiter character, the QUOTE character, the NULL string, a carriage return, or line feed character, then the whole value is prefixed and suffixed by the QUOTE character, and any occurrence within the value of a QUOTE character or the ESCAPE character is preceded by the escape character. You can also use FORCE_QUOTE to force quotes when outputting non-NULL values in specific columns.

The CSV format has no standard way to distinguish a NULL value from an empty string. Postgres Pro's COPY handles this by quoting. A NULL is output as the NULL parameter string and is not quoted, while a non-NULL value matching the NULL parameter string is quoted. For example, with the default settings, a NULL is written as an unquoted empty string, while an empty string data value is written with double quotes (""). Reading values follows similar rules. You can use FORCE_NOT_NULL to prevent NULL input comparisons for specific columns. You can also use FORCE_NULL to convert quoted null string data values to NULL.

Because backslash is not a special character in the CSV format, \., the end-of-data marker, could also appear as a data value. To avoid any misinterpretation, a \. data value appearing as a lone entry on a line is automatically quoted on output, and on input, if quoted, is not interpreted as the end-of-data marker. If you are loading a file created by another application that has a single unquoted column and might have a value of \., you might need to quote that value in the input file.

Note

In CSV format, all characters are significant. A quoted value surrounded by white space, or any characters other than DELIMITER, will include those characters. This can cause errors if you im-

port data from a system that pads `CSV` lines with white space out to some fixed width. If such a situation arises you might need to preprocess the `CSV` file to remove the trailing white space, before importing the data into Postgres Pro.

Note

CSV format will both recognize and produce CSV files with quoted values containing embedded carriage returns and line feeds. Thus the files are not strictly one line per table row like text-format files.

Note

Many programs produce strange and occasionally perverse CSV files, so the file format is more a convention than a standard. Thus you might encounter some files that cannot be imported using this mechanism, and `COPY` might produce files that other programs cannot process.

Binary Format

The `binary` format option causes all data to be stored/read as binary format rather than as text. It is somewhat faster than the text and `CSV` formats, but a binary-format file is less portable across machine architectures and Postgres Pro versions. Also, the binary format is very data type specific; for example it will not work to output binary data from a `smallint` column and read it into an `integer` column, even though that would work fine in text format.

The `binary` file format consists of a file header, zero or more tuples containing the row data, and a file trailer. Headers and data are in network byte order.

Note

PostgreSQL releases before 7.4 used a different binary file format.

File Header

The file header consists of 15 bytes of fixed fields, followed by a variable-length header extension area. The fixed fields are:

Signature

11-byte sequence `PGCOPY\n\377\r\n\0` — note that the zero byte is a required part of the signature. (The signature is designed to allow easy identification of files that have been munged by a non-8-bit-clean transfer. This signature will be changed by end-of-line-translation filters, dropped zero bytes, dropped high bits, or parity changes.)

Flags field

32-bit integer bit mask to denote important aspects of the file format. Bits are numbered from 0 (LSB) to 31 (MSB). Note that this field is stored in network byte order (most significant byte first), as are all the integer fields used in the file format. Bits 16–31 are reserved to denote critical file format issues; a reader should abort if it finds an unexpected bit set in this range. Bits 0–15 are reserved to signal backwards-compatible format issues; a reader should simply ignore any unexpected bits set in this range. Currently only one flag bit is defined, and the rest must be zero:

Bit 16

If 1, OIDs are included in the data; if 0, not. Oid system columns are not supported in Postgres Pro anymore, but the format still contains the indicator.

Header extension area length

32-bit integer, length in bytes of remainder of header, not including self. Currently, this is zero, and the first tuple follows immediately. Future changes to the format might allow additional data to be present in the header. A reader should silently skip over any header extension data it does not know what to do with.

The header extension area is envisioned to contain a sequence of self-identifying chunks. The flags field is not intended to tell readers what is in the extension area. Specific design of header extension contents is left for a later release.

This design allows for both backwards-compatible header additions (add header extension chunks, or set low-order flag bits) and non-backwards-compatible changes (set high-order flag bits to signal such changes, and add supporting data to the extension area if needed).

Tuples

Each tuple begins with a 16-bit integer count of the number of fields in the tuple. (Presently, all tuples in a table will have the same count, but that might not always be true.) Then, repeated for each field in the tuple, there is a 32-bit length word followed by that many bytes of field data. (The length word does not include itself, and can be zero.) As a special case, -1 indicates a NULL field value. No value bytes follow in the NULL case.

There is no alignment padding or any other extra data between fields.

Presently, all data values in a binary-format file are assumed to be in binary format (format code one). It is anticipated that a future extension might add a header field that allows per-column format codes to be specified.

If OIDs are included in the file, the OID field immediately follows the field-count word. It is a normal field except that it's not included in the field-count. Note that oid system columns are not supported in current versions of Postgres Pro.

File Trailer

The file trailer consists of a 16-bit integer word containing -1. This is easily distinguished from a tuple's field-count word.

A reader should report an error if a field-count word is neither -1 nor the expected number of columns. This provides an extra check against somehow getting out of sync with the data.

Examples

The following example copies a table to the client using the vertical bar (`|`) as the field delimiter:

```
COPY country TO STDOUT (DELIMITER '|');
```

To copy data from a file into the `country` table:

```
COPY country FROM '/usr1/proj/bray/sql/country_data';
```

To copy into a file just the countries whose names start with 'A':

```
COPY (SELECT * FROM country WHERE country_name LIKE 'A%') TO '/usr1/proj/bray/sql/
a_list_countries.copy';
```

To copy into a compressed file, you can pipe the output through an external compression program:

```
COPY country TO PROGRAM 'gzip > /usr1/proj/bray/sql/country_data.gz';
```

Here is a sample of data suitable for copying into a table from `STDIN`:

```
AF      AFGHANISTAN
AL      ALBANIA
```

```
DZ      ALGERIA
ZM      ZAMBIA
ZW      ZIMBABWE
```

Note that the white space on each line is actually a tab character.

The following is the same data, output in binary format. The data is shown after filtering through the Unix utility `od -c`. The table has three columns; the first has type `char(2)`, the second has type `text`, and the third has type `integer`. All the rows have a null value in the third column.

```
0000000   P   G   C   O   P   Y  \n 377  \r  \n  \0  \0  \0  \0  \0  \0
0000020  \0  \0  \0  \0 003  \0  \0  \0 002   A   F  \0  \0  \0 013   A
0000040   F   G   H   A   N   I   S   T   A   N 377 377 377 377  \0 003
0000060  \0  \0  \0 002   A   L  \0  \0  \0 007   A   L   B   A   N   I
0000100   A 377 377 377 377  \0 003  \0  \0  \0 002   D   Z  \0  \0  \0
0000120 007   A   L   G   E   R   I   A 377 377 377 377  \0 003  \0  \0
0000140  \0 002   Z   M  \0  \0  \0 006   Z   A   M   B   I   A 377 377
0000160 377 377  \0 003  \0  \0  \0 002   Z   W  \0  \0  \0  \b   Z   I
0000200   M   B   A   B   W   E 377 377 377 377 377 377
```

Compatibility

There is no `COPY` statement in the SQL standard.

The following syntax was used before PostgreSQL version 9.0 and is still supported:

```
COPY table_name [ ( column_name [, ...] ) ]
    FROM { 'filename' | STDIN }
    [ [ WITH ]
          [ BINARY ]
          [ DELIMITER [ AS ] 'delimiter_character' ]
          [ NULL [ AS ] 'null_string' ]
          [ CSV [ HEADER ]
                [ QUOTE [ AS ] 'quote_character' ]
                [ ESCAPE [ AS ] 'escape_character' ]
                [ FORCE NOT NULL column_name [, ...] ] ] ]

COPY { table_name [ ( column_name [, ...] ) ] | ( query ) }
    TO { 'filename' | STDOUT }
    [ [ WITH ]
          [ BINARY ]
          [ DELIMITER [ AS ] 'delimiter_character' ]
          [ NULL [ AS ] 'null_string' ]
          [ CSV [ HEADER ]
                [ QUOTE [ AS ] 'quote_character' ]
                [ ESCAPE [ AS ] 'escape_character' ]
                [ FORCE QUOTE { column_name [, ...] | * } ] ] ]
```

Note that in this syntax, `BINARY` and `CSV` are treated as independent keywords, not as arguments of a `FORMAT` option.

The following syntax was used before PostgreSQL version 7.3 and is still supported:

```
COPY [ BINARY ] table_name
    FROM { 'filename' | STDIN }
    [ [USING] DELIMITERS 'delimiter_character' ]
    [ WITH NULL AS 'null_string' ]

COPY [ BINARY ] table_name
    TO { 'filename' | STDOUT }
    [ [USING] DELIMITERS 'delimiter_character' ]
```

```
    [ WITH NULL AS 'null_string' ]
```

See Also

Section 27.4.6

CREATE ACCESS METHOD

CREATE ACCESS METHOD — define a new access method

Synopsis

```
CREATE ACCESS METHOD name
    TYPE access_method_type
    HANDLER handler_function
```

Description

`CREATE ACCESS METHOD` creates a new access method.

The access method name must be unique within the database.

Only superusers can define new access methods.

Parameters

name

The name of the access method to be created.

access_method_type

This clause specifies the type of access method to define. Only `TABLE` and `INDEX` are supported at present.

handler_function

handler_function is the name (possibly schema-qualified) of a previously registered function that represents the access method. The handler function must be declared to take a single argument of type `internal`, and its return type depends on the type of access method; for `TABLE` access methods, it must be `table_am_handler` and for `INDEX` access methods, it must be `index_am_handler`. The C-level API that the handler function must implement varies depending on the type of access method. The table access method API is described in Chapter 61 and the index access method API is described in Chapter 62.

Examples

Create an index access method `heptree` with handler function `heptree_handler`:

```
CREATE ACCESS METHOD heptree TYPE INDEX HANDLER heptree_handler;
```

Compatibility

`CREATE ACCESS METHOD` is a Postgres Pro extension.

See Also

DROP ACCESS METHOD, CREATE OPERATOR CLASS, CREATE OPERATOR FAMILY

CREATE AGGREGATE

CREATE AGGREGATE — define a new aggregate function

Synopsis

```
CREATE [ OR REPLACE ] AGGREGATE name ( [ argmode ] [ argname ] arg_data_type
 [ , ... ] ) (
    SFUNC = sfunc,
    STYPE = state_data_type
    [ , SSPACE = state_data_size ]
    [ , FINALFUNC = ffunc ]
    [ , FINALFUNC_EXTRA ]
    [ , FINALFUNC_MODIFY = { READ_ONLY | SHAREABLE | READ_WRITE } ]
    [ , COMBINEFUNC = combinefunc ]
    [ , SERIALFUNC = serialfunc ]
    [ , DESERIALFUNC = deserialfunc ]
    [ , INITCOND = initial_condition ]
    [ , MSFUNC = msfunc ]
    [ , MINVFUNC = minvfunc ]
    [ , MSTYPE = mstate_data_type ]
    [ , MSSPACE = mstate_data_size ]
    [ , MFINALFUNC = mffunc ]
    [ , MFINALFUNC_EXTRA ]
    [ , MFINALFUNC_MODIFY = { READ_ONLY | SHAREABLE | READ_WRITE } ]
    [ , MINITCOND = minitial_condition ]
    [ , SORTOP = sort_operator ]
    [ , PARALLEL = { SAFE | RESTRICTED | UNSAFE } ]
)

CREATE [ OR REPLACE ] AGGREGATE name ( [ [ argmode ] [ argname ] arg_data_type
 [ , ... ] ]
                        ORDER BY [ argmode ] [ argname ] arg_data_type [ , ... ] ) (
    SFUNC = sfunc,
    STYPE = state_data_type
    [ , SSPACE = state_data_size ]
    [ , FINALFUNC = ffunc ]
    [ , FINALFUNC_EXTRA ]
    [ , FINALFUNC_MODIFY = { READ_ONLY | SHAREABLE | READ_WRITE } ]
    [ , INITCOND = initial_condition ]
    [ , PARALLEL = { SAFE | RESTRICTED | UNSAFE } ]
    [ , HYPOTHETICAL ]
)

or the old syntax

CREATE [ OR REPLACE ] AGGREGATE name (
    BASETYPE = base_type,
    SFUNC = sfunc,
    STYPE = state_data_type
    [ , SSPACE = state_data_size ]
    [ , FINALFUNC = ffunc ]
    [ , FINALFUNC_EXTRA ]
    [ , FINALFUNC_MODIFY = { READ_ONLY | SHAREABLE | READ_WRITE } ]
    [ , COMBINEFUNC = combinefunc ]
    [ , SERIALFUNC = serialfunc ]
```

```
    [ , DESERIALFUNC = deserialfunc ]
    [ , INITCOND = initial_condition ]
    [ , MSFUNC = msfunc ]
    [ , MINVFUNC = minvfunc ]
    [ , MSTYPE = mstate_data_type ]
    [ , MSSPACE = mstate_data_size ]
    [ , MFINALFUNC = mffunc ]
    [ , MFINALFUNC_EXTRA ]
    [ , MFINALFUNC_MODIFY = { READ_ONLY | SHAREABLE | READ_WRITE } ]
    [ , MINITCOND = minitial_condition ]
    [ , SORTOP = sort_operator ]
)
```

Description

`CREATE AGGREGATE` defines a new aggregate function. `CREATE OR REPLACE AGGREGATE` will either define a new aggregate function or replace an existing definition. Some basic and commonly-used aggregate functions are included with the distribution; they are documented in Section 9.21. If one defines new types or needs an aggregate function not already provided, then `CREATE AGGREGATE` can be used to provide the desired features.

When replacing an existing definition, the argument types, result type, and number of direct arguments may not be changed. Also, the new definition must be of the same kind (ordinary aggregate, ordered-set aggregate, or hypothetical-set aggregate) as the old one.

If a schema name is given (for example, `CREATE AGGREGATE myschema.myagg ...`) then the aggregate function is created in the specified schema. Otherwise it is created in the current schema.

An aggregate function is identified by its name and input data type(s). Two aggregates in the same schema can have the same name if they operate on different input types. The name and input data type(s) of an aggregate must also be distinct from the name and input data type(s) of every ordinary function in the same schema. This behavior is identical to overloading of ordinary function names (see CREATE FUNCTION).

A simple aggregate function is made from one or two ordinary functions: a state transition function *`sfunc`*, and an optional final calculation function *`ffunc`*. These are used as follows:

```
sfunc( internal-state, next-data-values ) ---> next-internal-state
ffunc( internal-state ) ---> aggregate-value
```

Postgres Pro creates a temporary variable of data type *`stype`* to hold the current internal state of the aggregate. At each input row, the aggregate argument value(s) are calculated and the state transition function is invoked with the current state value and the new argument value(s) to calculate a new internal state value. After all the rows have been processed, the final function is invoked once to calculate the aggregate's return value. If there is no final function then the ending state value is returned as-is.

An aggregate function can provide an initial condition, that is, an initial value for the internal state value. This is specified and stored in the database as a value of type `text`, but it must be a valid external representation of a constant of the state value data type. If it is not supplied then the state value starts out null.

If the state transition function is declared “strict”, then it cannot be called with null inputs. With such a transition function, aggregate execution behaves as follows. Rows with any null input values are ignored (the function is not called and the previous state value is retained). If the initial state value is null, then at the first row with all-nonnull input values, the first argument value replaces the state value, and the transition function is invoked at each subsequent row with all-nonnull input values. This is handy for implementing aggregates like `max`. Note that this behavior is only available when *`state_data_type`* is the same as the first *`arg_data_type`*. When these types are different, you must supply a nonnull initial condition or use a nonstrict transition function.

If the state transition function is not strict, then it will be called unconditionally at each input row, and must deal with null inputs and null state values for itself. This allows the aggregate author to have full control over the aggregate's handling of null values.

If the final function is declared “strict”, then it will not be called when the ending state value is null; instead a null result will be returned automatically. (Of course this is just the normal behavior of strict functions.) In any case the final function has the option of returning a null value. For example, the final function for `avg` returns null when it sees there were zero input rows.

Sometimes it is useful to declare the final function as taking not just the state value, but extra parameters corresponding to the aggregate's input values. The main reason for doing this is if the final function is polymorphic and the state value's data type would be inadequate to pin down the result type. These extra parameters are always passed as NULL (and so the final function must not be strict when the `FINALFUNC_EXTRA` option is used), but nonetheless they are valid parameters. The final function could for example make use of `get_fn_expr_argtype` to identify the actual argument type in the current call.

An aggregate can optionally support *moving-aggregate mode*, as described in Section 40.12.1. This requires specifying the `MSFUNC`, `MINVFUNC`, and `MSTYPE` parameters, and optionally the `MSSPACE`, `MFINALFUNC`, `MFINALFUNC_EXTRA`, `MFINALFUNC_MODIFY`, and `MINITCOND` parameters. Except for `MINVFUNC`, these parameters work like the corresponding simple-aggregate parameters without `M`; they define a separate implementation of the aggregate that includes an inverse transition function.

The syntax with `ORDER BY` in the parameter list creates a special type of aggregate called an *ordered-set aggregate*; or if `HYPOTHETICAL` is specified, then a *hypothetical-set aggregate* is created. These aggregates operate over groups of sorted values in order-dependent ways, so that specification of an input sort order is an essential part of a call. Also, they can have *direct* arguments, which are arguments that are evaluated only once per aggregation rather than once per input row. Hypothetical-set aggregates are a subclass of ordered-set aggregates in which some of the direct arguments are required to match, in number and data types, the aggregated argument columns. This allows the values of those direct arguments to be added to the collection of aggregate-input rows as an additional “hypothetical” row.

An aggregate can optionally support *partial aggregation*, as described in Section 40.12.4. This requires specifying the `COMBINEFUNC` parameter. If the *`state_data_type`* is `internal`, it's usually also appropriate to provide the `SERIALFUNC` and `DESERIALFUNC` parameters so that parallel aggregation is possible. Note that the aggregate must also be marked `PARALLEL SAFE` to enable parallel aggregation.

Aggregates that behave like `MIN` or `MAX` can sometimes be optimized by looking into an index instead of scanning every input row. If this aggregate can be so optimized, indicate it by specifying a *sort operator*. The basic requirement is that the aggregate must yield the first element in the sort ordering induced by the operator; in other words:

```
SELECT agg(col) FROM tab;
```

must be equivalent to:

```
SELECT col FROM tab ORDER BY col USING sortop LIMIT 1;
```

Further assumptions are that the aggregate ignores null inputs, and that it delivers a null result if and only if there were no non-null inputs. Ordinarily, a data type's `<` operator is the proper sort operator for `MIN`, and `>` is the proper sort operator for `MAX`. Note that the optimization will never actually take effect unless the specified operator is the “less than” or “greater than” strategy member of a B-tree index operator class.

To be able to create an aggregate function, you must have `USAGE` privilege on the argument types, the state type(s), and the return type, as well as `EXECUTE` privilege on the supporting functions.

Parameters

`name`

The name (optionally schema-qualified) of the aggregate function to create.

argmode

The mode of an argument: IN or VARIADIC. (Aggregate functions do not support OUT arguments.) If omitted, the default is IN. Only the last argument can be marked VARIADIC.

argname

The name of an argument. This is currently only useful for documentation purposes. If omitted, the argument has no name.

arg_data_type

An input data type on which this aggregate function operates. To create a zero-argument aggregate function, write * in place of the list of argument specifications. (An example of such an aggregate is count(*).)

base_type

In the old syntax for CREATE AGGREGATE, the input data type is specified by a basetype parameter rather than being written next to the aggregate name. Note that this syntax allows only one input parameter. To define a zero-argument aggregate function with this syntax, specify the basetype as "ANY" (not *). Ordered-set aggregates cannot be defined with the old syntax.

sfunc

The name of the state transition function to be called for each input row. For a normal *N*-argument aggregate function, the *sfunc* must take *N*+1 arguments, the first being of type *state_data_type* and the rest matching the declared input data type(s) of the aggregate. The function must return a value of type *state_data_type*. This function takes the current state value and the current input data value(s), and returns the next state value.

For ordered-set (including hypothetical-set) aggregates, the state transition function receives only the current state value and the aggregated arguments, not the direct arguments. Otherwise it is the same.

state_data_type

The data type for the aggregate's state value.

state_data_size

The approximate average size (in bytes) of the aggregate's state value. If this parameter is omitted or is zero, a default estimate is used based on the *state_data_type*. The planner uses this value to estimate the memory required for a grouped aggregate query.

ffunc

The name of the final function called to compute the aggregate's result after all input rows have been traversed. For a normal aggregate, this function must take a single argument of type *state_data_type*. The return data type of the aggregate is defined as the return type of this function. If *ffunc* is not specified, then the ending state value is used as the aggregate's result, and the return type is *state_data_type*.

For ordered-set (including hypothetical-set) aggregates, the final function receives not only the final state value, but also the values of all the direct arguments.

If FINALFUNC_EXTRA is specified, then in addition to the final state value and any direct arguments, the final function receives extra NULL values corresponding to the aggregate's regular (aggregated) arguments. This is mainly useful to allow correct resolution of the aggregate result type when a polymorphic aggregate is being defined.

FINALFUNC_MODIFY = { READ_ONLY | SHAREABLE | READ_WRITE }

This option specifies whether the final function is a pure function that does not modify its arguments. READ_ONLY indicates it does not; the other two values indicate that it may change the transition state

value. See Notes below for more detail. The default is `READ_ONLY`, except for ordered-set aggregates, for which the default is `READ_WRITE`.

combinefunc

The *combinefunc* function may optionally be specified to allow the aggregate function to support partial aggregation. If provided, the *combinefunc* must combine two *state_data_type* values, each containing the result of aggregation over some subset of the input values, to produce a new *state_data_type* that represents the result of aggregating over both sets of inputs. This function can be thought of as an *sfunc*, where instead of acting upon an individual input row and adding it to the running aggregate state, it adds another aggregate state to the running state.

The *combinefunc* must be declared as taking two arguments of the *state_data_type* and returning a value of the *state_data_type*. Optionally this function may be "strict". In this case the function will not be called when either of the input states are null; the other state will be taken as the correct result.

For aggregate functions whose *state_data_type* is `internal`, the *combinefunc* must not be strict. In this case the *combinefunc* must ensure that null states are handled correctly and that the state being returned is properly stored in the aggregate memory context.

serialfunc

An aggregate function whose *state_data_type* is `internal` can participate in parallel aggregation only if it has a *serialfunc* function, which must serialize the aggregate state into a `bytea` value for transmission to another process. This function must take a single argument of type `internal` and return type `bytea`. A corresponding *deserialfunc* is also required.

deserialfunc

Deserialize a previously serialized aggregate state back into *state_data_type*. This function must take two arguments of types `bytea` and `internal`, and produce a result of type `internal`. (Note: the second, `internal` argument is unused, but is required for type safety reasons.)

initial_condition

The initial setting for the state value. This must be a string constant in the form accepted for the data type *state_data_type*. If not specified, the state value starts out null.

msfunc

The name of the forward state transition function to be called for each input row in moving-aggregate mode. This is exactly like the regular transition function, except that its first argument and result are of type *mstate_data_type*, which might be different from *state_data_type*.

minvfunc

The name of the inverse state transition function to be used in moving-aggregate mode. This function has the same argument and result types as *msfunc*, but it is used to remove a value from the current aggregate state, rather than add a value to it. The inverse transition function must have the same strictness attribute as the forward state transition function.

mstate_data_type

The data type for the aggregate's state value, when using moving-aggregate mode.

mstate_data_size

The approximate average size (in bytes) of the aggregate's state value, when using moving-aggregate mode. This works the same as *state_data_size*.

mffunc

The name of the final function called to compute the aggregate's result after all input rows have been traversed, when using moving-aggregate mode. This works the same as *ffunc*, except that

its first argument's type is *mstate_data_type* and extra dummy arguments are specified by writing MFINALFUNC_EXTRA. The aggregate result type determined by *mffunc* or *mstate_data_type* must match that determined by the aggregate's regular implementation.

MFINALFUNC_MODIFY = { READ_ONLY | SHAREABLE | READ_WRITE }

This option is like FINALFUNC_MODIFY, but it describes the behavior of the moving-aggregate final function.

minitial_condition

The initial setting for the state value, when using moving-aggregate mode. This works the same as *initial_condition*.

sort_operator

The associated sort operator for a MIN- or MAX-like aggregate. This is just an operator name (possibly schema-qualified). The operator is assumed to have the same input data types as the aggregate (which must be a single-argument normal aggregate).

PARALLEL = { SAFE | RESTRICTED | UNSAFE }

The meanings of PARALLEL SAFE, PARALLEL RESTRICTED, and PARALLEL UNSAFE are the same as in CREATE FUNCTION. An aggregate will not be considered for parallelization if it is marked PARALLEL UNSAFE (which is the default!) or PARALLEL RESTRICTED. Note that the parallel-safety markings of the aggregate's support functions are not consulted by the planner, only the marking of the aggregate itself.

HYPOTHETICAL

For ordered-set aggregates only, this flag specifies that the aggregate arguments are to be processed according to the requirements for hypothetical-set aggregates: that is, the last few direct arguments must match the data types of the aggregated (WITHIN GROUP) arguments. The HYPOTHETICAL flag has no effect on run-time behavior, only on parse-time resolution of the data types and collations of the aggregate's arguments.

The parameters of CREATE AGGREGATE can be written in any order, not just the order illustrated above.

Notes

In parameters that specify support function names, you can write a schema name if needed, for example SFUNC = public.sum. Do not write argument types there, however — the argument types of the support functions are determined from other parameters.

Ordinarily, Postgres Pro functions are expected to be true functions that do not modify their input values. However, an aggregate transition function, *when used in the context of an aggregate*, is allowed to cheat and modify its transition-state argument in place. This can provide substantial performance benefits compared to making a fresh copy of the transition state each time.

Likewise, while an aggregate final function is normally expected not to modify its input values, sometimes it is impractical to avoid modifying the transition-state argument. Such behavior must be declared using the FINALFUNC_MODIFY parameter. The READ_WRITE value indicates that the final function modifies the transition state in unspecified ways. This value prevents use of the aggregate as a window function, and it also prevents merging of transition states for aggregate calls that share the same input values and transition functions. The SHAREABLE value indicates that the transition function cannot be applied after the final function, but multiple final-function calls can be performed on the ending transition state value. This value prevents use of the aggregate as a window function, but it allows merging of transition states. (That is, the optimization of interest here is not applying the same final function repeatedly, but applying different final functions to the same ending transition state value. This is allowed as long as none of the final functions are marked READ_WRITE.)

If an aggregate supports moving-aggregate mode, it will improve calculation efficiency when the aggregate is used as a window function for a window with moving frame start (that is, a frame start mode other

than UNBOUNDED PRECEDING). Conceptually, the forward transition function adds input values to the aggregate's state when they enter the window frame from the bottom, and the inverse transition function removes them again when they leave the frame at the top. So, when values are removed, they are always removed in the same order they were added. Whenever the inverse transition function is invoked, it will thus receive the earliest added but not yet removed argument value(s). The inverse transition function can assume that at least one row will remain in the current state after it removes the oldest row. (When this would not be the case, the window function mechanism simply starts a fresh aggregation, rather than using the inverse transition function.)

The forward transition function for moving-aggregate mode is not allowed to return NULL as the new state value. If the inverse transition function returns NULL, this is taken as an indication that the inverse function cannot reverse the state calculation for this particular input, and so the aggregate calculation will be redone from scratch for the current frame starting position. This convention allows moving-aggregate mode to be used in situations where there are some infrequent cases that are impractical to reverse out of the running state value.

If no moving-aggregate implementation is supplied, the aggregate can still be used with moving frames, but Postgres Pro will recompute the whole aggregation whenever the start of the frame moves. Note that whether or not the aggregate supports moving-aggregate mode, Postgres Pro can handle a moving frame end without recalculation; this is done by continuing to add new values to the aggregate's state. This is why use of an aggregate as a window function requires that the final function be read-only: it must not damage the aggregate's state value, so that the aggregation can be continued even after an aggregate result value has been obtained for one set of frame boundaries.

The syntax for ordered-set aggregates allows VARIADIC to be specified for both the last direct parameter and the last aggregated (WITHIN GROUP) parameter. However, the current implementation restricts use of VARIADIC in two ways. First, ordered-set aggregates can only use VARIADIC "any", not other variadic array types. Second, if the last direct parameter is VARIADIC "any", then there can be only one aggregated parameter and it must also be VARIADIC "any". (In the representation used in the system catalogs, these two parameters are merged into a single VARIADIC "any" item, since pg_proc cannot represent functions with more than one VARIADIC parameter.) If the aggregate is a hypothetical-set aggregate, the direct arguments that match the VARIADIC "any" parameter are the hypothetical ones; any preceding parameters represent additional direct arguments that are not constrained to match the aggregated arguments.

Currently, ordered-set aggregates do not need to support moving-aggregate mode, since they cannot be used as window functions.

Partial (including parallel) aggregation is currently not supported for ordered-set aggregates. Also, it will never be used for aggregate calls that include DISTINCT or ORDER BY clauses, since those semantics cannot be supported during partial aggregation.

Examples

See Section 40.12.

Compatibility

CREATE AGGREGATE is a Postgres Pro language extension. The SQL standard does not provide for user-defined aggregate functions.

See Also

ALTER AGGREGATE, DROP AGGREGATE

CREATE CAST

CREATE CAST — define a new cast

Synopsis

```
CREATE CAST (source_type AS target_type)
    WITH FUNCTION function_name [ (argument_type [, ...]) ]
    [ AS ASSIGNMENT | AS IMPLICIT ]

CREATE CAST (source_type AS target_type)
    WITHOUT FUNCTION
    [ AS ASSIGNMENT | AS IMPLICIT ]

CREATE CAST (source_type AS target_type)
    WITH INOUT
    [ AS ASSIGNMENT | AS IMPLICIT ]
```

Description

`CREATE CAST` defines a new cast. A cast specifies how to perform a conversion between two data types. For example,

```
SELECT CAST(42 AS float8);
```

converts the integer constant 42 to type `float8` by invoking a previously specified function, in this case `float8(int4)`. (If no suitable cast has been defined, the conversion fails.)

Two types can be *binary coercible*, which means that the conversion can be performed "for free" without invoking any function. This requires that corresponding values use the same internal representation. For instance, the types `text` and `varchar` are binary coercible both ways. Binary coercibility is not necessarily a symmetric relationship. For example, the cast from `xml` to `text` can be performed for free in the present implementation, but the reverse direction requires a function that performs at least a syntax check. (Two types that are binary coercible both ways are also referred to as binary compatible.)

You can define a cast as an *I/O conversion cast* by using the `WITH INOUT` syntax. An I/O conversion cast is performed by invoking the output function of the source data type, and passing the resulting string to the input function of the target data type. In many common cases, this feature avoids the need to write a separate cast function for conversion. An I/O conversion cast acts the same as a regular function-based cast; only the implementation is different.

By default, a cast can be invoked only by an explicit cast request, that is an explicit `CAST(`*`x`* `AS` *`typename`*`)` or *`x`*`::`*`typename`* construct.

If the cast is marked `AS ASSIGNMENT` then it can be invoked implicitly when assigning a value to a column of the target data type. For example, supposing that `foo.f1` is a column of type `text`, then:

```
INSERT INTO foo (f1) VALUES (42);
```

will be allowed if the cast from type `integer` to type `text` is marked `AS ASSIGNMENT`, otherwise not. (We generally use the term *assignment cast* to describe this kind of cast.)

If the cast is marked `AS IMPLICIT` then it can be invoked implicitly in any context, whether assignment or internally in an expression. (We generally use the term *implicit cast* to describe this kind of cast.) For example, consider this query:

```
SELECT 2 + 4.0;
```

The parser initially marks the constants as being of type `integer` and `numeric` respectively. There is no `integer + numeric` operator in the system catalogs, but there is a `numeric + numeric` operator. The

query will therefore succeed if a cast from `integer` to `numeric` is available and is marked `AS IMPLICIT` — which in fact it is. The parser will apply the implicit cast and resolve the query as if it had been written

```
SELECT CAST ( 2 AS numeric ) + 4.0;
```

Now, the catalogs also provide a cast from `numeric` to `integer`. If that cast were marked `AS IMPLICIT` — which it is not — then the parser would be faced with choosing between the above interpretation and the alternative of casting the `numeric` constant to `integer` and applying the `integer + integer` operator. Lacking any knowledge of which choice to prefer, it would give up and declare the query ambiguous. The fact that only one of the two casts is implicit is the way in which we teach the parser to prefer resolution of a mixed `numeric`-and-`integer` expression as `numeric`; there is no built-in knowledge about that.

It is wise to be conservative about marking casts as implicit. An overabundance of implicit casting paths can cause Postgres Pro to choose surprising interpretations of commands, or to be unable to resolve commands at all because there are multiple possible interpretations. A good rule of thumb is to make a cast implicitly invokable only for information-preserving transformations between types in the same general type category. For example, the cast from `int2` to `int4` can reasonably be implicit, but the cast from `float8` to `int4` should probably be assignment-only. Cross-type-category casts, such as `text` to `int4`, are best made explicit-only.

> **Note**
>
> Sometimes it is necessary for usability or standards-compliance reasons to provide multiple implicit casts among a set of types, resulting in ambiguity that cannot be avoided as above. The parser has a fallback heuristic based on *type categories* and *preferred types* that can help to provide desired behavior in such cases. See CREATE TYPE for more information.

To be able to create a cast, you must own the source or the target data type and have `USAGE` privilege on the other type. To create a binary-coercible cast, you must be superuser. (This restriction is made because an erroneous binary-coercible cast conversion can easily crash the server.)

Parameters

source_type

The name of the source data type of the cast.

target_type

The name of the target data type of the cast.

function_name[(*argument_type* [, ...])]

The function used to perform the cast. The function name can be schema-qualified. If it is not, the function will be looked up in the schema search path. The function's result data type must match the target type of the cast. Its arguments are discussed below. If no argument list is specified, the function name must be unique in its schema.

`WITHOUT FUNCTION`

Indicates that the source type is binary-coercible to the target type, so no function is required to perform the cast.

`WITH INOUT`

Indicates that the cast is an I/O conversion cast, performed by invoking the output function of the source data type, and passing the resulting string to the input function of the target data type.

`AS ASSIGNMENT`

Indicates that the cast can be invoked implicitly in assignment contexts.

`AS IMPLICIT`

Indicates that the cast can be invoked implicitly in any context.

Cast implementation functions can have one to three arguments. The first argument type must be identical to or binary-coercible from the cast's source type. The second argument, if present, must be type `integer`; it receives the type modifier associated with the destination type, or `-1` if there is none. The third argument, if present, must be type `boolean`; it receives `true` if the cast is an explicit cast, `false` otherwise. (Bizarrely, the SQL standard demands different behaviors for explicit and implicit casts in some cases. This argument is supplied for functions that must implement such casts. It is not recommended that you design your own data types so that this matters.)

The return type of a cast function must be identical to or binary-coercible to the cast's target type.

Ordinarily a cast must have different source and target data types. However, it is allowed to declare a cast with identical source and target types if it has a cast implementation function with more than one argument. This is used to represent type-specific length coercion functions in the system catalogs. The named function is used to coerce a value of the type to the type modifier value given by its second argument.

When a cast has different source and target types and a function that takes more than one argument, it supports converting from one type to another and applying a length coercion in a single step. When no such entry is available, coercion to a type that uses a type modifier involves two cast steps, one to convert between data types and a second to apply the modifier.

A cast to or from a domain type currently has no effect. Casting to or from a domain uses the casts associated with its underlying type.

Notes

Use `DROP CAST` to remove user-defined casts.

Remember that if you want to be able to convert types both ways you need to declare casts both ways explicitly.

It is normally not necessary to create casts between user-defined types and the standard string types (`text`, `varchar`, and `char(n)`, as well as user-defined types that are defined to be in the string category). Postgres Pro provides automatic I/O conversion casts for that. The automatic casts to string types are treated as assignment casts, while the automatic casts from string types are explicit-only. You can override this behavior by declaring your own cast to replace an automatic cast, but usually the only reason to do so is if you want the conversion to be more easily invokable than the standard assignment-only or explicit-only setting. Another possible reason is that you want the conversion to behave differently from the type's I/O function; but that is sufficiently surprising that you should think twice about whether it's a good idea. (A small number of the built-in types do indeed have different behaviors for conversions, mostly because of requirements of the SQL standard.)

While not required, it is recommended that you continue to follow this old convention of naming cast implementation functions after the target data type. Many users are used to being able to cast data types using a function-style notation, that is *typename*(*x*). This notation is in fact nothing more nor less than a call of the cast implementation function; it is not specially treated as a cast. If your conversion functions are not named to support this convention then you will have surprised users. Since Postgres Pro allows overloading of the same function name with different argument types, there is no difficulty in having multiple conversion functions from different types that all use the target type's name.

Note

Actually the preceding paragraph is an oversimplification: there are two cases in which a function-call construct will be treated as a cast request without having matched it to an actual function. If a function call *name*(*x*) does not exactly match any existing function, but *name* is the name of a

data type and `pg_cast` provides a binary-coercible cast to this type from the type of *x*, then the call will be construed as a binary-coercible cast. This exception is made so that binary-coercible casts can be invoked using functional syntax, even though they lack any function. Likewise, if there is no `pg_cast` entry but the cast would be to or from a string type, the call will be construed as an I/O conversion cast. This exception allows I/O conversion casts to be invoked using functional syntax.

Note

There is also an exception to the exception: I/O conversion casts from composite types to string types cannot be invoked using functional syntax, but must be written in explicit cast syntax (either `CAST` or `::` notation). This exception was added because after the introduction of automatically-provided I/O conversion casts, it was found too easy to accidentally invoke such a cast when a function or column reference was intended.

Examples

To create an assignment cast from type `bigint` to type `int4` using the function `int4(bigint)`:

```
CREATE CAST (bigint AS int4) WITH FUNCTION int4(bigint) AS ASSIGNMENT;
```

(This cast is already predefined in the system.)

Compatibility

The `CREATE CAST` command conforms to the SQL standard, except that SQL does not make provisions for binary-coercible types or extra arguments to implementation functions. `AS IMPLICIT` is a Postgres Pro extension, too.

See Also

CREATE FUNCTION, CREATE TYPE, DROP CAST

CREATE COLLATION

CREATE COLLATION — define a new collation

Synopsis

```
CREATE COLLATION [ IF NOT EXISTS ] name (
    [ LOCALE = locale, ]
    [ LC_COLLATE = lc_collate, ]
    [ LC_CTYPE = lc_ctype, ]
    [ PROVIDER = provider, ]
    [ DETERMINISTIC = boolean, ]
    [ VERSION = version ]
)
CREATE COLLATION [ IF NOT EXISTS ] name FROM existing_collation
```

Description

`CREATE COLLATION` defines a new collation using the specified operating system locale settings, or by copying an existing collation.

To be able to create a collation, you must have `CREATE` privilege on the destination schema.

Parameters

`IF NOT EXISTS`

Do not throw an error if a collation with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing collation is anything like the one that would have been created.

name

The name of the collation. The collation name can be schema-qualified. If it is not, the collation is defined in the current schema. The collation name must be unique within that schema. (The system catalogs can contain collations with the same name for other encodings, but these are ignored if the database encoding does not match.)

locale

This is a shortcut for setting `LC_COLLATE` and `LC_CTYPE` at once. If you specify this, you cannot specify either of those parameters.

lc_collate

Use the specified operating system locale for the `LC_COLLATE` locale category.

lc_ctype

Use the specified operating system locale for the `LC_CTYPE` locale category.

provider

Specifies the provider to use for locale services associated with this collation. Possible values are: `icu`, `libc`. `libc` is the default. The available choices depend on the operating system and build options.

`DETERMINISTIC`

Specifies whether the collation should use deterministic comparisons. The default is true. A deterministic comparison considers strings that are not byte-wise equal to be unequal even if they are

considered logically equal by the comparison. Postgres Pro breaks ties using a byte-wise comparison. Comparison that is not deterministic can make the collation be, say, case- or accent-insensitive. For that, you need to choose an appropriate `LOCALE` setting *and* set the collation to not deterministic here.

Nondeterministic collations are only supported with the ICU provider.

version

Specifies the version string to store with the collation. Normally, this should be omitted, which will cause the version to be computed from the actual version of the collation as provided by the operating system. This option is intended to be used by `pg_upgrade` for copying the version from an existing installation.

See also ALTER COLLATION for how to handle collation version mismatches.

existing_collation

The name of an existing collation to copy. The new collation will have the same properties as the existing one, but it will be an independent object.

Notes

`CREATE COLLATION` takes a `SHARE ROW EXCLUSIVE` lock, which is self-conflicting, on the `pg_collation` system catalog, so only one `CREATE COLLATION` command can run at a time.

Use `DROP COLLATION` to remove user-defined collations.

See Section 23.2.2.3 for more information on how to create collations.

When using the `libc` collation provider, the locale must be applicable to the current database encoding. See CREATE DATABASE for the precise rules.

Examples

To create a collation from the operating system locale `ru_RU.utf8` (assuming the current database encoding is `UTF8`):

```
CREATE COLLATION russian (locale = 'ru_RU.utf8');
```

To create a collation using the ICU provider where Latin characters precede Cyrillic ones:

```
CREATE COLLATION latn_cyrl (provider = icu, locale = 'ru-RU-u-kr-latn-cyrl');
```

To create a collation from an existing collation:

```
CREATE COLLATION german FROM "de_DE";
```

This can be convenient to be able to use operating-system-independent collation names in applications.

Compatibility

There is a `CREATE COLLATION` statement in the SQL standard, but it is limited to copying an existing collation. The syntax to create a new collation is a Postgres Pro extension.

See Also

ALTER COLLATION, DROP COLLATION

CREATE CONVERSION

CREATE CONVERSION — define a new encoding conversion

Synopsis

```
CREATE [ DEFAULT ] CONVERSION name
    FOR source_encoding TO dest_encoding FROM function_name
```

Description

`CREATE CONVERSION` defines a new conversion between two character set encodings.

Conversions that are marked `DEFAULT` can be used for automatic encoding conversion between client and server. To support that usage, two conversions, from encoding A to B *and* from encoding B to A, must be defined.

To be able to create a conversion, you must have `EXECUTE` privilege on the function and `CREATE` privilege on the destination schema.

Parameters

`DEFAULT`

The `DEFAULT` clause indicates that this conversion is the default for this particular source to destination encoding. There should be only one default encoding in a schema for the encoding pair.

`name`

The name of the conversion. The conversion name can be schema-qualified. If it is not, the conversion is defined in the current schema. The conversion name must be unique within a schema.

`source_encoding`

The source encoding name.

`dest_encoding`

The destination encoding name.

`function_name`

The function used to perform the conversion. The function name can be schema-qualified. If it is not, the function will be looked up in the path.

The function must have the following signature:

```
conv_proc(
    integer,  -- source encoding ID
    integer,  -- destination encoding ID
    cstring,  -- source string (null terminated C string)
    internal, -- destination (fill with a null terminated C string)
    integer,  -- source string length
    boolean   -- if true, don't throw an error if conversion fails
) RETURNS integer;
```

The return value is the number of source bytes that were successfully converted. If the last argument is false, the function must throw an error on invalid input, and the return value is always equal to the source string length.

Notes

Neither the source nor the destination encoding can be `SQL_ASCII`, as the server's behavior for cases involving the `SQL_ASCII` “encoding” is hard-wired.

Use `DROP CONVERSION` to remove user-defined conversions.

The privileges required to create a conversion might be changed in a future release.

Examples

To create a conversion from encoding `UTF8` to `LATIN1` using `myfunc`:

```
CREATE CONVERSION myconv FOR 'UTF8' TO 'LATIN1' FROM myfunc;
```

Compatibility

`CREATE CONVERSION` is a Postgres Pro extension. There is no `CREATE CONVERSION` statement in the SQL standard, but a `CREATE TRANSLATION` statement that is very similar in purpose and syntax.

See Also

ALTER CONVERSION, CREATE FUNCTION, DROP CONVERSION

CREATE DATABASE

CREATE DATABASE — create a new database

Synopsis

```
CREATE DATABASE name
    [ WITH ] [ OWNER [=] user_name ]
           [ TEMPLATE [=] template ]
           [ ENCODING [=] encoding ]
           [ LOCALE [=] locale[@provider] ]
           [ LC_COLLATE [=] lc_collate[@provider] ]
           [ LC_CTYPE [=] lc_ctype ]
           [ TABLESPACE [=] tablespace_name ]
           [ ALLOW_CONNECTIONS [=] allowconn ]
           [ CONNECTION LIMIT [=] connlimit ]
           [ IS_TEMPLATE [=] istemplate ]
```

Description

`CREATE DATABASE` creates a new Postgres Pro database.

To create a database, you must be a superuser or have the special `CREATEDB` privilege. See CREATE ROLE.

By default, the new database will be created by cloning the standard system database `template1`. A different template can be specified by writing `TEMPLATE` *name*. In particular, by writing `TEMPLATE template0`, you can create a pristine database (one where no user-defined objects exist and where the system objects have not been altered) containing only the standard objects predefined by your version of Postgres Pro. This is useful if you wish to avoid copying any installation-local objects that might have been added to `template1`.

Parameters

name

The name of a database to create.

user_name

The role name of the user who will own the new database, or `DEFAULT` to use the default (namely, the user executing the command). To create a database owned by another role, you must be a direct or indirect member of that role, or be a superuser.

template

The name of the template from which to create the new database, or `DEFAULT` to use the default template (`template1`).

encoding

Character set encoding to use in the new database. Specify a string constant (e.g., `'SQL_ASCII'`), or an integer encoding number, or `DEFAULT` to use the default encoding (namely, the encoding of the template database). The character sets supported by the Postgres Pro server are described in Section 23.3.1. See below for additional restrictions.

locale[@*provider*]

This is a shortcut for setting `LC_COLLATE` and `LC_CTYPE` at once. If you specify this, you cannot specify either of those parameters. Optionally, you can specify the provider of the default collation same way as in *lc_collate*.

> **Tip**
>
> The other locale settings lc_messages, lc_monetary, lc_numeric, and lc_time are not fixed per database and are not set by this command. If you want to make them the default for a specific database, you can use `ALTER DATABASE ... SET`.

lc_collate[@*provider*]

Collation order (`LC_COLLATE`) to use in the new database. This affects the sort order applied to strings, e.g., in queries with ORDER BY, as well as the order used in indexes on text columns. The default is to use the collation order of the template database. Optionally, you can specify the provider of the default collation after the `@` symbol, as explained in Section 23.2.2. Supported values are `icu` and `libc`. See below for additional restrictions.

lc_ctype

Character classification (`LC_CTYPE`) to use in the new database. This affects the categorization of characters, e.g., lower, upper and digit. The default is to use the character classification of the template database. See below for additional restrictions.

tablespace_name

The name of the tablespace that will be associated with the new database, or `DEFAULT` to use the template database's tablespace. This tablespace will be the default tablespace used for objects created in this database. See CREATE TABLESPACE for more information.

allowconn

If false then no one can connect to this database. The default is true, allowing connections (except as restricted by other mechanisms, such as `GRANT`/`REVOKE CONNECT`).

connlimit

How many concurrent connections can be made to this database. -1 (the default) means no limit.

istemplate

If true, then this database can be cloned by any user with `CREATEDB` privileges; if false (the default), then only superusers or the owner of the database can clone it.

Optional parameters can be written in any order, not only the order illustrated above.

Notes

`CREATE DATABASE` cannot be executed inside a transaction block.

Errors along the line of "could not initialize database directory" are most likely related to insufficient permissions on the data directory, a full disk, or other file system problems.

Use `DROP DATABASE` to remove a database.

The program createdb is a wrapper program around this command, provided for convenience.

Database-level configuration parameters (set via `ALTER DATABASE`) and database-level permissions (set via `GRANT`) are not copied from the template database.

Although it is possible to copy a database other than `template1` by specifying its name as the template, this is not (yet) intended as a general-purpose "`COPY DATABASE`" facility. The principal limitation is that no other sessions can be connected to the template database while it is being copied. `CREATE DATABASE` will fail if any other connection exists when it starts; otherwise, new connections to the template database are locked out until `CREATE DATABASE` completes. See Section 22.3 for more information.

The character set encoding specified for the new database must be compatible with the chosen locale settings (`LC_COLLATE` and `LC_CTYPE`). If the locale is `C` (or equivalently `POSIX`), then all encodings are allowed, but for other locale settings there is only one encoding that will work properly. (On Windows, however, UTF-8 encoding can be used with any locale.) `CREATE DATABASE` will allow superusers to specify `SQL_ASCII` encoding regardless of the locale settings, but this choice is deprecated and may result in misbehavior of character-string functions if data that is not encoding-compatible with the locale is stored in the database.

The encoding and locale settings must match those of the template database, except when `template0` is used as template. This is because other databases might contain data that does not match the specified encoding, or might contain indexes whose sort ordering is affected by `LC_COLLATE` and `LC_CTYPE`. Copying such data would result in a database that is corrupt according to the new settings. `template0`, however, is known to not contain any data or indexes that would be affected.

The `CONNECTION LIMIT` option is only enforced approximately; if two new sessions start at about the same time when just one connection “slot” remains for the database, it is possible that both will fail. Also, the limit is not enforced against superusers or background worker processes.

Examples

To create a new database:

```
CREATE DATABASE lusiadas;
```

To create a database `sales` owned by user `salesapp` with a default tablespace of `salesspace`:

```
CREATE DATABASE sales OWNER salesapp TABLESPACE salesspace;
```

To create a database `music` with a different locale:

```
CREATE DATABASE music
    LOCALE 'sv_SE.utf8'
    TEMPLATE template0;
```

In this example, the `TEMPLATE template0` clause is required if the specified locale is different from the one in `template1`. (If it is not, then specifying the locale explicitly is redundant.)

To create a database `music2` with a different locale and a different character set encoding:

```
CREATE DATABASE music2
    LOCALE 'sv_SE.iso885915'
    ENCODING LATIN9
    TEMPLATE template0;
```

The specified locale and encoding settings must match, or an error will be reported.

Note that locale names are specific to the operating system, so that the above commands might not work in the same way everywhere.

Compatibility

There is no `CREATE DATABASE` statement in the SQL standard. Databases are equivalent to catalogs, whose creation is implementation-defined.

See Also

ALTER DATABASE, DROP DATABASE

CREATE DOMAIN

CREATE DOMAIN — define a new domain

Synopsis

```
CREATE DOMAIN name [ AS ] data_type
    [ COLLATE collation ]
    [ DEFAULT expression ]
    [ constraint [ ... ] ]

where constraint is:

[ CONSTRAINT constraint_name ]
{ NOT NULL | NULL | CHECK (expression) }
```

Description

`CREATE DOMAIN` creates a new domain. A domain is essentially a data type with optional constraints (restrictions on the allowed set of values). The user who defines a domain becomes its owner.

If a schema name is given (for example, `CREATE DOMAIN myschema.mydomain ...`) then the domain is created in the specified schema. Otherwise it is created in the current schema. The domain name must be unique among the types and domains existing in its schema.

Domains are useful for abstracting common constraints on fields into a single location for maintenance. For example, several tables might contain email address columns, all requiring the same CHECK constraint to verify the address syntax. Define a domain rather than setting up each table's constraint individually.

To be able to create a domain, you must have `USAGE` privilege on the underlying type.

Parameters

name

The name (optionally schema-qualified) of a domain to be created.

data_type

The underlying data type of the domain. This can include array specifiers.

collation

An optional collation for the domain. If no collation is specified, the domain has the same collation behavior as its underlying data type. The underlying type must be collatable if `COLLATE` is specified.

`DEFAULT` *expression*

The `DEFAULT` clause specifies a default value for columns of the domain data type. The value is any variable-free expression (but subqueries are not allowed). The data type of the default expression must match the data type of the domain. If no default value is specified, then the default value is the null value.

The default expression will be used in any insert operation that does not specify a value for the column. If a default value is defined for a particular column, it overrides any default associated with the domain. In turn, the domain default overrides any default value associated with the underlying data type.

`CONSTRAINT` *constraint_name*

An optional name for a constraint. If not specified, the system generates a name.

`NOT NULL`

Values of this domain are prevented from being null (but see notes below).

`NULL`

Values of this domain are allowed to be null. This is the default.

This clause is only intended for compatibility with nonstandard SQL databases. Its use is discouraged in new applications.

`CHECK (`*expression*`)`

`CHECK` clauses specify integrity constraints or tests which values of the domain must satisfy. Each constraint must be an expression producing a Boolean result. It should use the key word `VALUE` to refer to the value being tested. Expressions evaluating to TRUE or UNKNOWN succeed. If the expression produces a FALSE result, an error is reported and the value is not allowed to be converted to the domain type.

Currently, `CHECK` expressions cannot contain subqueries nor refer to variables other than `VALUE`.

When a domain has multiple `CHECK` constraints, they will be tested in alphabetical order by name. (PostgreSQL versions before 9.5 did not honor any particular firing order for `CHECK` constraints.)

Notes

Domain constraints, particularly `NOT NULL`, are checked when converting a value to the domain type. It is possible for a column that is nominally of the domain type to read as null despite there being such a constraint. For example, this can happen in an outer-join query, if the domain column is on the nullable side of the outer join. A more subtle example is

```
INSERT INTO tab (domcol) VALUES ((SELECT domcol FROM tab WHERE false));
```

The empty scalar sub-SELECT will produce a null value that is considered to be of the domain type, so no further constraint checking is applied to it, and the insertion will succeed.

It is very difficult to avoid such problems, because of SQL's general assumption that a null value is a valid value of every data type. Best practice therefore is to design a domain's constraints so that a null value is allowed, and then to apply column `NOT NULL` constraints to columns of the domain type as needed, rather than directly to the domain type.

Postgres Pro assumes that `CHECK` constraints' conditions are immutable, that is, they will always give the same result for the same input value. This assumption is what justifies examining `CHECK` constraints only when a value is first converted to be of a domain type, and not at other times. (This is essentially the same as the treatment of table `CHECK` constraints, as described in Section 5.4.1.)

An example of a common way to break this assumption is to reference a user-defined function in a `CHECK` expression, and then change the behavior of that function. Postgres Pro does not disallow that, but it will not notice if there are stored values of the domain type that now violate the `CHECK` constraint. That would cause a subsequent database dump and restore to fail. The recommended way to handle such a change is to drop the constraint (using `ALTER DOMAIN`), adjust the function definition, and re-add the constraint, thereby rechecking it against stored data.

Examples

This example creates the `us_postal_code` data type and then uses the type in a table definition. A regular expression test is used to verify that the value looks like a valid US postal code:

```
CREATE DOMAIN us_postal_code AS TEXT
CHECK(
   VALUE ~ '^\d{5}$'
OR VALUE ~ '^\d{5}-\d{4}$'
```

```
);

CREATE TABLE us_snail_addy (
  address_id SERIAL PRIMARY KEY,
  street1 TEXT NOT NULL,
  street2 TEXT,
  street3 TEXT,
  city TEXT NOT NULL,
  postal us_postal_code NOT NULL
);
```

Compatibility

The command `CREATE DOMAIN` conforms to the SQL standard.

See Also

ALTER DOMAIN, DROP DOMAIN

CREATE EVENT TRIGGER

CREATE EVENT TRIGGER — define a new event trigger

Synopsis

```
CREATE EVENT TRIGGER name
    ON event
    [ WHEN filter_variable IN (filter_value [, ... ]) [ AND ... ] ]
    EXECUTE { FUNCTION | PROCEDURE } function_name()
```

Description

`CREATE EVENT TRIGGER` creates a new event trigger. Whenever the designated event occurs and the `WHEN` condition associated with the trigger, if any, is satisfied, the trigger function will be executed. For a general introduction to event triggers, see Chapter 42. The user who creates an event trigger becomes its owner.

Parameters

name

The name to give the new trigger. This name must be unique within the database.

event

The name of the event that triggers a call to the given function. See Section 42.1 for more information on event names.

filter_variable

The name of a variable used to filter events. This makes it possible to restrict the firing of the trigger to a subset of the cases in which it is supported. Currently the only supported *filter_variable* is `TAG`.

filter_value

A list of values for the associated *filter_variable* for which the trigger should fire. For `TAG`, this means a list of command tags (e.g., `'DROP FUNCTION'`).

function_name

A user-supplied function that is declared as taking no argument and returning type `event_trigger`.

In the syntax of `CREATE EVENT TRIGGER`, the keywords `FUNCTION` and `PROCEDURE` are equivalent, but the referenced function must in any case be a function, not a procedure. The use of the keyword `PROCEDURE` here is historical and deprecated.

Notes

Only superusers can create event triggers.

Event triggers are disabled in single-user mode (see postgres). If an erroneous event trigger disables the database so much that you can't even drop the trigger, restart in single-user mode and you'll be able to do that. Event triggers can also be temporarily disabled for such troubleshooting, see ignore_event_trigger.

Examples

Forbid the execution of any DDL command:

```
CREATE OR REPLACE FUNCTION abort_any_command()
```

```
  RETURNS event_trigger
 LANGUAGE plpgsql
  AS $$
BEGIN
  RAISE EXCEPTION 'command % is disabled', tg_tag;
END;
$$;

CREATE EVENT TRIGGER abort_ddl ON ddl_command_start
   EXECUTE FUNCTION abort_any_command();
```

Compatibility

There is no `CREATE EVENT TRIGGER` statement in the SQL standard.

See Also

ALTER EVENT TRIGGER, DROP EVENT TRIGGER, CREATE FUNCTION

CREATE EXTENSION

CREATE EXTENSION — install an extension

Synopsis

```
CREATE EXTENSION [ IF NOT EXISTS ] extension_name
    [ WITH ] [ SCHEMA schema_name ]
             [ VERSION version ]
             [ CASCADE ]
```

Description

`CREATE EXTENSION` loads a new extension into the current database. There must not be an extension of the same name already loaded.

Loading an extension essentially amounts to running the extension's script file. The script will typically create new SQL objects such as functions, data types, operators and index support methods. `CREATE EXTENSION` additionally records the identities of all the created objects, so that they can be dropped again if `DROP EXTENSION` is issued.

The user who runs `CREATE EXTENSION` becomes the owner of the extension for purposes of later privilege checks, and normally also becomes the owner of any objects created by the extension's script.

Loading an extension ordinarily requires the same privileges that would be required to create its component objects. For many extensions this means superuser privileges are needed. However, if the extension is marked *trusted* in its control file, then it can be installed by any user who has `CREATE` privilege on the current database. In this case the extension object itself will be owned by the calling user, but the contained objects will be owned by the bootstrap superuser (unless the extension's script explicitly assigns them to the calling user). This configuration gives the calling user the right to drop the extension, but not to modify individual objects within it.

Parameters

`IF NOT EXISTS`

Do not throw an error if an extension with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing extension is anything like the one that would have been created from the currently-available script file.

`extension_name`

The name of the extension to be installed. Postgres Pro will create the extension using details from the file `SHAREDIR/extension/`*`extension_name`*`.control`.

`schema_name`

The name of the schema in which to install the extension's objects, given that the extension allows its contents to be relocated. The named schema must already exist. If not specified, and the extension's control file does not specify a schema either, the current default object creation schema is used.

If the extension specifies a `schema` parameter in its control file, then that schema cannot be overridden with a `SCHEMA` clause. Normally, an error will be raised if a `SCHEMA` clause is given and it conflicts with the extension's `schema` parameter. However, if the `CASCADE` clause is also given, then *`schema_name`* is ignored when it conflicts. The given *`schema_name`* will be used for installation of any needed extensions that do not specify `schema` in their control files.

Remember that the extension itself is not considered to be within any schema: extensions have unqualified names that must be unique database-wide. But objects belonging to the extension can be within schemas.

version

The version of the extension to install. This can be written as either an identifier or a string literal. The default version is whatever is specified in the extension's control file.

CASCADE

Automatically install any extensions that this extension depends on that are not already installed. Their dependencies are likewise automatically installed, recursively. The SCHEMA clause, if given, applies to all extensions that get installed this way. Other options of the statement are not applied to automatically-installed extensions; in particular, their default versions are always selected.

Notes

Before you can use CREATE EXTENSION to load an extension into a database, the extension's supporting files must be installed. Information about installing the extensions supplied with Postgres Pro can be found in Additional Supplied Modules.

The extensions currently available for loading can be identified from the pg_available_extensions or pg_available_extension_versions system views.

Caution

Installing an extension as superuser requires trusting that the extension's author wrote the extension installation script in a secure fashion. It is not terribly difficult for a malicious user to create trojan-horse objects that will compromise later execution of a carelessly-written extension script, allowing that user to acquire superuser privileges. However, trojan-horse objects are only hazardous if they are in the search_path during script execution, meaning that they are in the extension's installation target schema or in the schema of some extension it depends on. Therefore, a good rule of thumb when dealing with extensions whose scripts have not been carefully vetted is to install them only into schemas for which CREATE privilege has not been and will not be granted to any untrusted users. Likewise for any extensions they depend on.

The extensions supplied with Postgres Pro are believed to be secure against installation-time attacks of this sort, except for a few that depend on other extensions. As stated in the documentation for those extensions, they should be installed into secure schemas, or installed into the same schemas as the extensions they depend on, or both.

For information about writing new extensions, see Section 40.17.

Examples

Install the hstore extension into the current database, placing its objects in schema addons:

```
CREATE EXTENSION hstore SCHEMA addons;
```

Another way to accomplish the same thing:

```
SET search_path = addons;
CREATE EXTENSION hstore;
```

Compatibility

CREATE EXTENSION is a Postgres Pro extension.

See Also

ALTER EXTENSION, DROP EXTENSION

CREATE FOREIGN DATA WRAPPER

CREATE FOREIGN DATA WRAPPER — define a new foreign-data wrapper

Synopsis

```
CREATE FOREIGN DATA WRAPPER name
    [ HANDLER handler_function | NO HANDLER ]
    [ VALIDATOR validator_function | NO VALIDATOR ]
    [ OPTIONS ( option 'value' [, ... ] ) ]
```

Description

`CREATE FOREIGN DATA WRAPPER` creates a new foreign-data wrapper. The user who defines a foreign-data wrapper becomes its owner.

The foreign-data wrapper name must be unique within the database.

Only superusers can create foreign-data wrappers.

Parameters

name

The name of the foreign-data wrapper to be created.

`HANDLER` *handler_function*

handler_function is the name of a previously registered function that will be called to retrieve the execution functions for foreign tables. The handler function must take no arguments, and its return type must be `fdw_handler`.

It is possible to create a foreign-data wrapper with no handler function, but foreign tables using such a wrapper can only be declared, not accessed.

`VALIDATOR` *validator_function*

validator_function is the name of a previously registered function that will be called to check the generic options given to the foreign-data wrapper, as well as options for foreign servers, user mappings and foreign tables using the foreign-data wrapper. If no validator function or `NO VALIDATOR` is specified, then options will not be checked at creation time. (Foreign-data wrappers will possibly ignore or reject invalid option specifications at run time, depending on the implementation.) The validator function must take two arguments: one of type `text[]`, which will contain the array of options as stored in the system catalogs, and one of type `oid`, which will be the OID of the system catalog containing the options. The return type is ignored; the function should report invalid options using the `ereport(ERROR)` function.

`OPTIONS ( option 'value' [, ... ] )`

This clause specifies options for the new foreign-data wrapper. The allowed option names and values are specific to each foreign data wrapper and are validated using the foreign-data wrapper's validator function. Option names must be unique.

Notes

Postgres Pro's foreign-data functionality is still under active development. Optimization of queries is primitive (and mostly left to the wrapper, too). Thus, there is considerable room for future performance improvements.

Examples

Create a useless foreign-data wrapper `dummy`:

```
CREATE FOREIGN DATA WRAPPER dummy;
```

Create a foreign-data wrapper `file` with handler function `file_fdw_handler`:

```
CREATE FOREIGN DATA WRAPPER file HANDLER file_fdw_handler;
```

Create a foreign-data wrapper `mywrapper` with some options:

```
CREATE FOREIGN DATA WRAPPER mywrapper
    OPTIONS (debug 'true');
```

Compatibility

`CREATE FOREIGN DATA WRAPPER` conforms to ISO/IEC 9075-9 (SQL/MED), with the exception that the `HANDLER` and `VALIDATOR` clauses are extensions and the standard clauses `LIBRARY` and `LANGUAGE` are not implemented in Postgres Pro.

Note, however, that the SQL/MED functionality as a whole is not yet conforming.

See Also

ALTER FOREIGN DATA WRAPPER, DROP FOREIGN DATA WRAPPER, CREATE SERVER, CREATE USER MAPPING, CREATE FOREIGN TABLE

CREATE FOREIGN TABLE

CREATE FOREIGN TABLE — define a new foreign table

Synopsis

```
CREATE FOREIGN TABLE [ IF NOT EXISTS ] table_name ( [
  { column_name data_type [ OPTIONS ( option 'value' [, ... ] ) ] [ COLLATE collation ]
 [ column_constraint [ ... ] ]
    | table_constraint }
    [, ... ]
] )
[ INHERITS ( parent_table [, ... ] ) ]
  SERVER server_name
[ OPTIONS ( option 'value' [, ... ] ) ]

CREATE FOREIGN TABLE [ IF NOT EXISTS ] table_name
  PARTITION OF parent_table [ (
  { column_name [ WITH OPTIONS ] [ column_constraint [ ... ] ]
    | table_constraint }
    [, ... ]
) ]
{ FOR VALUES partition_bound_spec | DEFAULT }
  SERVER server_name
[ OPTIONS ( option 'value' [, ... ] ) ]

where column_constraint is:

[ CONSTRAINT constraint_name ]
{ NOT NULL |
  NULL |
  CHECK ( expression ) [ NO INHERIT ] |
  DEFAULT default_expr |
  GENERATED ALWAYS AS ( generation_expr ) STORED }

and table_constraint is:

[ CONSTRAINT constraint_name ]
CHECK ( expression ) [ NO INHERIT ]

and partition_bound_spec is:

IN ( partition_bound_expr [, ...] ) |
FROM ( { partition_bound_expr | MINVALUE | MAXVALUE } [, ...] )
  TO ( { partition_bound_expr | MINVALUE | MAXVALUE } [, ...] ) |
WITH ( MODULUS numeric_literal, REMAINDER numeric_literal )
```

Description

`CREATE FOREIGN TABLE` creates a new foreign table in the current database. The table will be owned by the user issuing the command.

If a schema name is given (for example, `CREATE FOREIGN TABLE myschema.mytable ...`) then the table is created in the specified schema. Otherwise it is created in the current schema. The name of the foreign table must be distinct from the name of any other foreign table, table, sequence, index, view, or materialized view in the same schema.

`CREATE FOREIGN TABLE` also automatically creates a data type that represents the composite type corresponding to one row of the foreign table. Therefore, foreign tables cannot have the same name as any existing data type in the same schema.

If `PARTITION OF` clause is specified then the table is created as a partition of `parent_table` with specified bounds.

To be able to create a foreign table, you must have `USAGE` privilege on the foreign server, as well as `USAGE` privilege on all column types used in the table.

Parameters

`IF NOT EXISTS`

Do not throw an error if a relation with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing relation is anything like the one that would have been created.

`table_name`

The name (optionally schema-qualified) of the table to be created.

`column_name`

The name of a column to be created in the new table.

`data_type`

The data type of the column. This can include array specifiers. For more information on the data types supported by Postgres Pro, refer to Chapter 8.

`COLLATE` *`collation`*

The `COLLATE` clause assigns a collation to the column (which must be of a collatable data type). If not specified, the column data type's default collation is used.

`INHERITS ( parent_table [, ... ] )`

The optional `INHERITS` clause specifies a list of tables from which the new foreign table automatically inherits all columns. Parent tables can be plain tables or foreign tables. See the similar form of `CREATE TABLE` for more details.

`PARTITION OF` *`parent_table`* `{ FOR VALUES` *`partition_bound_spec`* `| DEFAULT }`

This form can be used to create the foreign table as partition of the given parent table with specified partition bound values. See the similar form of `CREATE TABLE` for more details. Note that it is currently not allowed to create the foreign table as a partition of the parent table if there are `UNIQUE` indexes on the parent table. (See also `ALTER TABLE ATTACH PARTITION`.)

`CONSTRAINT` *`constraint_name`*

An optional name for a column or table constraint. If the constraint is violated, the constraint name is present in error messages, so constraint names like `col must be positive` can be used to communicate helpful constraint information to client applications. (Double-quotes are needed to specify constraint names that contain spaces.) If a constraint name is not specified, the system generates a name.

`NOT NULL`

The column is not allowed to contain null values.

`NULL`

The column is allowed to contain null values. This is the default.

This clause is only provided for compatibility with non-standard SQL databases. Its use is discouraged in new applications.

`CHECK ( expression ) [ NO INHERIT ]`

The `CHECK` clause specifies an expression producing a Boolean result which each row in the foreign table is expected to satisfy; that is, the expression should produce TRUE or UNKNOWN, never FALSE, for all rows in the foreign table. A check constraint specified as a column constraint should reference that column's value only, while an expression appearing in a table constraint can reference multiple columns.

Currently, `CHECK` expressions cannot contain subqueries nor refer to variables other than columns of the current row. The system column `tableoid` may be referenced, but not any other system column.

A constraint marked with `NO INHERIT` will not propagate to child tables.

`DEFAULT default_expr`

The `DEFAULT` clause assigns a default data value for the column whose column definition it appears within. The value is any variable-free expression (subqueries and cross-references to other columns in the current table are not allowed). The data type of the default expression must match the data type of the column.

The default expression will be used in any insert operation that does not specify a value for the column. If there is no default for a column, then the default is null.

`GENERATED ALWAYS AS ( generation_expr ) STORED`

This clause creates the column as a *generated column*. The column cannot be written to, and when read the result of the specified expression will be returned.

The keyword `STORED` is required to signify that the column will be computed on write. (The computed value will be presented to the foreign-data wrapper for storage and must be returned on reading.)

The generation expression can refer to other columns in the table, but not other generated columns. Any functions and operators used must be immutable. References to other tables are not allowed.

server_name

The name of an existing foreign server to use for the foreign table. For details on defining a server, see CREATE SERVER.

`OPTIONS ( option 'value' [, ...] )`

Options to be associated with the new foreign table or one of its columns. The allowed option names and values are specific to each foreign data wrapper and are validated using the foreign-data wrapper's validator function. Duplicate option names are not allowed (although it's OK for a table option and a column option to have the same name).

Notes

Constraints on foreign tables (such as `CHECK` or `NOT NULL` clauses) are not enforced by the core Postgres Pro system, and most foreign data wrappers do not attempt to enforce them either; that is, the constraint is simply assumed to hold true. There would be little point in such enforcement since it would only apply to rows inserted or updated via the foreign table, and not to rows modified by other means, such as directly on the remote server. Instead, a constraint attached to a foreign table should represent a constraint that is being enforced by the remote server.

Some special-purpose foreign data wrappers might be the only access mechanism for the data they access, and in that case it might be appropriate for the foreign data wrapper itself to perform constraint enforcement. But you should not assume that a wrapper does that unless its documentation says so.

Although Postgres Pro does not attempt to enforce constraints on foreign tables, it does assume that they are correct for purposes of query optimization. If there are rows visible in the foreign table that do not satisfy a declared constraint, queries on the table might produce errors or incorrect answers. It is the user's responsibility to ensure that the constraint definition matches reality.

> **Caution**
>
> When a foreign table is used as a partition of a partitioned table, there is an implicit constraint that its contents must satisfy the partitioning rule. Again, it is the user's responsibility to ensure that that is true, which is best done by installing a matching constraint on the remote server.

Within a partitioned table containing foreign-table partitions, an `UPDATE` that changes the partition key value can cause a row to be moved from a local partition to a foreign-table partition, provided the foreign data wrapper supports tuple routing. However, it is not currently possible to move a row from a foreign-table partition to another partition. An `UPDATE` that would require doing that will fail due to the partitioning constraint, assuming that that is properly enforced by the remote server.

Similar considerations apply to generated columns. Stored generated columns are computed on insert or update on the local Postgres Pro server and handed to the foreign-data wrapper for writing out to the foreign data store, but it is not enforced that a query of the foreign table returns values for stored generated columns that are consistent with the generation expression. Again, this might result in incorrect query results.

Examples

Create foreign table `films`, which will be accessed through the server `film_server`:

```
CREATE FOREIGN TABLE films (
    code        char(5) NOT NULL,
    title       varchar(40) NOT NULL,
    did         integer NOT NULL,
    date_prod   date,
    kind        varchar(10),
    len         interval hour to minute
)
SERVER film_server;
```

Create foreign table `measurement_y2016m07`, which will be accessed through the server `server_07`, as a partition of the range partitioned table `measurement`:

```
CREATE FOREIGN TABLE measurement_y2016m07
    PARTITION OF measurement FOR VALUES FROM ('2016-07-01') TO ('2016-08-01')
    SERVER server_07;
```

Compatibility

The `CREATE FOREIGN TABLE` command largely conforms to the SQL standard; however, much as with `CREATE TABLE`, `NULL` constraints and zero-column foreign tables are permitted. The ability to specify column default values is also a Postgres Pro extension. Table inheritance, in the form defined by Postgres Pro, is nonstandard.

See Also

ALTER FOREIGN TABLE, DROP FOREIGN TABLE, CREATE TABLE, CREATE SERVER, IMPORT FOREIGN SCHEMA

CREATE FUNCTION

CREATE FUNCTION — define a new function

Synopsis

```
CREATE [ OR REPLACE ] FUNCTION
    name ( [ [ argmode ] [ argname ] argtype [ { DEFAULT | = } default_expr ]
 [, ...] ] )
    [ RETURNS rettype
      | RETURNS TABLE ( column_name column_type [, ...] ) ]
  { LANGUAGE lang_name
    | TRANSFORM { FOR TYPE type_name } [, ... ]
    | WINDOW
    | { IMMUTABLE | STABLE | VOLATILE }
    | [ NOT ] LEAKPROOF
    | { CALLED ON NULL INPUT | RETURNS NULL ON NULL INPUT | STRICT }
    | { [ EXTERNAL ] SECURITY INVOKER | [ EXTERNAL ] SECURITY DEFINER }
    | PARALLEL { UNSAFE | RESTRICTED | SAFE }
    | COST execution_cost
    | ROWS result_rows
    | SUPPORT support_function
    | SET configuration_parameter { TO value | = value | FROM CURRENT }
    | AS 'definition'
    | AS 'obj_file', 'link_symbol'
    | sql_body
  } ...
```

Description

`CREATE FUNCTION` defines a new function. `CREATE OR REPLACE FUNCTION` will either create a new function, or replace an existing definition. To be able to define a function, the user must have the `USAGE` privilege on the language.

If a schema name is included, then the function is created in the specified schema. Otherwise it is created in the current schema. The name of the new function must not match any existing function or procedure with the same input argument types in the same schema. However, functions and procedures of different argument types can share a name (this is called *overloading*).

To replace the current definition of an existing function, use `CREATE OR REPLACE FUNCTION`. It is not possible to change the name or argument types of a function this way (if you tried, you would actually be creating a new, distinct function). Also, `CREATE OR REPLACE FUNCTION` will not let you change the return type of an existing function. To do that, you must drop and recreate the function. (When using `OUT` parameters, that means you cannot change the types of any `OUT` parameters except by dropping the function.)

When `CREATE OR REPLACE FUNCTION` is used to replace an existing function, the ownership and permissions of the function do not change. All other function properties are assigned the values specified or implied in the command. You must own the function to replace it (this includes being a member of the owning role).

If you drop and then recreate a function, the new function is not the same entity as the old; you will have to drop existing rules, views, triggers, etc. that refer to the old function. Use `CREATE OR REPLACE FUNCTION` to change a function definition without breaking objects that refer to the function. Also, `ALTER FUNCTION` can be used to change most of the auxiliary properties of an existing function.

The user that creates the function becomes the owner of the function.

To be able to create a function, you must have USAGE privilege on the argument types and the return type.

Refer to Section 40.3 for further information on writing functions.

Parameters

name

The name (optionally schema-qualified) of the function to create.

argmode

The mode of an argument: IN, OUT, INOUT, or VARIADIC. If omitted, the default is IN. Only OUT arguments can follow a VARIADIC one. Also, OUT and INOUT arguments cannot be used together with the RETURNS TABLE notation.

argname

The name of an argument. Some languages (including SQL and PL/pgSQL) let you use the name in the function body. For other languages the name of an input argument is just extra documentation, so far as the function itself is concerned; but you can use input argument names when calling a function to improve readability (see Section 4.3). In any case, the name of an output argument is significant, because it defines the column name in the result row type. (If you omit the name for an output argument, the system will choose a default column name.)

argtype

The data type(s) of the function's arguments (optionally schema-qualified), if any. The argument types can be base, composite, or domain types, or can reference the type of a table column.

Depending on the implementation language it might also be allowed to specify "pseudo-types" such as cstring. Pseudo-types indicate that the actual argument type is either incompletely specified, or outside the set of ordinary SQL data types.

The type of a column is referenced by writing *table_name*.*column_name*%TYPE. Using this feature can sometimes help make a function independent of changes to the definition of a table.

default_expr

An expression to be used as default value if the parameter is not specified. The expression has to be coercible to the argument type of the parameter. Only input (including INOUT) parameters can have a default value. All input parameters following a parameter with a default value must have default values as well.

rettype

The return data type (optionally schema-qualified). The return type can be a base, composite, or domain type, or can reference the type of a table column. Depending on the implementation language it might also be allowed to specify "pseudo-types" such as cstring. If the function is not supposed to return a value, specify void as the return type.

When there are OUT or INOUT parameters, the RETURNS clause can be omitted. If present, it must agree with the result type implied by the output parameters: RECORD if there are multiple output parameters, or the same type as the single output parameter.

The SETOF modifier indicates that the function will return a set of items, rather than a single item.

The type of a column is referenced by writing *table_name*.*column_name*%TYPE.

column_name

The name of an output column in the RETURNS TABLE syntax. This is effectively another way of declaring a named OUT parameter, except that RETURNS TABLE also implies RETURNS SETOF.

column_type

The data type of an output column in the RETURNS TABLE syntax.

lang_name

The name of the language that the function is implemented in. It can be sql, c, internal, or the name of a user-defined procedural language, e.g., plpgsql. The default is sql if *sql_body* is specified. Enclosing the name in single quotes is deprecated and requires matching case.

TRANSFORM { FOR TYPE *type_name* } [, ...] }

Lists which transforms a call to the function should apply. Transforms convert between SQL types and language-specific data types; see CREATE TRANSFORM. Procedural language implementations usually have hardcoded knowledge of the built-in types, so those don't need to be listed here. If a procedural language implementation does not know how to handle a type and no transform is supplied, it will fall back to a default behavior for converting data types, but this depends on the implementation.

WINDOW

WINDOW indicates that the function is a *window function* rather than a plain function. This is currently only useful for functions written in C. The WINDOW attribute cannot be changed when replacing an existing function definition.

IMMUTABLE
STABLE
VOLATILE

These attributes inform the query optimizer about the behavior of the function. At most one choice can be specified. If none of these appear, VOLATILE is the default assumption.

IMMUTABLE indicates that the function cannot modify the database and always returns the same result when given the same argument values; that is, it does not do database lookups or otherwise use information not directly present in its argument list. If this option is given, any call of the function with all-constant arguments can be immediately replaced with the function value.

STABLE indicates that the function cannot modify the database, and that within a single table scan it will consistently return the same result for the same argument values, but that its result could change across SQL statements. This is the appropriate selection for functions whose results depend on database lookups, parameter variables (such as the current time zone), etc. (It is inappropriate for AFTER triggers that wish to query rows modified by the current command.) Also note that the current_timestamp family of functions qualify as stable, since their values do not change within a transaction.

VOLATILE indicates that the function value can change even within a single table scan, so no optimizations can be made. Relatively few database functions are volatile in this sense; some examples are random(), currval(), timeofday(). But note that any function that has side-effects must be classified volatile, even if its result is quite predictable, to prevent calls from being optimized away; an example is setval().

For additional details see Section 40.7.

LEAKPROOF

LEAKPROOF indicates that the function has no side effects. It reveals no information about its arguments other than by its return value. For example, a function which throws an error message for some argument values but not others, or which includes the argument values in any error message, is not leakproof. This affects how the system executes queries against views created with the security_barrier option or tables with row level security enabled. The system will enforce conditions from security policies and security barrier views before any user-supplied conditions from the query itself that contain non-leakproof functions, in order to prevent the inadvertent exposure of data.

Functions and operators marked as leakproof are assumed to be trustworthy, and may be executed before conditions from security policies and security barrier views. In addition, functions which do not take arguments or which are not passed any arguments from the security barrier view or table do not have to be marked as leakproof to be executed before security conditions. See CREATE VIEW and Section 43.5. This option can only be set by the superuser.

`CALLED ON NULL INPUT`
`RETURNS NULL ON NULL INPUT`
`STRICT`

`CALLED ON NULL INPUT` (the default) indicates that the function will be called normally when some of its arguments are null. It is then the function author's responsibility to check for null values if necessary and respond appropriately.

`RETURNS NULL ON NULL INPUT` or `STRICT` indicates that the function always returns null whenever any of its arguments are null. If this parameter is specified, the function is not executed when there are null arguments; instead a null result is assumed automatically.

`[EXTERNAL] SECURITY INVOKER`
`[EXTERNAL] SECURITY DEFINER`

`SECURITY INVOKER` indicates that the function is to be executed with the privileges of the user that calls it. That is the default. `SECURITY DEFINER` specifies that the function is to be executed with the privileges of the user that owns it.

The key word `EXTERNAL` is allowed for SQL conformance, but it is optional since, unlike in SQL, this feature applies to all functions not only external ones.

`PARALLEL`

`PARALLEL UNSAFE` indicates that the function can't be executed in parallel mode and the presence of such a function in an SQL statement forces a serial execution plan. This is the default. `PARALLEL RESTRICTED` indicates that the function can be executed in parallel mode, but the execution is restricted to parallel group leader. `PARALLEL SAFE` indicates that the function is safe to run in parallel mode without restriction.

Functions should be labeled parallel unsafe if they modify any database state, or if they make changes to the transaction such as using sub-transactions, or if they access sequences or attempt to make persistent changes to settings (e.g., `setval`). They should be labeled as parallel restricted if they access temporary tables, client connection state, cursors, prepared statements, or miscellaneous backend-local state which the system cannot synchronize in parallel mode (e.g., `setseed` cannot be executed other than by the group leader because a change made by another process would not be reflected in the leader). In general, if a function is labeled as being safe when it is restricted or unsafe, or if it is labeled as being restricted when it is in fact unsafe, it may throw errors or produce wrong answers when used in a parallel query. C-language functions could in theory exhibit totally undefined behavior if mislabeled, since there is no way for the system to protect itself against arbitrary C code, but in most likely cases the result will be no worse than for any other function. If in doubt, functions should be labeled as `UNSAFE`, which is the default.

`COST` *`execution_cost`*

A positive number giving the estimated execution cost for the function, in units of cpu_operator_cost. If the function returns a set, this is the cost per returned row. If the cost is not specified, 1 unit is assumed for C-language and internal functions, and 100 units for functions in all other languages. Larger values cause the planner to try to avoid evaluating the function more often than necessary.

`ROWS` *`result_rows`*

A positive number giving the estimated number of rows that the planner should expect the function to return. This is only allowed when the function is declared to return a set. The default assumption is 1000 rows.

SUPPORT *support_function*

The name (optionally schema-qualified) of a *planner support function* to use for this function. See Section 40.11 for details. You must be superuser to use this option.

configuration_parameter
value

The SET clause causes the specified configuration parameter to be set to the specified value when the function is entered, and then restored to its prior value when the function exits. SET FROM CURRENT saves the value of the parameter that is current when CREATE FUNCTION is executed as the value to be applied when the function is entered.

If a SET clause is attached to a function, then the effects of a SET LOCAL command executed inside the function for the same variable are restricted to the function: the configuration parameter's prior value is still restored at function exit. However, an ordinary SET command (without LOCAL) overrides the SET clause, much as it would do for a previous SET LOCAL command: the effects of such a command will persist after function exit, unless the current transaction is rolled back.

See SET and Chapter 19 for more information about allowed parameter names and values.

definition

A string constant defining the function; the meaning depends on the language. It can be an internal function name, the path to an object file, an SQL command, or text in a procedural language.

It is often helpful to use dollar quoting (see Section 4.1.2.4) to write the function definition string, rather than the normal single quote syntax. Without dollar quoting, any single quotes or backslashes in the function definition must be escaped by doubling them.

obj_file, *link_symbol*

This form of the AS clause is used for dynamically loadable C language functions when the function name in the C language source code is not the same as the name of the SQL function. The string *obj_file* is the name of the shared library file containing the compiled C function, and is interpreted as for the LOAD command. The string *link_symbol* is the function's link symbol, that is, the name of the function in the C language source code. If the link symbol is omitted, it is assumed to be the same as the name of the SQL function being defined. The C names of all functions must be different, so you must give overloaded C functions different C names (for example, use the argument types as part of the C names).

When repeated CREATE FUNCTION calls refer to the same object file, the file is only loaded once per session. To unload and reload the file (perhaps during development), start a new session.

sql_body

The body of a LANGUAGE SQL function. This can either be a single statement

```
RETURN expression
```

or a block

```
BEGIN ATOMIC
  statement;
  statement;
  ...
  statement;
END
```

This is similar to writing the text of the function body as a string constant (see *definition* above), but there are some differences: This form only works for LANGUAGE SQL, the string constant form works for all languages. This form is parsed at function definition time, the string constant form is parsed at execution time; therefore this form cannot support polymorphic argument types and other

constructs that are not resolvable at function definition time. This form tracks dependencies between the function and objects used in the function body, so `DROP ... CASCADE` will work correctly, whereas the form using string literals may leave dangling functions. Finally, this form is more compatible with the SQL standard and other SQL implementations.

Overloading

Postgres Pro allows function *overloading*; that is, the same name can be used for several different functions so long as they have distinct input argument types. Whether or not you use it, this capability entails security precautions when calling functions in databases where some users mistrust other users; see Section 10.3.

Two functions are considered the same if they have the same names and *input* argument types, ignoring any `OUT` parameters. Thus for example these declarations conflict:

```
CREATE FUNCTION foo(int) ...
CREATE FUNCTION foo(int, out text) ...
```

Functions that have different argument type lists will not be considered to conflict at creation time, but if defaults are provided they might conflict in use. For example, consider

```
CREATE FUNCTION foo(int) ...
CREATE FUNCTION foo(int, int default 42) ...
```

A call `foo(10)` will fail due to the ambiguity about which function should be called.

Notes

The full SQL type syntax is allowed for declaring a function's arguments and return value. However, parenthesized type modifiers (e.g., the precision field for type `numeric`) are discarded by `CREATE FUNCTION`. Thus for example `CREATE FUNCTION foo (varchar(10)) ...` is exactly the same as `CREATE FUNCTION foo (varchar) ...`.

When replacing an existing function with `CREATE OR REPLACE FUNCTION`, there are restrictions on changing parameter names. You cannot change the name already assigned to any input parameter (although you can add names to parameters that had none before). If there is more than one output parameter, you cannot change the names of the output parameters, because that would change the column names of the anonymous composite type that describes the function's result. These restrictions are made to ensure that existing calls of the function do not stop working when it is replaced.

If a function is declared `STRICT` with a `VARIADIC` argument, the strictness check tests that the variadic array *as a whole* is non-null. The function will still be called if the array has null elements.

Examples

Add two integers using an SQL function:

```
CREATE FUNCTION add(integer, integer) RETURNS integer
    AS 'select $1 + $2;'
    LANGUAGE SQL
    IMMUTABLE
    RETURNS NULL ON NULL INPUT;
```

The same function written in a more SQL-conforming style, using argument names and an unquoted body:

```
CREATE FUNCTION add(a integer, b integer) RETURNS integer
    LANGUAGE SQL
    IMMUTABLE
    RETURNS NULL ON NULL INPUT
    RETURN a + b;
```

Increment an integer, making use of an argument name, in PL/pgSQL:

```
CREATE OR REPLACE FUNCTION increment(i integer) RETURNS integer AS $$
        BEGIN
                RETURN i + 1;
        END;
$$ LANGUAGE plpgsql;
```

Return a record containing multiple output parameters:

```
CREATE FUNCTION dup(in int, out f1 int, out f2 text)
    AS $$ SELECT $1, CAST($1 AS text) || ' is text' $$
    LANGUAGE SQL;

SELECT * FROM dup(42);
```

You can do the same thing more verbosely with an explicitly named composite type:

```
CREATE TYPE dup_result AS (f1 int, f2 text);

CREATE FUNCTION dup(int) RETURNS dup_result
    AS $$ SELECT $1, CAST($1 AS text) || ' is text' $$
    LANGUAGE SQL;

SELECT * FROM dup(42);
```

Another way to return multiple columns is to use a `TABLE` function:

```
CREATE FUNCTION dup(int) RETURNS TABLE(f1 int, f2 text)
    AS $$ SELECT $1, CAST($1 AS text) || ' is text' $$
    LANGUAGE SQL;

SELECT * FROM dup(42);
```

However, a `TABLE` function is different from the preceding examples, because it actually returns a *set* of records, not just one record.

Writing `SECURITY DEFINER` Functions Safely

Because a `SECURITY DEFINER` function is executed with the privileges of the user that owns it, care is needed to ensure that the function cannot be misused. For security, search_path should be set to exclude any schemas writable by untrusted users. This prevents malicious users from creating objects (e.g., tables, functions, and operators) that mask objects intended to be used by the function. Particularly important in this regard is the temporary-table schema, which is searched first by default, and is normally writable by anyone. A secure arrangement can be obtained by forcing the temporary schema to be searched last. To do this, write `pg_temp`as the last entry in `search_path`. This function illustrates safe usage:

```
CREATE FUNCTION check_password(uname TEXT, pass TEXT)
RETURNS BOOLEAN AS $$
DECLARE passed BOOLEAN;
BEGIN
        SELECT  (pwd = $2) INTO passed
        FROM    pwds
        WHERE   username = $1;

        RETURN passed;
END;
$$  LANGUAGE plpgsql
    SECURITY DEFINER
    -- Set a secure search_path: trusted schema(s), then 'pg_temp'.
    SET search_path = admin, pg_temp;
```

This function's intention is to access a table `admin.pwds`. But without the `SET` clause, or with a `SET` clause mentioning only `admin`, the function could be subverted by creating a temporary table named `pwds`.

Before PostgreSQL version 8.3, the SET clause was not available, and so older functions may contain rather complicated logic to save, set, and restore search_path. The SET clause is far easier to use for this purpose.

Another point to keep in mind is that by default, execute privilege is granted to PUBLIC for newly created functions (see Section 5.7 for more information). Frequently you will wish to restrict use of a security definer function to only some users. To do that, you must revoke the default PUBLIC privileges and then grant execute privilege selectively. To avoid having a window where the new function is accessible to all, create it and set the privileges within a single transaction. For example:

```
BEGIN;
CREATE FUNCTION check_password(uname TEXT, pass TEXT) ... SECURITY DEFINER;
REVOKE ALL ON FUNCTION check_password(uname TEXT, pass TEXT) FROM PUBLIC;
GRANT EXECUTE ON FUNCTION check_password(uname TEXT, pass TEXT) TO admins;
COMMIT;
```

Compatibility

A CREATE FUNCTION command is defined in the SQL standard. The Postgres Pro implementation can be used in a compatible way but has many extensions. Conversely, the SQL standard specifies a number of optional features that are not implemented in Postgres Pro.

The following are important compatibility issues:

- OR REPLACE is a PostgreSQL extension.
- For compatibility with some other database systems, *argmode* can be written either before or after *argname*. But only the first way is standard-compliant.
- For parameter defaults, the SQL standard specifies only the syntax with the DEFAULT key word. The syntax with = is used in T-SQL and Firebird.
- The SETOF modifier is a PostgreSQL extension.
- Only SQL is standardized as a language.
- All other attributes except CALLED ON NULL INPUT and RETURNS NULL ON NULL INPUT are not standardized.
- For the body of LANGUAGE SQL functions, the SQL standard only specifies the *sql_body* form.

Simple LANGUAGE SQL functions can be written in a way that is both standard-conforming and portable to other implementations. More complex functions using advanced features, optimization attributes, or other languages will necessarily be specific to PostgreSQL in a significant way.

See Also

ALTER FUNCTION, DROP FUNCTION, GRANT, LOAD, REVOKE

CREATE GROUP

CREATE GROUP — define a new database role

Synopsis

```
CREATE GROUP name [ [ WITH ] option [ ... ] ]

where option can be:

      SUPERUSER | NOSUPERUSER
    | CREATEDB | NOCREATEDB
    | CREATEROLE | NOCREATEROLE
    | INHERIT | NOINHERIT
    | LOGIN | NOLOGIN
    | REPLICATION | NOREPLICATION
    | BYPASSRLS | NOBYPASSRLS
    | CONNECTION LIMIT connlimit
    | [ ENCRYPTED ] PASSWORD 'password' | PASSWORD NULL
    | VALID UNTIL 'timestamp'
    | IN ROLE role_name [, ...]
    | IN GROUP role_name [, ...]
    | ROLE role_name [, ...]
    | ADMIN role_name [, ...]
    | USER role_name [, ...]
    | SYSID uid
```

Description

`CREATE GROUP` is now an alias for CREATE ROLE.

Compatibility

There is no `CREATE GROUP` statement in the SQL standard.

See Also

CREATE ROLE

CREATE INDEX

CREATE INDEX — define a new index

Synopsis

```
CREATE [ UNIQUE ] INDEX [ CONCURRENTLY ] [ [ IF NOT EXISTS ] name ] ON
 [ ONLY ] table_name [ USING method ]
    ( { column_name | ( expression ) } [ COLLATE collation ] [ opclass
 [ ( opclass_parameter = value [, ... ] ) ] ] [ ASC | DESC ] [ NULLS { FIRST | LAST } ]
 [, ...] )
    [ INCLUDE ( column_name [, ...] ) ]
    [ WITH ( storage_parameter [= value] [, ... ] ) ]
    [ TABLESPACE tablespace_name ]
    [ WHERE predicate ]
```

Description

`CREATE INDEX` constructs an index on the specified column(s) of the specified relation, which can be a table or a materialized view. Indexes are primarily used to enhance database performance (though inappropriate use can result in slower performance).

The key field(s) for the index are specified as column names, or alternatively as expressions written in parentheses. Multiple fields can be specified if the index method supports multicolumn indexes.

An index field can be an expression computed from the values of one or more columns of the table row. This feature can be used to obtain fast access to data based on some transformation of the basic data. For example, an index computed on `upper(col)` would allow the clause `WHERE upper(col) = 'JIM'` to use an index.

Postgres Pro provides the index methods B-tree, hash, GiST, SP-GiST, GIN, RUM, and BRIN. Users can also define their own index methods, but that is fairly complicated.

When the `WHERE` clause is present, a *partial index* is created. A partial index is an index that contains entries for only a portion of a table, usually a portion that is more useful for indexing than the rest of the table. For example, if you have a table that contains both billed and unbilled orders where the unbilled orders take up a small fraction of the total table and yet that is an often used section, you can improve performance by creating an index on just that portion. Another possible application is to use `WHERE` with `UNIQUE` to enforce uniqueness over a subset of a table. See Section 11.8 for more discussion.

The expression used in the `WHERE` clause can refer only to columns of the underlying table, but it can use all columns, not just the ones being indexed. Presently, subqueries and aggregate expressions are also forbidden in `WHERE`. The same restrictions apply to index fields that are expressions.

All functions and operators used in an index definition must be “immutable”, that is, their results must depend only on their arguments and never on any outside influence (such as the contents of another table or the current time). This restriction ensures that the behavior of the index is well-defined. To use a user-defined function in an index expression or `WHERE` clause, remember to mark the function immutable when you create it.

Parameters

`UNIQUE`

Causes the system to check for duplicate values in the table when the index is created (if data already exist) and each time data is added. Attempts to insert or update data which would result in duplicate entries will generate an error.

Additional restrictions apply when unique indexes are applied to partitioned tables; see CREATE TABLE.

`CONCURRENTLY`

When this option is used, Postgres Pro will build the index without taking any locks that prevent concurrent inserts, updates, or deletes on the table; whereas a standard index build locks out writes (but not reads) on the table until it's done. There are several caveats to be aware of when using this option — see Building Indexes Concurrently below.

For temporary tables, `CREATE INDEX` is always non-concurrent, as no other session can access them, and non-concurrent index creation is cheaper.

`IF NOT EXISTS`

Do not throw an error if a relation with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing index is anything like the one that would have been created. Index name is required when `IF NOT EXISTS` is specified.

`INCLUDE`

The optional `INCLUDE` clause specifies a list of columns which will be included in the index as *non-key* columns. A non-key column cannot be used in an index scan search qualification, and it is disregarded for purposes of any uniqueness or exclusion constraint enforced by the index. However, an index-only scan can return the contents of non-key columns without having to visit the index's table, since they are available directly from the index entry. Thus, addition of non-key columns allows index-only scans to be used for queries that otherwise could not use them.

It's wise to be conservative about adding non-key columns to an index, especially wide columns. If an index tuple exceeds the maximum size allowed for the index type, data insertion will fail. In any case, non-key columns duplicate data from the index's table and bloat the size of the index, thus potentially slowing searches. Furthermore, B-tree deduplication is never used with indexes that have a non-key column.

Columns listed in the `INCLUDE` clause don't need appropriate operator classes; the clause can include columns whose data types don't have operator classes defined for a given access method.

Expressions are not supported as included columns since they cannot be used in index-only scans.

Currently, the B-tree, GiST and SP-GiST index access methods support this feature. In these indexes, the values of columns listed in the `INCLUDE` clause are included in leaf tuples which correspond to heap tuples, but are not included in upper-level index entries used for tree navigation.

`name`

The name of the index to be created. No schema name can be included here; the index is always created in the same schema as its parent table. If the name is omitted, Postgres Pro chooses a suitable name based on the parent table's name and the indexed column name(s).

`ONLY`

Indicates not to recurse creating indexes on partitions, if the table is partitioned. The default is to recurse.

`table_name`

The name (possibly schema-qualified) of the table to be indexed.

`method`

The name of the index method to be used. Choices are `btree`, `hash`, `gist`, `spgist`, `gin`, `brin`, or user-installed access methods like bloom. The default method is `btree`.

column_name

The name of a column of the table.

expression

An expression based on one or more columns of the table. The expression usually must be written with surrounding parentheses, as shown in the syntax. However, the parentheses can be omitted if the expression has the form of a function call.

collation

The name of the collation to use for the index. By default, the index uses the collation declared for the column to be indexed or the result collation of the expression to be indexed. Indexes with non-default collations can be useful for queries that involve expressions using non-default collations.

opclass

The name of an operator class. See below for details.

opclass_parameter

The name of an operator class parameter. See below for details.

ASC

Specifies ascending sort order (which is the default).

DESC

Specifies descending sort order.

NULLS FIRST

Specifies that nulls sort before non-nulls. This is the default when DESC is specified.

NULLS LAST

Specifies that nulls sort after non-nulls. This is the default when DESC is not specified.

storage_parameter

The name of an index-method-specific storage parameter. See Index Storage Parameters below for details.

tablespace_name

The tablespace in which to create the index. If not specified, default_tablespace is consulted, or temp_tablespaces for indexes on temporary tables.

predicate

The constraint expression for a partial index.

Index Storage Parameters

The optional WITH clause specifies *storage parameters* for the index. Each index method has its own set of allowed storage parameters. The B-tree, hash, GiST and SP-GiST index methods all accept this parameter:

fillfactor (integer)

The fillfactor for an index is a percentage that determines how full the index method will try to pack index pages. For B-trees, leaf pages are filled to this percentage during initial index builds, and also when extending the index at the right (adding new largest key values). If pages subsequently become completely full, they will be split, leading to fragmentation of the on-disk index structure. B-trees use a default fillfactor of 90, but any integer value from 10 to 100 can be selected.

B-tree indexes on tables where many inserts and/or updates are anticipated can benefit from lower fillfactor settings at `CREATE INDEX` time (following bulk loading into the table). Values in the range of 50 - 90 can usefully "smooth out" the *rate* of page splits during the early life of the B-tree index (lowering fillfactor like this may even lower the absolute number of page splits, though this effect is highly workload dependent). The B-tree bottom-up index deletion technique described in Section 64.4.2 is dependent on having some "extra" space on pages to store "extra" tuple versions, and so can be affected by fillfactor (though the effect is usually not significant).

In other specific cases it might be useful to increase fillfactor to 100 at `CREATE INDEX` time as a way of maximizing space utilization. You should only consider this when you are completely sure that the table is static (i.e. that it will never be affected by either inserts or updates). A fillfactor setting of 100 otherwise risks *harming* performance: even a few updates or inserts will cause a sudden flood of page splits.

The other index methods use fillfactor in different but roughly analogous ways; the default fillfactor varies between methods.

B-tree indexes additionally accept this parameter:

`deduplicate_items` (`boolean`)

Controls usage of the B-tree deduplication technique described in Section 64.4.3. Set to `ON` or `OFF` to enable or disable the optimization. (Alternative spellings of `ON` and `OFF` are allowed as described in Section 19.1.) The default is `ON`.

> **Note**
>
> Turning `deduplicate_items` off via `ALTER INDEX` prevents future insertions from triggering deduplication, but does not in itself make existing posting list tuples use the standard tuple representation.

GiST indexes additionally accept this parameter:

`buffering` (`enum`)

Determines whether the buffered build technique described in Section 65.4.1 is used to build the index. With `OFF` buffering is disabled, with `ON` it is enabled, and with `AUTO` it is initially disabled, but is turned on on-the-fly once the index size reaches effective_cache_size. The default is `AUTO`. Note that if sorted build is possible, it will be used instead of buffered build unless `buffering=ON` is specified.

GIN indexes accept different parameters:

`fastupdate` (`boolean`)

This setting controls usage of the fast update technique described in Section 67.4.1. It is a Boolean parameter: `ON` enables fast update, `OFF` disables it. The default is `ON`.

> **Note**
>
> Turning `fastupdate` off via `ALTER INDEX` prevents future insertions from going into the list of pending index entries, but does not in itself flush previous entries. You might want to `VACUUM` the table or call `gin_clean_pending_list` function afterward to ensure the pending list is emptied.

`gin_pending_list_limit` (`integer`)

Custom gin_pending_list_limit parameter. This value is specified in kilobytes.

RUM indexes accept different parameters:

`attach` (`text`)

This setting specifies the name of the column to attach as additional information.

`to` (`text`)

This setting specifies the name of the column to add ordering by.

`order_by_attach` (`boolean`)

This setting controls whether to use the (`attach`, `itempointer`) order instead of just `itempointer`.

BRIN indexes accept different parameters:

`pages_per_range` (`integer`)

Defines the number of table blocks that make up one block range for each entry of a BRIN index (see Section 68.1 for more details). The default is `128`.

`autosummarize` (`boolean`)

Defines whether a summarization run is queued for the previous page range whenever an insertion is detected on the next one. See Section 68.1.1 for more details. The default is `off`.

Building Indexes Concurrently

Creating an index can interfere with regular operation of a database. Normally Postgres Pro locks the table to be indexed against writes and performs the entire index build with a single scan of the table. Other transactions can still read the table, but if they try to insert, update, or delete rows in the table they will block until the index build is finished. This could have a severe effect if the system is a live production database. Very large tables can take many hours to be indexed, and even for smaller tables, an index build can lock out writers for periods that are unacceptably long for a production system.

Postgres Pro supports building indexes without locking out writes. This method is invoked by specifying the `CONCURRENTLY` option of `CREATE INDEX`. When this option is used, Postgres Pro must perform two scans of the table, and in addition it must wait for all existing transactions that could potentially modify or use the index to terminate. Thus this method requires more total work than a standard index build and takes significantly longer to complete. However, since it allows normal operations to continue while the index is built, this method is useful for adding new indexes in a production environment. Of course, the extra CPU and I/O load imposed by the index creation might slow other operations.

In a concurrent index build, the index is actually entered as an “invalid” index into the system catalogs in one transaction, then two table scans occur in two more transactions. Before each table scan, the index build must wait for existing transactions that have modified the table to terminate. After the second scan, the index build must wait for any transactions that have a snapshot (see Chapter 13) predating the second scan to terminate, including transactions used by any phase of concurrent index builds on other tables, if the indexes involved are partial or have columns that are not simple column references. Then finally the index can be marked “valid” and ready for use, and the `CREATE INDEX` command terminates. Even then, however, the index may not be immediately usable for queries: in the worst case, it cannot be used as long as transactions exist that predate the start of the index build.

If a problem arises while scanning the table, such as a deadlock or a uniqueness violation in a unique index, the `CREATE INDEX` command will fail but leave behind an “invalid” index. This index will be ignored for querying purposes because it might be incomplete; however it will still consume update overhead. The psql `\d` command will report such an index as `INVALID`:

```
postgres=# \d tab
       Table "public.tab"
 Column |  Type   | Collation | Nullable | Default
--------+---------+-----------+----------+---------
 col    | integer |           |          |
Indexes:
    "idx" btree (col) INVALID
```

The recommended recovery method in such cases is to drop the index and try again to perform CREATE INDEX CONCURRENTLY. (Another possibility is to rebuild the index with REINDEX INDEX CONCURRENTLY).

Another caveat when building a unique index concurrently is that the uniqueness constraint is already being enforced against other transactions when the second table scan begins. This means that constraint violations could be reported in other queries prior to the index becoming available for use, or even in cases where the index build eventually fails. Also, if a failure does occur in the second scan, the "invalid" index continues to enforce its uniqueness constraint afterwards.

Concurrent builds of expression indexes and partial indexes are supported. Errors occurring in the evaluation of these expressions could cause behavior similar to that described above for unique constraint violations.

Regular index builds permit other regular index builds on the same table to occur simultaneously, but only one concurrent index build can occur on a table at a time. In either case, schema modification of the table is not allowed while the index is being built. Another difference is that a regular CREATE INDEX command can be performed within a transaction block, but CREATE INDEX CONCURRENTLY cannot.

Concurrent builds for indexes on partitioned tables are currently not supported. However, you may concurrently build the index on each partition individually and then finally create the partitioned index non-concurrently in order to reduce the time where writes to the partitioned table will be locked out. In this case, building the partitioned index is a metadata only operation.

Notes

See Chapter 11 for information about when indexes can be used, when they are not used, and in which particular situations they can be useful.

Currently, only the B-tree, GiST, GIN, and BRIN index methods support multiple-key-column indexes. Whether there can be multiple key columns is independent of whether INCLUDE columns can be added to the index. Indexes can have up to 32 columns, including INCLUDE columns. (This limit can be altered when building Postgres Pro.) Only B-tree currently supports unique indexes.

An *operator class* with optional parameters can be specified for each column of an index. The operator class identifies the operators to be used by the index for that column. For example, a B-tree index on four-byte integers would use the int4_ops class; this operator class includes comparison functions for four-byte integers. In practice the default operator class for the column's data type is usually sufficient. The main point of having operator classes is that for some data types, there could be more than one meaningful ordering. For example, we might want to sort a complex-number data type either by absolute value or by real part. We could do this by defining two operator classes for the data type and then selecting the proper class when creating an index. More information about operator classes is in Section 11.10 and in Section 40.16.

When CREATE INDEX is invoked on a partitioned table, the default behavior is to recurse to all partitions to ensure they all have matching indexes. Each partition is first checked to determine whether an equivalent index already exists, and if so, that index will become attached as a partition index to the index being created, which will become its parent index. If no matching index exists, a new index will be created and automatically attached; the name of the new index in each partition will be determined as if no index name had been specified in the command. If the ONLY option is specified, no recursion is done, and the index is marked invalid. (ALTER INDEX ... ATTACH PARTITION marks the index valid, once all partitions acquire matching indexes.) Note, however, that any partition that is created in the future using CREATE TABLE ... PARTITION OF will automatically have a matching index, regardless of whether ONLY is specified.

For index methods that support ordered scans (currently, only B-tree), the optional clauses ASC, DESC, NULLS FIRST, and/or NULLS LAST can be specified to modify the sort ordering of the index. Since an ordered index can be scanned either forward or backward, it is not normally useful to create a single-column DESC index — that sort ordering is already available with a regular index. The value of these options is that multicolumn indexes can be created that match the sort ordering requested by a mixed-ordering

query, such as `SELECT ... ORDER BY x ASC, y DESC`. The `NULLS` options are useful if you need to support “nulls sort low” behavior, rather than the default “nulls sort high”, in queries that depend on indexes to avoid sorting steps.

The system regularly collects statistics on all of a table's columns. Newly-created non-expression indexes can immediately use these statistics to determine an index's usefulness. For new expression indexes, it is necessary to run `ANALYZE` or wait for the autovacuum daemon to analyze the table to generate statistics for these indexes.

For most index methods, the speed of creating an index is dependent on the setting of maintenance_work_mem. Larger values will reduce the time needed for index creation, so long as you don't make it larger than the amount of memory really available, which would drive the machine into swapping.

Postgres Pro can build indexes while leveraging multiple CPUs in order to process the table rows faster. This feature is known as *parallel index build*. For index methods that support building indexes in parallel (currently, only B-tree), `maintenance_work_mem` specifies the maximum amount of memory that can be used by each index build operation as a whole, regardless of how many worker processes were started. Generally, a cost model automatically determines how many worker processes should be requested, if any.

Parallel index builds may benefit from increasing `maintenance_work_mem` where an equivalent serial index build will see little or no benefit. Note that `maintenance_work_mem` may influence the number of worker processes requested, since parallel workers must have at least a `32MB` share of the total `maintenance_work_mem` budget. There must also be a remaining `32MB` share for the leader process. Increasing max_parallel_maintenance_workers may allow more workers to be used, which will reduce the time needed for index creation, so long as the index build is not already I/O bound. Of course, there should also be sufficient CPU capacity that would otherwise lie idle.

Setting a value for `parallel_workers` via `ALTER TABLE` directly controls how many parallel worker processes will be requested by a `CREATE INDEX` against the table. This bypasses the cost model completely, and prevents `maintenance_work_mem` from affecting how many parallel workers are requested. Setting `parallel_workers` to 0 via `ALTER TABLE` will disable parallel index builds on the table in all cases.

> **Tip**
>
> You might want to reset `parallel_workers` after setting it as part of tuning an index build. This avoids inadvertent changes to query plans, since `parallel_workers` affects *all* parallel table scans.

While `CREATE INDEX` with the `CONCURRENTLY` option supports parallel builds without special restrictions, only the first table scan is actually performed in parallel.

Use `DROP INDEX` to remove an index.

Like any long-running transaction, `CREATE INDEX` on a table can affect which tuples can be removed by concurrent `VACUUM` on any other table.

Prior releases of Postgres Pro also had an R-tree index method. This method has been removed because it had no significant advantages over the GiST method. If `USING rtree` is specified, `CREATE INDEX` will interpret it as `USING gist`, to simplify conversion of old databases to GiST.

Each backend running `CREATE INDEX` will report its progress in the `pg_stat_progress_create_index` view. See Section 27.4.2 for details.

Examples

To create a unique B-tree index on the column `title` in the table `films`:

```
CREATE UNIQUE INDEX title_idx ON films (title);
```

To create a unique B-tree index on the column `title` with included columns `director` and `rating` in the table `films`:

```
CREATE UNIQUE INDEX title_idx ON films (title) INCLUDE (director, rating);
```

To create a B-Tree index with deduplication disabled:

```
CREATE INDEX title_idx ON films (title) WITH (deduplicate_items = off);
```

To create an index on the expression `lower(title)`, allowing efficient case-insensitive searches:

```
CREATE INDEX ON films ((lower(title)));
```

(In this example we have chosen to omit the index name, so the system will choose a name, typically `films_lower_idx`.)

To create an index with non-default collation:

```
CREATE INDEX title_idx_german ON films (title COLLATE "de_DE");
```

To create an index with non-default sort ordering of nulls:

```
CREATE INDEX title_idx_nulls_low ON films (title NULLS FIRST);
```

To create an index with non-default fill factor:

```
CREATE UNIQUE INDEX title_idx ON films (title) WITH (fillfactor = 70);
```

To create a GIN index with fast updates disabled:

```
CREATE INDEX gin_idx ON documents_table USING GIN (locations) WITH (fastupdate = off);
```

To create an index on the column `code` in the table `films` and have the index reside in the tablespace `indexspace`:

```
CREATE INDEX code_idx ON films (code) TABLESPACE indexspace;
```

To create a GiST index on a point attribute so that we can efficiently use box operators on the result of the conversion function:

```
CREATE INDEX pointloc
    ON points USING gist (box(location,location));
SELECT * FROM points
    WHERE box(location,location) && '(0,0),(1,1)'::box;
```

To create an index without locking out writes to the table:

```
CREATE INDEX CONCURRENTLY sales_quantity_index ON sales_table (quantity);
```

Compatibility

`CREATE INDEX` is a Postgres Pro language extension. There are no provisions for indexes in the SQL standard.

See Also

ALTER INDEX, DROP INDEX, REINDEX, Section 27.4.2

CREATE LANGUAGE

CREATE LANGUAGE — define a new procedural language

Synopsis

```
CREATE [ OR REPLACE ] [ TRUSTED ] [ PROCEDURAL ] LANGUAGE name
    HANDLER call_handler [ INLINE inline_handler ] [ VALIDATOR valfunction ]
CREATE [ OR REPLACE ] [ TRUSTED ] [ PROCEDURAL ] LANGUAGE name
```

Description

`CREATE LANGUAGE` registers a new procedural language with a Postgres Pro database. Subsequently, functions and procedures can be defined in this new language.

`CREATE LANGUAGE` effectively associates the language name with handler function(s) that are responsible for executing functions written in the language. Refer to Chapter 56 for more information about language handlers.

`CREATE OR REPLACE LANGUAGE` will either create a new language, or replace an existing definition. If the language already exists, its parameters are updated according to the command, but the language's ownership and permissions settings do not change, and any existing functions written in the language are assumed to still be valid.

One must have the Postgres Pro superuser privilege to register a new language or change an existing language's parameters. However, once the language is created it is valid to assign ownership of it to a non-superuser, who may then drop it, change its permissions, rename it, or assign it to a new owner. (Do not, however, assign ownership of the underlying C functions to a non-superuser; that would create a privilege escalation path for that user.)

The form of `CREATE LANGUAGE` that does not supply any handler function is obsolete. For backwards compatibility with old dump files, it is interpreted as `CREATE EXTENSION`. That will work if the language has been packaged into an extension of the same name, which is the conventional way to set up procedural languages.

Parameters

`TRUSTED`

`TRUSTED` specifies that the language does not grant access to data that the user would not otherwise have. If this key word is omitted when registering the language, only users with the Postgres Pro superuser privilege can use this language to create new functions.

`PROCEDURAL`

This is a noise word.

`name`

The name of the new procedural language. The name must be unique among the languages in the database.

`HANDLER` *`call_handler`*

`call_handler` is the name of a previously registered function that will be called to execute the procedural language's functions. The call handler for a procedural language must be written in a compiled language such as C with version 1 call convention and registered with Postgres Pro as a function taking no arguments and returning the `language_handler` type, a placeholder type that is simply used to identify the function as a call handler.

INLINE *inline_handler*

inline_handler is the name of a previously registered function that will be called to execute an anonymous code block (DO command) in this language. If no *inline_handler* function is specified, the language does not support anonymous code blocks. The handler function must take one argument of type internal, which will be the DO command's internal representation, and it will typically return void. The return value of the handler is ignored.

VALIDATOR *valfunction*

valfunction is the name of a previously registered function that will be called when a new function in the language is created, to validate the new function. If no validator function is specified, then a new function will not be checked when it is created. The validator function must take one argument of type oid, which will be the OID of the to-be-created function, and will typically return void.

A validator function would typically inspect the function body for syntactical correctness, but it can also look at other properties of the function, for example if the language cannot handle certain argument types. To signal an error, the validator function should use the ereport() function. The return value of the function is ignored.

Notes

Use DROP LANGUAGE to drop procedural languages.

The system catalog pg_language (see Section 54.29) records information about the currently installed languages. Also, the psql command \dL lists the installed languages.

To create functions in a procedural language, a user must have the USAGE privilege for the language. By default, USAGE is granted to PUBLIC (i.e., everyone) for trusted languages. This can be revoked if desired.

Procedural languages are local to individual databases. However, a language can be installed into the template1 database, which will cause it to be available automatically in all subsequently-created databases.

Examples

A minimal sequence for creating a new procedural language is:

```
CREATE FUNCTION plsample_call_handler() RETURNS language_handler
    AS '$libdir/plsample'
    LANGUAGE C;
CREATE LANGUAGE plsample
    HANDLER plsample_call_handler;
```

Typically that would be written in an extension's creation script, and users would do this to install the extension:

```
CREATE EXTENSION plsample;
```

Compatibility

CREATE LANGUAGE is a Postgres Pro extension.

See Also

ALTER LANGUAGE, CREATE FUNCTION, DROP LANGUAGE, GRANT, REVOKE

CREATE MATERIALIZED VIEW

CREATE MATERIALIZED VIEW — define a new materialized view

Synopsis

```
CREATE MATERIALIZED VIEW [ IF NOT EXISTS ] table_name
    [ (column_name [, ...] ) ]
    [ USING method ]
    [ WITH ( storage_parameter [= value] [, ... ] ) ]
    [ TABLESPACE tablespace_name ]
    AS query
    [ WITH [ NO ] DATA ]
```

Description

`CREATE MATERIALIZED VIEW` defines a materialized view of a query. The query is executed and used to populate the view at the time the command is issued (unless `WITH NO DATA` is used) and may be refreshed later using `REFRESH MATERIALIZED VIEW`.

`CREATE MATERIALIZED VIEW` is similar to `CREATE TABLE AS`, except that it also remembers the query used to initialize the view, so that it can be refreshed later upon demand. A materialized view has many of the same properties as a table, but there is no support for temporary materialized views.

`CREATE MATERIALIZED VIEW` requires `CREATE` privilege on the schema used for the materialized view.

Parameters

`IF NOT EXISTS`

Do not throw an error if a materialized view with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing materialized view is anything like the one that would have been created.

`table_name`

The name (optionally schema-qualified) of the materialized view to be created.

`column_name`

The name of a column in the new materialized view. If column names are not provided, they are taken from the output column names of the query.

`USING` *`method`*

This optional clause specifies the table access method to use to store the contents for the new materialized view; the method needs be an access method of type `TABLE`. See Chapter 61 for more information. If this option is not specified, the default table access method is chosen for the new materialized view. See default_table_access_method for more information.

`WITH ( storage_parameter [= value] [, ... ] )`

This clause specifies optional storage parameters for the new materialized view; see Storage Parameters in the CREATE TABLE documentation for more information. All parameters supported for `CREATE TABLE` are also supported for `CREATE MATERIALIZED VIEW`. See CREATE TABLE for more information.

`TABLESPACE` *`tablespace_name`*

The *`tablespace_name`* is the name of the tablespace in which the new materialized view is to be created. If not specified, default_tablespace is consulted.

query

A SELECT, TABLE, or VALUES command. This query will run within a security-restricted operation; in particular, calls to functions that themselves create temporary tables will fail.

WITH [NO] DATA

This clause specifies whether or not the materialized view should be populated at creation time. If not, the materialized view will be flagged as unscannable and cannot be queried until REFRESH MATERIALIZED VIEW is used.

Compatibility

CREATE MATERIALIZED VIEW is a Postgres Pro extension.

See Also

ALTER MATERIALIZED VIEW, CREATE TABLE AS, CREATE VIEW, DROP MATERIALIZED VIEW, REFRESH MATERIALIZED VIEW

CREATE OPERATOR

CREATE OPERATOR — define a new operator

Synopsis

```
CREATE OPERATOR name (
    {FUNCTION|PROCEDURE} = function_name
    [, LEFTARG = left_type ] [, RIGHTARG = right_type ]
    [, COMMUTATOR = com_op ] [, NEGATOR = neg_op ]
    [, RESTRICT = res_proc ] [, JOIN = join_proc ]
    [, HASHES ] [, MERGES ]
)
```

Description

`CREATE OPERATOR` defines a new operator, *name*. The user who defines an operator becomes its owner. If a schema name is given then the operator is created in the specified schema. Otherwise it is created in the current schema.

The operator name is a sequence of up to `NAMEDATALEN`-1 (63 by default) characters from the following list:

+ - * / < > = ~ ! @ # % ^ & | ` ?

There are a few restrictions on your choice of name:

- `--` and `/*` cannot appear anywhere in an operator name, since they will be taken as the start of a comment.
- A multicharacter operator name cannot end in `+` or `-`, unless the name also contains at least one of these characters:

  ~ ! @ # % ^ & | ` ?

  For example, `@-` is an allowed operator name, but `*-` is not. This restriction allows Postgres Pro to parse SQL-compliant commands without requiring spaces between tokens.
- The symbol `=>` is reserved by the SQL grammar, so it cannot be used as an operator name.

The operator `!=` is mapped to `<>` on input, so these two names are always equivalent.

For binary operators, both `LEFTARG` and `RIGHTARG` must be defined. For prefix operators only `RIGHTARG` should be defined. The *function_name* function must have been previously defined using `CREATE FUNCTION` and must be defined to accept the correct number of arguments (either one or two) of the indicated types.

In the syntax of `CREATE OPERATOR`, the keywords `FUNCTION` and `PROCEDURE` are equivalent, but the referenced function must in any case be a function, not a procedure. The use of the keyword `PROCEDURE` here is historical and deprecated.

The other clauses specify optional operator optimization clauses. Their meaning is detailed in Section 40.15.

To be able to create an operator, you must have `USAGE` privilege on the argument types and the return type, as well as `EXECUTE` privilege on the underlying function. If a commutator or negator operator is specified, you must own these operators.

Parameters

name

The name of the operator to be defined. See above for allowable characters. The name can be schema-qualified, for example `CREATE OPERATOR myschema.+ (...)`. If not, then the operator is created in

the current schema. Two operators in the same schema can have the same name if they operate on different data types. This is called *overloading*.

function_name

The function used to implement this operator.

left_type

The data type of the operator's left operand, if any. This option would be omitted for a prefix operator.

right_type

The data type of the operator's right operand.

com_op

The commutator of this operator.

neg_op

The negator of this operator.

res_proc

The restriction selectivity estimator function for this operator.

join_proc

The join selectivity estimator function for this operator.

HASHES

Indicates this operator can support a hash join.

MERGES

Indicates this operator can support a merge join.

To give a schema-qualified operator name in *com_op* or the other optional arguments, use the OPERATOR() syntax, for example:

```
COMMUTATOR = OPERATOR(myschema.===) ,
```

Notes

Refer to Section 40.14 for further information.

It is not possible to specify an operator's lexical precedence in CREATE OPERATOR, because the parser's precedence behavior is hard-wired. See Section 4.1.6 for precedence details.

The obsolete options SORT1, SORT2, LTCMP, and GTCMP were formerly used to specify the names of sort operators associated with a merge-joinable operator. This is no longer necessary, since information about associated operators is found by looking at B-tree operator families instead. If one of these options is given, it is ignored except for implicitly setting MERGES true.

Use DROP OPERATOR to delete user-defined operators from a database. Use ALTER OPERATOR to modify operators in a database.

Examples

The following command defines a new operator, area-equality, for the data type box:

```
CREATE OPERATOR === (
    LEFTARG = box,
    RIGHTARG = box,
```

```
    FUNCTION = area_equal_function,
    COMMUTATOR = ===,
    NEGATOR = !==,
    RESTRICT = area_restriction_function,
    JOIN = area_join_function,
    HASHES, MERGES
);
```

Compatibility

`CREATE OPERATOR` is a Postgres Pro extension. There are no provisions for user-defined operators in the SQL standard.

See Also

ALTER OPERATOR, CREATE OPERATOR CLASS, DROP OPERATOR

CREATE OPERATOR CLASS

CREATE OPERATOR CLASS — define a new operator class

Synopsis

```
CREATE OPERATOR CLASS name [ DEFAULT ] FOR TYPE data_type
  USING index_method [ FAMILY family_name ] AS
  {  OPERATOR strategy_number operator_name [ ( op_type, op_type ) ] [ FOR SEARCH | FOR
 ORDER BY sort_family_name ]
    | FUNCTION support_number [ ( op_type [ , op_type ] ) ] function_name
 ( argument_type [, ...] )
    | STORAGE storage_type
  } [, ... ]
```

Description

`CREATE OPERATOR CLASS` creates a new operator class. An operator class defines how a particular data type can be used with an index. The operator class specifies that certain operators will fill particular roles or “strategies” for this data type and this index method. The operator class also specifies the support functions to be used by the index method when the operator class is selected for an index column. All the operators and functions used by an operator class must be defined before the operator class can be created.

If a schema name is given then the operator class is created in the specified schema. Otherwise it is created in the current schema. Two operator classes in the same schema can have the same name only if they are for different index methods.

The user who defines an operator class becomes its owner. Presently, the creating user must be a superuser. (This restriction is made because an erroneous operator class definition could confuse or even crash the server.)

`CREATE OPERATOR CLASS` does not presently check whether the operator class definition includes all the operators and functions required by the index method, nor whether the operators and functions form a self-consistent set. It is the user's responsibility to define a valid operator class.

Related operator classes can be grouped into *operator families*. To add a new operator class to an existing family, specify the `FAMILY` option in `CREATE OPERATOR CLASS`. Without this option, the new class is placed into a family named the same as the new class (creating that family if it doesn't already exist).

Refer to Section 40.16 for further information.

Parameters

name

The name of the operator class to be created. The name can be schema-qualified.

`DEFAULT`

If present, the operator class will become the default operator class for its data type. At most one operator class can be the default for a specific data type and index method.

data_type

The column data type that this operator class is for.

index_method

The name of the index method this operator class is for.

family_name

The name of the existing operator family to add this operator class to. If not specified, a family named the same as the operator class is used (creating it, if it doesn't already exist).

strategy_number

The index method's strategy number for an operator associated with the operator class.

operator_name

The name (optionally schema-qualified) of an operator associated with the operator class.

op_type

In an `OPERATOR` clause, the operand data type(s) of the operator, or `NONE` to signify a prefix operator. The operand data types can be omitted in the normal case where they are the same as the operator class's data type.

In a `FUNCTION` clause, the operand data type(s) the function is intended to support, if different from the input data type(s) of the function (for B-tree comparison functions and hash functions) or the class's data type (for B-tree sort support functions, B-tree equal image functions, and all functions in GiST, SP-GiST, GIN and BRIN operator classes). These defaults are correct, and so *op_type* need not be specified in `FUNCTION` clauses, except for the case of a B-tree sort support function that is meant to support cross-data-type comparisons.

sort_family_name

The name (optionally schema-qualified) of an existing `btree` operator family that describes the sort ordering associated with an ordering operator.

If neither `FOR SEARCH` nor `FOR ORDER BY` is specified, `FOR SEARCH` is the default.

support_number

The index method's support function number for a function associated with the operator class.

function_name

The name (optionally schema-qualified) of a function that is an index method support function for the operator class.

argument_type

The parameter data type(s) of the function.

storage_type

The data type actually stored in the index. Normally this is the same as the column data type, but some index methods (currently GiST, GIN, SP-GiST and BRIN) allow it to be different. The `STORAGE` clause must be omitted unless the index method allows a different type to be used. If the column *data_type* is specified as `anyarray`, the *storage_type* can be declared as `anyelement` to indicate that the index entries are members of the element type belonging to the actual array type that each particular index is created for.

The `OPERATOR`, `FUNCTION`, and `STORAGE` clauses can appear in any order.

Notes

Because the index machinery does not check access permissions on functions before using them, including a function or operator in an operator class is tantamount to granting public execute permission on it. This is usually not an issue for the sorts of functions that are useful in an operator class.

The operators should not be defined by SQL functions. An SQL function is likely to be inlined into the calling query, which will prevent the optimizer from recognizing that the query matches an index.

Before PostgreSQL 8.4, the OPERATOR clause could include a RECHECK option. This is no longer supported because whether an index operator is “lossy” is now determined on-the-fly at run time. This allows efficient handling of cases where an operator might or might not be lossy.

Examples

The following example command defines a GiST index operator class for the data type _int4 (array of int4). See the intarray module for the complete example.

```
CREATE OPERATOR CLASS gist__int_ops
    DEFAULT FOR TYPE _int4 USING gist AS
        OPERATOR        3       &&,
        OPERATOR        6       = (anyarray, anyarray),
        OPERATOR        7       @>,
        OPERATOR        8       <@,
        OPERATOR        20      @@ (_int4, query_int),
        FUNCTION        1       g_int_consistent (internal, _int4, smallint, oid,
 internal),
        FUNCTION        2       g_int_union (internal, internal),
        FUNCTION        3       g_int_compress (internal),
        FUNCTION        4       g_int_decompress (internal),
        FUNCTION        5       g_int_penalty (internal, internal, internal),
        FUNCTION        6       g_int_picksplit (internal, internal),
        FUNCTION        7       g_int_same (_int4, _int4, internal);
```

Compatibility

CREATE OPERATOR CLASS is a Postgres Pro extension. There is no CREATE OPERATOR CLASS statement in the SQL standard.

See Also

ALTER OPERATOR CLASS, DROP OPERATOR CLASS, CREATE OPERATOR FAMILY, ALTER OPERATOR FAMILY

CREATE OPERATOR FAMILY

CREATE OPERATOR FAMILY — define a new operator family

Synopsis

```
CREATE OPERATOR FAMILY name USING index_method
```

Description

`CREATE OPERATOR FAMILY` creates a new operator family. An operator family defines a collection of related operator classes, and perhaps some additional operators and support functions that are compatible with these operator classes but not essential for the functioning of any individual index. (Operators and functions that are essential to indexes should be grouped within the relevant operator class, rather than being "loose" in the operator family. Typically, single-data-type operators are bound to operator classes, while cross-data-type operators can be loose in an operator family containing operator classes for both data types.)

The new operator family is initially empty. It should be populated by issuing subsequent `CREATE OPERATOR CLASS` commands to add contained operator classes, and optionally `ALTER OPERATOR FAMILY` commands to add "loose" operators and their corresponding support functions.

If a schema name is given then the operator family is created in the specified schema. Otherwise it is created in the current schema. Two operator families in the same schema can have the same name only if they are for different index methods.

The user who defines an operator family becomes its owner. Presently, the creating user must be a superuser. (This restriction is made because an erroneous operator family definition could confuse or even crash the server.)

Refer to Section 40.16 for further information.

Parameters

name

The name of the operator family to be created. The name can be schema-qualified.

index_method

The name of the index method this operator family is for.

Compatibility

`CREATE OPERATOR FAMILY` is a Postgres Pro extension. There is no `CREATE OPERATOR FAMILY` statement in the SQL standard.

See Also

ALTER OPERATOR FAMILY, DROP OPERATOR FAMILY, CREATE OPERATOR CLASS, ALTER OPERATOR CLASS, DROP OPERATOR CLASS

CREATE POLICY

CREATE POLICY — define a new row-level security policy for a table

Synopsis

```
CREATE POLICY name ON table_name
    [ AS { PERMISSIVE | RESTRICTIVE } ]
    [ FOR { ALL | SELECT | INSERT | UPDATE | DELETE } ]
    [ TO { role_name | PUBLIC | CURRENT_ROLE | CURRENT_USER | SESSION_USER } [, ...] ]
    [ USING ( using_expression ) ]
    [ WITH CHECK ( check_expression ) ]
```

Description

The `CREATE POLICY` command defines a new row-level security policy for a table. Note that row-level security must be enabled on the table (using `ALTER TABLE ... ENABLE ROW LEVEL SECURITY`) in order for created policies to be applied.

A policy grants the permission to select, insert, update, or delete rows that match the relevant policy expression. Existing table rows are checked against the expression specified in `USING`, while new rows that would be created via `INSERT` or `UPDATE` are checked against the expression specified in `WITH CHECK`. When a `USING` expression returns true for a given row then that row is visible to the user, while if false or null is returned then the row is not visible. When a `WITH CHECK` expression returns true for a row then that row is inserted or updated, while if false or null is returned then an error occurs.

For `INSERT` and `UPDATE` statements, `WITH CHECK` expressions are enforced after `BEFORE` triggers are fired, and before any actual data modifications are made. Thus a `BEFORE ROW` trigger may modify the data to be inserted, affecting the result of the security policy check. `WITH CHECK` expressions are enforced before any other constraints.

Policy names are per-table. Therefore, one policy name can be used for many different tables and have a definition for each table which is appropriate to that table.

Policies can be applied for specific commands or for specific roles. The default for newly created policies is that they apply for all commands and roles, unless otherwise specified. Multiple policies may apply to a single command; see below for more details. Table 289 summarizes how the different types of policy apply to specific commands.

For policies that can have both `USING` and `WITH CHECK` expressions (`ALL` and `UPDATE`), if no `WITH CHECK` expression is defined, then the `USING` expression will be used both to determine which rows are visible (normal `USING` case) and which new rows will be allowed to be added (`WITH CHECK` case).

If row-level security is enabled for a table, but no applicable policies exist, a “default deny” policy is assumed, so that no rows will be visible or updatable.

Parameters

name

The name of the policy to be created. This must be distinct from the name of any other policy for the table.

table_name

The name (optionally schema-qualified) of the table the policy applies to.

`PERMISSIVE`

Specify that the policy is to be created as a permissive policy. All permissive policies which are applicable to a given query will be combined together using the Boolean “OR” operator. By creating

permissive policies, administrators can add to the set of records which can be accessed. Policies are permissive by default.

`RESTRICTIVE`

Specify that the policy is to be created as a restrictive policy. All restrictive policies which are applicable to a given query will be combined together using the Boolean "AND" operator. By creating restrictive policies, administrators can reduce the set of records which can be accessed as all restrictive policies must be passed for each record.

Note that there needs to be at least one permissive policy to grant access to records before restrictive policies can be usefully used to reduce that access. If only restrictive policies exist, then no records will be accessible. When a mix of permissive and restrictive policies are present, a record is only accessible if at least one of the permissive policies passes, in addition to all the restrictive policies.

`command`

The command to which the policy applies. Valid options are `ALL`, `SELECT`, `INSERT`, `UPDATE`, and `DELETE`. `ALL` is the default. See below for specifics regarding how these are applied.

`role_name`

The role(s) to which the policy is to be applied. The default is `PUBLIC`, which will apply the policy to all roles.

`using_expression`

Any SQL conditional expression (returning `boolean`). The conditional expression cannot contain any aggregate or window functions. This expression will be added to queries that refer to the table if row-level security is enabled. Rows for which the expression returns true will be visible. Any rows for which the expression returns false or null will not be visible to the user (in a `SELECT`), and will not be available for modification (in an `UPDATE` or `DELETE`). Such rows are silently suppressed; no error is reported.

`check_expression`

Any SQL conditional expression (returning `boolean`). The conditional expression cannot contain any aggregate or window functions. This expression will be used in `INSERT` and `UPDATE` queries against the table if row-level security is enabled. Only rows for which the expression evaluates to true will be allowed. An error will be thrown if the expression evaluates to false or null for any of the records inserted or any of the records that result from the update. Note that the *`check_expression`* is evaluated against the proposed new contents of the row, not the original contents.

Per-Command Policies

`ALL`

Using `ALL` for a policy means that it will apply to all commands, regardless of the type of command. If an `ALL` policy exists and more specific policies exist, then both the `ALL` policy and the more specific policy (or policies) will be applied. Additionally, `ALL` policies will be applied to both the selection side of a query and the modification side, using the `USING` expression for both cases if only a `USING` expression has been defined.

As an example, if an `UPDATE` is issued, then the `ALL` policy will be applicable both to what the `UPDATE` will be able to select as rows to be updated (applying the `USING` expression), and to the resulting updated rows, to check if they are permitted to be added to the table (applying the `WITH CHECK` expression, if defined, and the `USING` expression otherwise). If an `INSERT` or `UPDATE` command attempts to add rows to the table that do not pass the `ALL` policy's `WITH CHECK` expression, the entire command will be aborted.

`SELECT`

Using `SELECT` for a policy means that it will apply to `SELECT` queries and whenever `SELECT` permissions are required on the relation the policy is defined for. The result is that only those records from the

relation that pass the SELECT policy will be returned during a SELECT query, and that queries that require SELECT permissions, such as UPDATE, will also only see those records that are allowed by the SELECT policy. A SELECT policy cannot have a WITH CHECK expression, as it only applies in cases where records are being retrieved from the relation.

INSERT

Using INSERT for a policy means that it will apply to INSERT commands. Rows being inserted that do not pass this policy will result in a policy violation error, and the entire INSERT command will be aborted. An INSERT policy cannot have a USING expression, as it only applies in cases where records are being added to the relation.

Note that INSERT with ON CONFLICT DO UPDATE checks INSERT policies' WITH CHECK expressions only for rows appended to the relation by the INSERT path.

UPDATE

Using UPDATE for a policy means that it will apply to UPDATE, SELECT FOR UPDATE and SELECT FOR SHARE commands, as well as auxiliary ON CONFLICT DO UPDATE clauses of INSERT commands. Since UPDATE involves pulling an existing record and replacing it with a new modified record, UPDATE policies accept both a USING expression and a WITH CHECK expression. The USING expression determines which records the UPDATE command will see to operate against, while the WITH CHECK expression defines which modified rows are allowed to be stored back into the relation.

Any rows whose updated values do not pass the WITH CHECK expression will cause an error, and the entire command will be aborted. If only a USING clause is specified, then that clause will be used for both USING and WITH CHECK cases.

Typically an UPDATE command also needs to read data from columns in the relation being updated (e.g., in a WHERE clause or a RETURNING clause, or in an expression on the right hand side of the SET clause). In this case, SELECT rights are also required on the relation being updated, and the appropriate SELECT or ALL policies will be applied in addition to the UPDATE policies. Thus the user must have access to the row(s) being updated through a SELECT or ALL policy in addition to being granted permission to update the row(s) via an UPDATE or ALL policy.

When an INSERT command has an auxiliary ON CONFLICT DO UPDATE clause, if the UPDATE path is taken, the row to be updated is first checked against the USING expressions of any UPDATE policies, and then the new updated row is checked against the WITH CHECK expressions. Note, however, that unlike a standalone UPDATE command, if the existing row does not pass the USING expressions, an error will be thrown (the UPDATE path will *never* be silently avoided).

DELETE

Using DELETE for a policy means that it will apply to DELETE commands. Only rows that pass this policy will be seen by a DELETE command. There can be rows that are visible through a SELECT that are not available for deletion, if they do not pass the USING expression for the DELETE policy.

In most cases a DELETE command also needs to read data from columns in the relation that it is deleting from (e.g., in a WHERE clause or a RETURNING clause). In this case, SELECT rights are also required on the relation, and the appropriate SELECT or ALL policies will be applied in addition to the DELETE policies. Thus the user must have access to the row(s) being deleted through a SELECT or ALL policy in addition to being granted permission to delete the row(s) via a DELETE or ALL policy.

A DELETE policy cannot have a WITH CHECK expression, as it only applies in cases where records are being deleted from the relation, so that there is no new row to check.

Table 289. Policies Applied by Command Type

Command	SELECT/ALL policy	INSERT/ALL policy	UPDATE/ALL policy		DELETE/ALL policy
	USING expression	WITH CHECK expression	USING expression	WITH CHECK expression	USING expression
SELECT	Existing row	—	—	—	—
SELECT FOR UPDATE/SHARE	Existing row	—	Existing row	—	—
INSERT	—	New row	—	—	—
INSERT ... RETURNING	New row [a]	New row	—	—	—
UPDATE	Existing & new rows [a]	—	Existing row	New row	—
DELETE	Existing row [a]	—	—	—	Existing row
ON CONFLICT DO UPDATE	Existing & new rows	—	Existing row	New row	—

[a] If read access is required to the existing or new row (for example, a WHERE or RETURNING clause that refers to columns from the relation).

Application of Multiple Policies

When multiple policies of different command types apply to the same command (for example, SELECT and UPDATE policies applied to an UPDATE command), then the user must have both types of permissions (for example, permission to select rows from the relation as well as permission to update them). Thus the expressions for one type of policy are combined with the expressions for the other type of policy using the AND operator.

When multiple policies of the same command type apply to the same command, then there must be at least one PERMISSIVE policy granting access to the relation, and all of the RESTRICTIVE policies must pass. Thus all the PERMISSIVE policy expressions are combined using OR, all the RESTRICTIVE policy expressions are combined using AND, and the results are combined using AND. If there are no PERMISSIVE policies, then access is denied.

Note that, for the purposes of combining multiple policies, ALL policies are treated as having the same type as whichever other type of policy is being applied.

For example, in an UPDATE command requiring both SELECT and UPDATE permissions, if there are multiple applicable policies of each type, they will be combined as follows:

```
expression from RESTRICTIVE SELECT/ALL policy 1
AND
expression from RESTRICTIVE SELECT/ALL policy 2
AND
...
AND
(
  expression from PERMISSIVE SELECT/ALL policy 1
  OR
  expression from PERMISSIVE SELECT/ALL policy 2
  OR
  ...
)
AND
expression from RESTRICTIVE UPDATE/ALL policy 1
AND
expression from RESTRICTIVE UPDATE/ALL policy 2
```

```
AND
...
AND
(
  expression from PERMISSIVE UPDATE/ALL policy 1
  OR
  expression from PERMISSIVE UPDATE/ALL policy 2
  OR
  ...
)
```

Notes

You must be the owner of a table to create or change policies for it.

While policies will be applied for explicit queries against tables in the database, they are not applied when the system is performing internal referential integrity checks or validating constraints. This means there are indirect ways to determine that a given value exists. An example of this is attempting to insert a duplicate value into a column that is a primary key or has a unique constraint. If the insert fails then the user can infer that the value already exists. (This example assumes that the user is permitted by policy to insert records which they are not allowed to see.) Another example is where a user is allowed to insert into a table which references another, otherwise hidden table. Existence can be determined by the user inserting values into the referencing table, where success would indicate that the value exists in the referenced table. These issues can be addressed by carefully crafting policies to prevent users from being able to insert, delete, or update records at all which might possibly indicate a value they are not otherwise able to see, or by using generated values (e.g., surrogate keys) instead of keys with external meanings.

Generally, the system will enforce filter conditions imposed using security policies prior to qualifications that appear in user queries, in order to prevent inadvertent exposure of the protected data to user-defined functions which might not be trustworthy. However, functions and operators marked by the system (or the system administrator) as `LEAKPROOF` may be evaluated before policy expressions, as they are assumed to be trustworthy.

Since policy expressions are added to the user's query directly, they will be run with the rights of the user running the overall query. Therefore, users who are using a given policy must be able to access any tables or functions referenced in the expression or they will simply receive a permission denied error when attempting to query the table that has row-level security enabled. This does not change how views work, however. As with normal queries and views, permission checks and policies for the tables which are referenced by a view will use the view owner's rights and any policies which apply to the view owner.

Additional discussion and practical examples can be found in Section 5.8.

Compatibility

`CREATE POLICY` is a Postgres Pro extension.

See Also

ALTER POLICY, DROP POLICY, ALTER TABLE

CREATE PROCEDURE

CREATE PROCEDURE — define a new procedure

Synopsis

```
CREATE [ OR REPLACE ] PROCEDURE
    name ( [ [ argmode ] [ argname ] argtype [ { DEFAULT | = } default_expr ]
 [, ...] ] )
  { LANGUAGE lang_name
    | TRANSFORM { FOR TYPE type_name } [, ... ]
    | [ EXTERNAL ] SECURITY INVOKER | [ EXTERNAL ] SECURITY DEFINER
    | SET configuration_parameter { TO value | = value | FROM CURRENT }
    | AS 'definition'
    | AS 'obj_file', 'link_symbol'
    | sql_body
  } ...
```

Description

`CREATE PROCEDURE` defines a new procedure. `CREATE OR REPLACE PROCEDURE` will either create a new procedure, or replace an existing definition. To be able to define a procedure, the user must have the `USAGE` privilege on the language.

If a schema name is included, then the procedure is created in the specified schema. Otherwise it is created in the current schema. The name of the new procedure must not match any existing procedure or function with the same input argument types in the same schema. However, procedures and functions of different argument types can share a name (this is called *overloading*).

To replace the current definition of an existing procedure, use `CREATE OR REPLACE PROCEDURE`. It is not possible to change the name or argument types of a procedure this way (if you tried, you would actually be creating a new, distinct procedure).

When `CREATE OR REPLACE PROCEDURE` is used to replace an existing procedure, the ownership and permissions of the procedure do not change. All other procedure properties are assigned the values specified or implied in the command. You must own the procedure to replace it (this includes being a member of the owning role).

The user that creates the procedure becomes the owner of the procedure.

To be able to create a procedure, you must have `USAGE` privilege on the argument types.

Refer to Section 40.4 for further information on writing procedures.

Parameters

name

The name (optionally schema-qualified) of the procedure to create.

argmode

The mode of an argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN`.

argname

The name of an argument.

argtype

The data type(s) of the procedure's arguments (optionally schema-qualified), if any. The argument types can be base, composite, or domain types, or can reference the type of a table column.

Depending on the implementation language it might also be allowed to specify “pseudo-types” such as `cstring`. Pseudo-types indicate that the actual argument type is either incompletely specified, or outside the set of ordinary SQL data types.

The type of a column is referenced by writing *`table_name.column_name%TYPE`*. Using this feature can sometimes help make a procedure independent of changes to the definition of a table.

`default_expr`

An expression to be used as default value if the parameter is not specified. The expression has to be coercible to the argument type of the parameter. All input parameters following a parameter with a default value must have default values as well.

`lang_name`

The name of the language that the procedure is implemented in. It can be `sql`, `c`, `internal`, or the name of a user-defined procedural language, e.g., `plpgsql`. The default is `sql` if *`sql_body`* is specified. Enclosing the name in single quotes is deprecated and requires matching case.

`TRANSFORM { FOR TYPE` *`type_name`* `} [, ... ] }`

Lists which transforms a call to the procedure should apply. Transforms convert between SQL types and language-specific data types; see CREATE TRANSFORM. Procedural language implementations usually have hardcoded knowledge of the built-in types, so those don't need to be listed here. If a procedural language implementation does not know how to handle a type and no transform is supplied, it will fall back to a default behavior for converting data types, but this depends on the implementation.

`[EXTERNAL] SECURITY INVOKER`
`[EXTERNAL] SECURITY DEFINER`

`SECURITY INVOKER` indicates that the procedure is to be executed with the privileges of the user that calls it. That is the default. `SECURITY DEFINER` specifies that the procedure is to be executed with the privileges of the user that owns it.

The key word `EXTERNAL` is allowed for SQL conformance, but it is optional since, unlike in SQL, this feature applies to all procedures not only external ones.

A `SECURITY DEFINER` procedure cannot execute transaction control statements (for example, `COMMIT` and `ROLLBACK`, depending on the language).

`configuration_parameter`
`value`

The `SET` clause causes the specified configuration parameter to be set to the specified value when the procedure is entered, and then restored to its prior value when the procedure exits. `SET FROM CURRENT` saves the value of the parameter that is current when `CREATE PROCEDURE` is executed as the value to be applied when the procedure is entered.

If a `SET` clause is attached to a procedure, then the effects of a `SET LOCAL` command executed inside the procedure for the same variable are restricted to the procedure: the configuration parameter's prior value is still restored at procedure exit. However, an ordinary `SET` command (without `LOCAL`) overrides the `SET` clause, much as it would do for a previous `SET LOCAL` command: the effects of such a command will persist after procedure exit, unless the current transaction is rolled back.

If a `SET` clause is attached to a procedure, then that procedure cannot execute transaction control statements (for example, `COMMIT` and `ROLLBACK`, depending on the language).

See SET and Chapter 19 for more information about allowed parameter names and values.

`definition`

A string constant defining the procedure; the meaning depends on the language. It can be an internal procedure name, the path to an object file, an SQL command, or text in a procedural language.

It is often helpful to use dollar quoting (see Section 4.1.2.4) to write the procedure definition string, rather than the normal single quote syntax. Without dollar quoting, any single quotes or backslashes in the procedure definition must be escaped by doubling them.

obj_file, *link_symbol*

This form of the AS clause is used for dynamically loadable C language procedures when the procedure name in the C language source code is not the same as the name of the SQL procedure. The string *obj_file* is the name of the shared library file containing the compiled C procedure, and is interpreted as for the LOAD command. The string *link_symbol* is the procedure's link symbol, that is, the name of the procedure in the C language source code. If the link symbol is omitted, it is assumed to be the same as the name of the SQL procedure being defined.

When repeated CREATE PROCEDURE calls refer to the same object file, the file is only loaded once per session. To unload and reload the file (perhaps during development), start a new session.

sql_body

The body of a LANGUAGE SQL procedure. This should be a block

```
BEGIN ATOMIC
  statement;
  statement;
  ...
  statement;
END
```

This is similar to writing the text of the procedure body as a string constant (see *definition* above), but there are some differences: This form only works for LANGUAGE SQL, the string constant form works for all languages. This form is parsed at procedure definition time, the string constant form is parsed at execution time; therefore this form cannot support polymorphic argument types and other constructs that are not resolvable at procedure definition time. This form tracks dependencies between the procedure and objects used in the procedure body, so DROP ... CASCADE will work correctly, whereas the form using string literals may leave dangling procedures. Finally, this form is more compatible with the SQL standard and other SQL implementations.

Notes

See CREATE FUNCTION for more details on function creation that also apply to procedures.

Use CALL to execute a procedure.

Examples

```
CREATE PROCEDURE insert_data(a integer, b integer)
LANGUAGE SQL
AS $$
INSERT INTO tbl VALUES (a);
INSERT INTO tbl VALUES (b);
$$;
```

or

```
CREATE PROCEDURE insert_data(a integer, b integer)
LANGUAGE SQL
BEGIN ATOMIC
  INSERT INTO tbl VALUES (a);
  INSERT INTO tbl VALUES (b);
END;
```

and call like this:

```
CALL insert_data(1, 2);
```

Compatibility

A `CREATE PROCEDURE` command is defined in the SQL standard. The Postgres Pro implementation can be used in a compatible way but has many extensions. For details see also CREATE FUNCTION.

See Also

ALTER PROCEDURE, DROP PROCEDURE, CALL, CREATE FUNCTION

CREATE PROFILE

CREATE PROFILE — define a new profile

Synopsis

```
CREATE PROFILE [ IF NOT EXISTS ] name [ LIMIT parameter value [ ... ] ]

where parameter can be:

      FAILED_LOGIN_ATTEMPTS
    | PASSWORD_REUSE_TIME
    | PASSWORD_REUSE_MAX
    | PASSWORD_LIFE_TIME
    | PASSWORD_GRACE_TIME
    | USER_INACTIVE_TIME
    | FAILED_AUTH_KEEP_TIME
    | PASSWORD_MIN_UNIQUE_CHARS
    | PASSWORD_MIN_LEN
    | PASSWORD_REQUIRE_COMPLEX

CREATE PROFILE [ IF NOT EXISTS ] name FROM existing_profile
```

Description

The `CREATE PROFILE` command adds a new profile for the Postgres Pro database cluster. You must be a database superuser to use this command.

A *profile* defines a set of parameters that restrict database usage. In particular, Postgres Pro profiles enforce password management policy for the roles assigned to them. Profiles are defined at the database cluster level, so they apply to all databases in the cluster.

By default, all parameter values of a new profile are set to `DEFAULT`, which inherits the actual values from the built-in `default` profile. Initially, the `default` profile provides no usage restrictions, but it can be changed by the `ALTER PROFILE` command. The `UNLIMITED` value indicates that no restrictions apply to a particular parameter.

Once a profile is assigned to a role, all restrictions of this profile apply to this role. All newly created roles have the `default` profile, unless you explicitly assign a different profile to this role.

Parameters

name

The name of the new profile.

`FAILED_LOGIN_ATTEMPTS` *value*

Specifies the number of failed login attempts before the role is locked. A superuser can unlock the locked role by running the ALTER ROLE command with the `ACCOUNT UNLOCK` clause.

Note that there can be several actual login attempts made behind each user-perceived login attempt. For example, when the user tries to log in with SSL enabled, libpq-based clients by default also make a non-SSL connection attempt if an SSL connection fails.

Possible values are integers greater than `0`, `DEFAULT`, or `UNLIMITED`.

PASSWORD_REUSE_TIME *value*

Specifies for how long an old password cannot be reused. Measured in days. Possible values are real numbers greater than or equal to 0, interval values, DEFAULT, or UNLIMITED.

Set this parameter together with PASSWORD_REUSE_MAX as its effect depends on the combination. If both these parameters are set to UNLIMITED, there are no restrictions on password reuse. If only one of them is set to UNLIMITED, password reuse is always forbidden.

PASSWORD_REUSE_MAX *value*

Specifies the number of password changes required before the current password can be reused. Possible values are integers greater than or equal to 0, DEFAULT, or UNLIMITED.

Set this parameter together with PASSWORD_REUSE_TIME as its effect depends on the combination. If both these parameters are set to UNLIMITED, there are no restrictions on password reuse. If only one of them is set to UNLIMITED, password reuse is always forbidden.

PASSWORD_LIFE_TIME *value*

Specifies for how long the password can be used for authentication on the primary server. Measured in days. Possible values are real numbers, interval values, DEFAULT, or UNLIMITED. The resulting value in seconds must be greater than 0. Once the password expires, all further connections of the corresponding role are rejected. The role can be unlocked with the ALTER ROLE command.

However, if the LDAP authentication is configured, this role still can connect to standby servers, unless it is locked in LDAP too.

If PASSWORD_GRACE_TIME parameter is also set, the specified grace period is added to the password lifetime. During the grace period, the role is prompted to change the password while still allowed to log in.

PASSWORD_GRACE_TIME *value*

Specifies for how long a warning is raised that the password is going to expire while login is still allowed, measured in days. You can set the password life time in the VALID UNTIL attribute of the role or in the PASSWORD_LIFE_TIME parameter of the profile.

Possible values are real numbers greater than or equal to 0, interval values, DEFAULT, or UNLIMITED. If the PASSWORD_GRACE_TIME parameter is set to UNLIMITED, the password life time effectively becomes unlimited.

USER_INACTIVE_TIME *value*

Specifies for how long the user can be inactive since the last login before the role is locked. Measured in days. A superuser can unlock the locked role by running the ALTER ROLE command with the ACCOUNT UNLOCK clause. Possible values are real numbers, interval values, DEFAULT, or UNLIMITED. The resulting value in seconds must be greater than 0.

FAILED_AUTH_KEEP_TIME *value*

Specifies for how long the information on the user's first authentication failure is kept. Measured in days. Possible values are real numbers, interval values, DEFAULT, or UNLIMITED. The resulting value in seconds must be greater than 0. When the user attempts to log in after this time interval expires, the failed login attempts counter (see FAILED_LOGIN_ATTEMPTS parameter) is reset and the user is unlocked if they were locked previously due to authentication failures.

PASSWORD_MIN_UNIQUE_CHARS *value*

Specifies minimum number of unique characters for a password. Possible values are integers greater than 0, DEFAULT, or UNLIMITED.

PASSWORD_MIN_LEN *value*

Specifies minimum number of characters for a password. Possible values are positive integers, DEFAULT, or UNLIMITED.

PASSWORD_REQUIRE_COMPLEX [value]

Specifies whether password complexity is checked. If this check is enabled, a password must meet the following requirements:

- Password contains at least one character from three of the following groups: lowercase letters, uppercase letters, digits, and special characters
- Password doesn't contain the user name

Possible values are booleans or DEFAULT. If the parameter is used without a value, it is set as true.

IF NOT EXISTS

Do not throw an error if a profile with the same name already exists.

existing_profile

The name of an existing profile to copy. The new profile will have the same properties as the existing one, but it will be an independent object.

> **Important**
>
> All letters of languages without case distinction (Hindi, Chinese, etc.) in the UTF-8 encoding are considered lowercase.

Notes

Use ALTER PROFILE to change the parameter values of a profile, and DROP PROFILE to remove a profile. All the parameters specified by CREATE PROFILE can be modified later by running the ALTER PROFILE command.

> **Warning**
>
> PASSWORD_REUSE_TIME and PASSWORD_REUSE_MAX parameters might not work if the password is passed in an encrypted form during the password change. The \password command of psql encrypts the password (see the section called “Meta-Commands” for details). If the password is MD5 encrypted, it can be checked for equivalence, and PASSWORD_REUSE_TIME or PASSWORD_REUSE_MAX parameters can be applied. But there is no way to check for equivalence for SCRAM-SHA-256 encrypted passwords.

> **Warning**
>
> PASSWORD_MIN_UNIQUE_CHARS, PASSWORD_MIN_LEN, and PASSWORD_REQUIRE_COMPLEX parameters don't work if the password is passed in an encrypted form during the password change.

Examples

Create a profile admin_profile:

```
CREATE PROFILE admin_profile
    LIMIT PASSWORD_REUSE_MAX 10
          PASSWORD_REUSE_TIME 30;
```

Create a role having `admin_profile`:

```
CREATE ROLE admin WITH PROFILE admin_profile;
```

Create a profile from an existing profile:

```
CREATE PROFILE administrator FROM admin_profile;
```

This can be convenient to be able to use an existing profile as a template for a new one.

See Also

ALTER PROFILE, DROP PROFILE, CREATE ROLE

CREATE PUBLICATION

CREATE PUBLICATION — define a new publication

Synopsis

```
CREATE PUBLICATION name
    [ FOR TABLE [ ONLY ] table_name [ * ] [, ...]
      | FOR ALL TABLES ]
    [ WITH ( publication_parameter [= value] [, ... ] ) ]
```

Description

`CREATE PUBLICATION` adds a new publication into the current database. The publication name must be distinct from the name of any existing publication in the current database.

A publication is essentially a group of tables whose data changes are intended to be replicated through logical replication. See Section 30.1 for details about how publications fit into the logical replication setup.

Parameters

name

The name of the new publication.

`FOR TABLE`

Specifies a list of tables to add to the publication. If `ONLY` is specified before the table name, only that table is added to the publication. If `ONLY` is not specified, the table and all its descendant tables (if any) are added. Optionally, `*` can be specified after the table name to explicitly indicate that descendant tables are included. This does not apply to a partitioned table, however. The partitions of a partitioned table are always implicitly considered part of the publication, so they are never explicitly added to the publication.

Only persistent base tables and partitioned tables can be part of a publication. Temporary tables, unlogged tables, foreign tables, materialized views, and regular views cannot be part of a publication.

When a partitioned table is added to a publication, all of its existing and future partitions are implicitly considered to be part of the publication. So, even operations that are performed directly on a partition are also published via publications that its ancestors are part of.

`FOR ALL TABLES`

Marks the publication as one that replicates changes for all tables in the database, including tables created in the future.

`WITH ( publication_parameter [= value] [, ... ] )`

This clause specifies optional parameters for a publication. The following parameters are supported:

`publish` (`string`)

This parameter determines which DML operations will be published by the new publication to the subscribers. The value is comma-separated list of operations. The allowed operations are `insert`, `update`, `delete`, and `truncate`. The default is to publish all actions, and so the default value for this option is `'insert, update, delete, truncate'`.

`publish_via_partition_root` (`boolean`)

This parameter determines whether changes in a partitioned table (or on its partitions) contained in the publication will be published using the identity and schema of the partitioned table rather

than that of the individual partitions that are actually changed; the latter is the default. Enabling this allows the changes to be replicated into a non-partitioned table or a partitioned table consisting of a different set of partitions.

If this is enabled, `TRUNCATE` operations performed directly on partitions are not replicated.

Notes

If neither `FOR TABLE` nor `FOR ALL TABLES` is specified, then the publication starts out with an empty set of tables. That is useful if tables are to be added later.

The creation of a publication does not start replication. It only defines a grouping and filtering logic for future subscribers.

To create a publication, the invoking user must have the `CREATE` privilege for the current database. (Of course, superusers bypass this check.)

To add a table to a publication, the invoking user must have ownership rights on the table. The `FOR ALL TABLES` clause requires the invoking user to be a superuser.

The tables added to a publication that publishes `UPDATE` and/or `DELETE` operations must have `REPLICA IDENTITY` defined. Otherwise those operations will be disallowed on those tables.

For an `INSERT ... ON CONFLICT` command, the publication will publish the operation that results from the command. Depending on the outcome, it may be published as either `INSERT` or `UPDATE`, or it may not be published at all.

`ATTACH`ing a table into a partition tree whose root is published using a publication with `publish_via_partition_root` set to `true` does not result in the table's existing contents being replicated.

`COPY ... FROM` commands are published as `INSERT` operations.

DDL operations are not published.

Examples

Create a publication that publishes all changes in two tables:

```
CREATE PUBLICATION mypublication FOR TABLE users, departments;
```

Create a publication that publishes all changes in all tables:

```
CREATE PUBLICATION alltables FOR ALL TABLES;
```

Create a publication that only publishes `INSERT` operations in one table:

```
CREATE PUBLICATION insert_only FOR TABLE mydata
    WITH (publish = 'insert');
```

Compatibility

`CREATE PUBLICATION` is a Postgres Pro extension.

See Also

ALTER PUBLICATION, DROP PUBLICATION, CREATE SUBSCRIPTION, ALTER SUBSCRIPTION

CREATE ROLE

CREATE ROLE — define a new database role

Synopsis

```
CREATE ROLE name [ [ WITH ] option [ ... ] ]

where option can be:

      SUPERUSER | NOSUPERUSER
    | CREATEDB | NOCREATEDB
    | CREATEROLE | NOCREATEROLE
    | INHERIT | NOINHERIT
    | LOGIN | NOLOGIN
    | REPLICATION | NOREPLICATION
    | BYPASSRLS | NOBYPASSRLS
    | CONNECTION LIMIT connlimit
    | [ ENCRYPTED ] PASSWORD 'password' | PASSWORD NULL
    | VALID UNTIL 'timestamp'
    | IN ROLE role_name [, ...]
    | IN GROUP role_name [, ...]
    | ROLE role_name [, ...]
    | ADMIN role_name [, ...]
    | USER role_name [, ...]
    | SYSID uid
    | PROFILE profile_name
```

Description

`CREATE ROLE` adds a new role to a Postgres Pro database cluster. A role is an entity that can own database objects and have database privileges; a role can be considered a “user”, a “group”, or both depending on how it is used. Refer to Chapter 21 and Chapter 20 for information about managing users and authentication. You must have `CREATEROLE` privilege or be a database superuser to use this command.

Note that roles are defined at the database cluster level, and so are valid in all databases in the cluster.

Parameters

name

The name of the new role.

`SUPERUSER`
`NOSUPERUSER`

These clauses determine whether the new role is a “superuser”, who can override all access restrictions within the database. Superuser status is dangerous and should be used only when really needed. You must yourself be a superuser to create a new superuser. If not specified, `NOSUPERUSER` is the default.

`CREATEDB`
`NOCREATEDB`

These clauses define a role's ability to create databases. If `CREATEDB` is specified, the role being defined will be allowed to create new databases. Specifying `NOCREATEDB` will deny a role the ability to create databases. If not specified, `NOCREATEDB` is the default. Only superuser roles or roles with `CREATEDB` can specify `CREATEDB`.

`CREATEROLE`
`NOCREATEROLE`

These clauses determine whether a role will be permitted to create, alter, drop, comment on, and change the security label for other roles. See role creation for more details about what capabilities are conferred by this privilege. If not specified, `NOCREATEROLE` is the default.

`INHERIT`
`NOINHERIT`

These clauses determine whether a role "inherits" the privileges of roles it is a member of. A role with the `INHERIT` attribute can automatically use whatever database privileges have been granted to all roles it is directly or indirectly a member of. Without `INHERIT`, membership in another role only grants the ability to `SET ROLE` to that other role; the privileges of the other role are only available after having done so. If not specified, `INHERIT` is the default.

`LOGIN`
`NOLOGIN`

These clauses determine whether a role is allowed to log in; that is, whether the role can be given as the initial session authorization name during client connection. A role having the `LOGIN` attribute can be thought of as a user. Roles without this attribute are useful for managing database privileges, but are not users in the usual sense of the word. If not specified, `NOLOGIN` is the default, except when `CREATE ROLE` is invoked through its alternative spelling `CREATE USER`.

`REPLICATION`
`NOREPLICATION`

These clauses determine whether a role is a replication role. A role must have this attribute (or be a superuser) in order to be able to connect to the server in replication mode (physical or logical replication) and in order to be able to create or drop replication slots. A role having the `REPLICATION` attribute is a very highly privileged role, and should only be used on roles actually used for replication. If not specified, `NOREPLICATION` is the default. Only superuser roles or roles with `REPLICATION` can specify `REPLICATION`.

`BYPASSRLS`
`NOBYPASSRLS`

These clauses determine whether a role bypasses every row-level security (RLS) policy. `NOBYPASSRLS` is the default. Only superuser roles or roles with `BYPASSRLS` can specify `BYPASSRLS`.

Note that pg_dump will set `row_security` to `OFF` by default, to ensure all contents of a table are dumped out. If the user running pg_dump does not have appropriate permissions, an error will be returned. However, superusers and the owner of the table being dumped always bypass RLS.

`CONNECTION LIMIT` *connlimit*

If role can log in, this specifies how many concurrent connections the role can make. -1 (the default) means no limit. Note that only normal connections are counted towards this limit. Neither prepared transactions nor background worker connections are counted towards this limit.

[`ENCRYPTED`] `PASSWORD` '*password*'
`PASSWORD NULL`

Sets the role's password. (A password is only of use for roles having the `LOGIN` attribute, but you can nonetheless define one for roles without it.) If you do not plan to use password authentication you can omit this option. If no password is specified, the password will be set to null and password authentication will always fail for that user. A null password can optionally be written explicitly as `PASSWORD NULL`.

> **Note**
>
> Specifying an empty string will also set the password to null, but that was not the case before Postgres Pro version 10. In earlier versions, an empty string could be used, or not, depending

on the authentication method and the exact version, and libpq would refuse to use it in any case. To avoid the ambiguity, specifying an empty string should be avoided.

The password is always stored encrypted in the system catalogs. The `ENCRYPTED` keyword has no effect, but is accepted for backwards compatibility. The method of encryption is determined by the configuration parameter password_encryption. If the presented password string is already in MD5-encrypted or SCRAM-encrypted format, then it is stored as-is regardless of `password_encryption` (since the system cannot decrypt the specified encrypted password string, to encrypt it in a different format). This allows reloading of encrypted passwords during dump/restore.

`VALID UNTIL '`*`timestamp`*`'`

The `VALID UNTIL` clause sets a date and time after which the role's password is no longer valid. If this clause is omitted the password will be valid for all time.

`IN ROLE` *`role_name`*

The `IN ROLE` clause lists one or more existing roles to which the new role will be immediately added as a new member. (Note that there is no option to add the new role as an administrator; use a separate `GRANT` command to do that.)

`IN GROUP` *`role_name`*

`IN GROUP` is an obsolete spelling of `IN ROLE`.

`ROLE` *`role_name`*

The `ROLE` clause lists one or more existing roles which are automatically added as members of the new role. (This in effect makes the new role a “group”.)

`ADMIN` *`role_name`*

The `ADMIN` clause is like `ROLE`, but the named roles are added to the new role `WITH ADMIN OPTION`, giving them the right to grant membership in this role to others.

`USER` *`role_name`*

The `USER` clause is an obsolete spelling of the `ROLE` clause.

`SYSID` *`uid`*

The `SYSID` clause is ignored, but is accepted for backwards compatibility.

`PROFILE` *`profile_name`*

Sets the role's profile. If this clause is omitted, the `default` profile is assigned to a role (see CREATE PROFILE for details).

Notes

Use `ALTER ROLE` to change the attributes of a role, and `DROP ROLE` to remove a role. All the attributes specified by `CREATE ROLE` can be modified by later `ALTER ROLE` commands.

The preferred way to add and remove members of roles that are being used as groups is to use `GRANT` and `REVOKE`.

The `VALID UNTIL` clause defines an expiration time for a password only, not for the role per se. In particular, the expiration time is not enforced when logging in using a non-password-based authentication method.

The `INHERIT` attribute governs inheritance of grantable privileges (that is, access privileges for database objects and role memberships). It does not apply to the special role attributes set by `CREATE ROLE` and

ALTER ROLE. For example, being a member of a role with CREATEDB privilege does not immediately grant the ability to create databases, even if INHERIT is set; it would be necessary to become that role via SET ROLE before creating a database.

The INHERIT attribute is the default for reasons of backwards compatibility: in prior releases of Postgres Pro, users always had access to all privileges of groups they were members of. However, NOINHERIT provides a closer match to the semantics specified in the SQL standard.

Postgres Pro includes a program createuser that has the same functionality as CREATE ROLE (in fact, it calls this command) but can be run from the command shell.

The CONNECTION LIMIT option is only enforced approximately; if two new sessions start at about the same time when just one connection “slot” remains for the role, it is possible that both will fail. Also, the limit is never enforced for superusers.

Caution must be exercised when specifying an unencrypted password with this command. The password will be transmitted to the server in cleartext, and it might also be logged in the client's command history or the server log. The command createuser, however, transmits the password encrypted. Also, psql contains a command \password that can be used to safely change the password later.

Examples

Create a role that can log in, but don't give it a password:

```
CREATE ROLE jonathan LOGIN;
```

Create a role with a password:

```
CREATE USER davide WITH PASSWORD 'jw8s0F4';
```

(CREATE USER is the same as CREATE ROLE except that it implies LOGIN.)

Create a role with a profile:

```
CREATE ROLE davide WITH PROFILE admin_profile;
```

Create a role with a password that is valid until the end of 2004. After one second has ticked in 2005, the password is no longer valid.

```
CREATE ROLE miriam WITH LOGIN PASSWORD 'jw8s0F4' VALID UNTIL '2005-01-01';
```

Create a role that can create databases and manage roles:

```
CREATE ROLE admin WITH CREATEDB CREATEROLE;
```

Compatibility

The CREATE ROLE statement is in the SQL standard, but the standard only requires the syntax

```
CREATE ROLE name [ WITH ADMIN role_name ]
```

Multiple initial administrators, and all the other options of CREATE ROLE, are Postgres Pro extensions.

The SQL standard defines the concepts of users and roles, but it regards them as distinct concepts and leaves all commands defining users to be specified by each database implementation. In Postgres Pro we have chosen to unify users and roles into a single kind of entity. Roles therefore have many more optional attributes than they do in the standard.

The behavior specified by the SQL standard is most closely approximated by giving users the NOINHERIT attribute, while roles are given the INHERIT attribute.

See Also

SET ROLE, ALTER ROLE, DROP ROLE, GRANT, REVOKE, createuser, CREATE PROFILE

CREATE RULE

CREATE RULE — define a new rewrite rule

Synopsis

```
CREATE [ OR REPLACE ] RULE name AS ON event
    TO table_name [ WHERE condition ]
    DO [ ALSO | INSTEAD ] { NOTHING | command | ( command ; command ... ) }

where event can be one of:

    SELECT | INSERT | UPDATE | DELETE
```

Description

`CREATE RULE` defines a new rule applying to a specified table or view. `CREATE OR REPLACE RULE` will either create a new rule, or replace an existing rule of the same name for the same table.

The Postgres Pro rule system allows one to define an alternative action to be performed on insertions, updates, or deletions in database tables. Roughly speaking, a rule causes additional commands to be executed when a given command on a given table is executed. Alternatively, an `INSTEAD` rule can replace a given command by another, or cause a command not to be executed at all. Rules are used to implement SQL views as well. It is important to realize that a rule is really a command transformation mechanism, or command macro. The transformation happens before the execution of the command starts. If you actually want an operation that fires independently for each physical row, you probably want to use a trigger, not a rule. More information about the rules system is in Chapter 43.

Presently, `ON SELECT` rules can only be attached to views. (Attaching one to a table converts the table into a view.) Such a rule must be named `"_RETURN"`, must be an unconditional `INSTEAD` rule, and must have an action that consists of a single `SELECT` command. This command defines the visible contents of the view. (The view itself is basically a dummy table with no storage.) It's best to regard such a rule as an implementation detail. While a view can be redefined via `CREATE OR REPLACE RULE "_RETURN" AS ...`, it's better style to use `CREATE OR REPLACE VIEW`.

You can create the illusion of an updatable view by defining `ON INSERT`, `ON UPDATE`, and `ON DELETE` rules (or any subset of those that's sufficient for your purposes) to replace update actions on the view with appropriate updates on other tables. If you want to support `INSERT RETURNING` and so on, then be sure to put a suitable `RETURNING` clause into each of these rules.

There is a catch if you try to use conditional rules for complex view updates: there *must* be an unconditional `INSTEAD` rule for each action you wish to allow on the view. If the rule is conditional, or is not `INSTEAD`, then the system will still reject attempts to perform the update action, because it thinks it might end up trying to perform the action on the dummy table of the view in some cases. If you want to handle all the useful cases in conditional rules, add an unconditional `DO INSTEAD NOTHING` rule to ensure that the system understands it will never be called on to update the dummy table. Then make the conditional rules non-`INSTEAD`; in the cases where they are applied, they add to the default `INSTEAD NOTHING` action. (This method does not currently work to support `RETURNING` queries, however.)

Note

A view that is simple enough to be automatically updatable (see CREATE VIEW) does not require a user-created rule in order to be updatable. While you can create an explicit rule anyway, the automatic update transformation will generally outperform an explicit rule.

Another alternative worth considering is to use `INSTEAD OF` triggers (see CREATE TRIGGER) in place of rules.

Parameters

name

The name of a rule to create. This must be distinct from the name of any other rule for the same table. Multiple rules on the same table and same event type are applied in alphabetical name order.

event

The event is one of SELECT, INSERT, UPDATE, or DELETE. Note that an INSERT containing an ON CONFLICT clause cannot be used on tables that have either INSERT or UPDATE rules. Consider using an updatable view instead.

table_name

The name (optionally schema-qualified) of the table or view the rule applies to.

condition

Any SQL conditional expression (returning boolean). The condition expression cannot refer to any tables except NEW and OLD, and cannot contain aggregate functions.

INSTEAD

INSTEAD indicates that the commands should be executed *instead of* the original command.

ALSO

ALSO indicates that the commands should be executed *in addition to* the original command.

If neither ALSO nor INSTEAD is specified, ALSO is the default.

command

The command or commands that make up the rule action. Valid commands are SELECT, INSERT, UPDATE, DELETE, or NOTIFY.

Within *condition* and *command*, the special table names NEW and OLD can be used to refer to values in the referenced table. NEW is valid in ON INSERT and ON UPDATE rules to refer to the new row being inserted or updated. OLD is valid in ON UPDATE and ON DELETE rules to refer to the existing row being updated or deleted.

Notes

You must be the owner of a table to create or change rules for it.

In a rule for INSERT, UPDATE, or DELETE on a view, you can add a RETURNING clause that emits the view's columns. This clause will be used to compute the outputs if the rule is triggered by an INSERT RETURNING, UPDATE RETURNING, or DELETE RETURNING command respectively. When the rule is triggered by a command without RETURNING, the rule's RETURNING clause will be ignored. The current implementation allows only unconditional INSTEAD rules to contain RETURNING; furthermore there can be at most one RETURNING clause among all the rules for the same event. (This ensures that there is only one candidate RETURNING clause to be used to compute the results.) RETURNING queries on the view will be rejected if there is no RETURNING clause in any available rule.

It is very important to take care to avoid circular rules. For example, though each of the following two rule definitions are accepted by Postgres Pro, the SELECT command would cause Postgres Pro to report an error because of recursive expansion of a rule:

```
CREATE RULE "_RETURN" AS
    ON SELECT TO t1
    DO INSTEAD
        SELECT * FROM t2;
```

```
CREATE RULE "_RETURN" AS
    ON SELECT TO t2
    DO INSTEAD
        SELECT * FROM t1;

SELECT * FROM t1;
```

Presently, if a rule action contains a `NOTIFY` command, the `NOTIFY` command will be executed unconditionally, that is, the `NOTIFY` will be issued even if there are not any rows that the rule should apply to. For example, in:

```
CREATE RULE notify_me AS ON UPDATE TO mytable DO ALSO NOTIFY mytable;

UPDATE mytable SET name = 'foo' WHERE id = 42;
```

one `NOTIFY` event will be sent during the `UPDATE`, whether or not there are any rows that match the condition `id = 42`. This is an implementation restriction that might be fixed in future releases.

Compatibility

`CREATE RULE` is a Postgres Pro language extension, as is the entire query rewrite system.

See Also

ALTER RULE, DROP RULE

CREATE SCHEMA

CREATE SCHEMA — define a new schema

Synopsis

```
CREATE SCHEMA schema_name [ AUTHORIZATION role_specification ] [ schema_element
 [ ... ] ]
CREATE SCHEMA AUTHORIZATION role_specification [ schema_element [ ... ] ]
CREATE SCHEMA IF NOT EXISTS schema_name [ AUTHORIZATION role_specification ]
CREATE SCHEMA IF NOT EXISTS AUTHORIZATION role_specification

where role_specification can be:

    user_name
  | CURRENT_ROLE
  | CURRENT_USER
  | SESSION_USER
```

Description

`CREATE SCHEMA` enters a new schema into the current database. The schema name must be distinct from the name of any existing schema in the current database.

A schema is essentially a namespace: it contains named objects (tables, data types, functions, and operators) whose names can duplicate those of other objects existing in other schemas. Named objects are accessed either by "qualifying" their names with the schema name as a prefix, or by setting a search path that includes the desired schema(s). A `CREATE` command specifying an unqualified object name creates the object in the current schema (the one at the front of the search path, which can be determined with the function `current_schema`).

Optionally, `CREATE SCHEMA` can include subcommands to create objects within the new schema. The subcommands are treated essentially the same as separate commands issued after creating the schema, except that if the `AUTHORIZATION` clause is used, all the created objects will be owned by that user.

Parameters

schema_name

The name of a schema to be created. If this is omitted, the *user_name* is used as the schema name. The name cannot begin with `pg_`, as such names are reserved for system schemas.

user_name

The role name of the user who will own the new schema. If omitted, defaults to the user executing the command. To create a schema owned by another role, you must be a direct or indirect member of that role, or be a superuser.

schema_element

An SQL statement defining an object to be created within the schema. Currently, only `CREATE TABLE`, `CREATE VIEW`, `CREATE INDEX`, `CREATE SEQUENCE`, `CREATE TRIGGER` and `GRANT` are accepted as clauses within `CREATE SCHEMA`. Other kinds of objects may be created in separate commands after the schema is created.

`IF NOT EXISTS`

Do nothing (except issuing a notice) if a schema with the same name already exists. *schema_element* subcommands cannot be included when this option is used.

Notes

To create a schema, the invoking user must have the `CREATE` privilege for the current database. (Of course, superusers bypass this check.)

Examples

Create a schema:

```
CREATE SCHEMA myschema;
```

Create a schema for user `joe`; the schema will also be named `joe`:

```
CREATE SCHEMA AUTHORIZATION joe;
```

Create a schema named `test` that will be owned by user `joe`, unless there already is a schema named `test`. (It does not matter whether `joe` owns the pre-existing schema.)

```
CREATE SCHEMA IF NOT EXISTS test AUTHORIZATION joe;
```

Create a schema and create a table and view within it:

```
CREATE SCHEMA hollywood
    CREATE TABLE films (title text, release date, awards text[])
    CREATE VIEW winners AS
        SELECT title, release FROM films WHERE awards IS NOT NULL;
```

Notice that the individual subcommands do not end with semicolons.

The following is an equivalent way of accomplishing the same result:

```
CREATE SCHEMA hollywood;
CREATE TABLE hollywood.films (title text, release date, awards text[]);
CREATE VIEW hollywood.winners AS
    SELECT title, release FROM hollywood.films WHERE awards IS NOT NULL;
```

Compatibility

The SQL standard allows a `DEFAULT CHARACTER SET` clause in `CREATE SCHEMA`, as well as more subcommand types than are presently accepted by Postgres Pro.

The SQL standard specifies that the subcommands in `CREATE SCHEMA` can appear in any order. The present Postgres Pro implementation does not handle all cases of forward references in subcommands; it might sometimes be necessary to reorder the subcommands in order to avoid forward references.

According to the SQL standard, the owner of a schema always owns all objects within it. Postgres Pro allows schemas to contain objects owned by users other than the schema owner. This can happen only if the schema owner grants the `CREATE` privilege on their schema to someone else, or a superuser chooses to create objects in it.

The `IF NOT EXISTS` option is a Postgres Pro extension.

See Also

ALTER SCHEMA, DROP SCHEMA

CREATE SEQUENCE

CREATE SEQUENCE — define a new sequence generator

Synopsis

```
CREATE [ TEMPORARY | TEMP ] SEQUENCE [ IF NOT EXISTS ] name
    [ AS data_type ]
    [ INCREMENT [ BY ] increment ]
    [ MINVALUE minvalue | NO MINVALUE ] [ MAXVALUE maxvalue | NO MAXVALUE ]
    [ START [ WITH ] start ] [ CACHE cache ] [ [ NO ] CYCLE ]
    [ OWNED BY { table_name.column_name | NONE } ]
```

Description

`CREATE SEQUENCE` creates a new sequence number generator. This involves creating and initializing a new special single-row table with the name *name*. The generator will be owned by the user issuing the command.

If a schema name is given then the sequence is created in the specified schema. Otherwise it is created in the current schema. Temporary sequences exist in a special schema, so a schema name cannot be given when creating a temporary sequence. The sequence name must be distinct from the name of any other sequence, table, index, view, or foreign table in the same schema.

After a sequence is created, you use the functions `nextval`, `currval`, and `setval` to operate on the sequence. These functions are documented in Section 9.17.

Although you cannot update a sequence directly, you can use a query like:

```
SELECT * FROM name;
```

to examine the parameters and current state of a sequence. In particular, the `last_value` field of the sequence shows the last value allocated by any session. (Of course, this value might be obsolete by the time it's printed, if other sessions are actively doing `nextval` calls.)

Parameters

`TEMPORARY` or `TEMP`

If specified, the sequence object is created only for this session, and is automatically dropped on session exit. Existing permanent sequences with the same name are not visible (in this session) while the temporary sequence exists, unless they are referenced with schema-qualified names.

`IF NOT EXISTS`

Do not throw an error if a relation with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing relation is anything like the sequence that would have been created — it might not even be a sequence.

name

The name (optionally schema-qualified) of the sequence to be created.

data_type

The optional clause `AS data_type` specifies the data type of the sequence. Valid types are `smallint`, `integer`, and `bigint`. `bigint` is the default. The data type determines the default minimum and maximum values of the sequence.

increment

The optional clause `INCREMENT BY increment` specifies which value is added to the current sequence value to create a new value. A positive value will make an ascending sequence, a negative one a descending sequence. The default value is 1.

minvalue
NO MINVALUE

The optional clause MINVALUE *minvalue* determines the minimum value a sequence can generate. If this clause is not supplied or NO MINVALUE is specified, then defaults will be used. The default for an ascending sequence is 1. The default for a descending sequence is the minimum value of the data type.

maxvalue
NO MAXVALUE

The optional clause MAXVALUE *maxvalue* determines the maximum value for the sequence. If this clause is not supplied or NO MAXVALUE is specified, then default values will be used. The default for an ascending sequence is the maximum value of the data type. The default for a descending sequence is -1.

start

The optional clause START WITH *start* allows the sequence to begin anywhere. The default starting value is *minvalue* for ascending sequences and *maxvalue* for descending ones.

cache

The optional clause CACHE *cache* specifies how many sequence numbers are to be preallocated and stored in memory for faster access. The minimum value is 1 (only one value can be generated at a time, i.e., no cache), and this is also the default.

CYCLE
NO CYCLE

The CYCLE option allows the sequence to wrap around when the *maxvalue* or *minvalue* has been reached by an ascending or descending sequence respectively. If the limit is reached, the next number generated will be the *minvalue* or *maxvalue*, respectively.

If NO CYCLE is specified, any calls to nextval after the sequence has reached its maximum value will return an error. If neither CYCLE or NO CYCLE are specified, NO CYCLE is the default.

OWNED BY *table_name.column_name*
OWNED BY NONE

The OWNED BY option causes the sequence to be associated with a specific table column, such that if that column (or its whole table) is dropped, the sequence will be automatically dropped as well. The specified table must have the same owner and be in the same schema as the sequence. OWNED BY NONE, the default, specifies that there is no such association.

Notes

Use DROP SEQUENCE to remove a sequence.

Sequences are based on bigint arithmetic, so the range cannot exceed the range of an eight-byte integer (-9223372036854775808 to 9223372036854775807).

Because nextval and setval calls are never rolled back, sequence objects cannot be used if “gapless” assignment of sequence numbers is needed. It is possible to build gapless assignment by using exclusive locking of a table containing a counter; but this solution is much more expensive than sequence objects, especially if many transactions need sequence numbers concurrently.

Unexpected results might be obtained if a *cache* setting greater than one is used for a sequence object that will be used concurrently by multiple sessions. Each session will allocate and cache successive sequence values during one access to the sequence object and increase the sequence object's last_value accordingly. Then, the next *cache*-1 uses of nextval within that session simply return the preallocated

values without touching the sequence object. So, any numbers allocated but not used within a session will be lost when that session ends, resulting in “holes” in the sequence.

Furthermore, although multiple sessions are guaranteed to allocate distinct sequence values, the values might be generated out of sequence when all the sessions are considered. For example, with a *cache* setting of 10, session A might reserve values 1..10 and return `nextval`=1, then session B might reserve values 11..20 and return `nextval`=11 before session A has generated `nextval`=2. Thus, with a *cache* setting of one it is safe to assume that `nextval` values are generated sequentially; with a *cache* setting greater than one you should only assume that the `nextval` values are all distinct, not that they are generated purely sequentially. Also, `last_value` will reflect the latest value reserved by any session, whether or not it has yet been returned by `nextval`.

Another consideration is that a `setval` executed on such a sequence will not be noticed by other sessions until they have used up any preallocated values they have cached.

Examples

Create an ascending sequence called `serial`, starting at 101:

```
CREATE SEQUENCE serial START 101;
```

Select the next number from this sequence:

```
SELECT nextval('serial');

 nextval
---------
     101
```

Select the next number from this sequence:

```
SELECT nextval('serial');

 nextval
---------
     102
```

Use this sequence in an `INSERT` command:

```
INSERT INTO distributors VALUES (nextval('serial'), 'nothing');
```

Update the sequence value after a `COPY FROM`:

```
BEGIN;
COPY distributors FROM 'input_file';
SELECT setval('serial', max(id)) FROM distributors;
END;
```

Compatibility

`CREATE SEQUENCE` conforms to the SQL standard, with the following exceptions:

- Obtaining the next value is done using the `nextval()` function instead of the standard's `NEXT VALUE FOR` expression.
- The `OWNED BY` clause is a Postgres Pro extension.

See Also

ALTER SEQUENCE, DROP SEQUENCE

CREATE SERVER

CREATE SERVER — define a new foreign server

Synopsis

```
CREATE SERVER [ IF NOT EXISTS ] server_name [ TYPE 'server_type' ] [ VERSION
 'server_version' ]
    FOREIGN DATA WRAPPER fdw_name
    [ OPTIONS ( option 'value' [, ... ] ) ]
```

Description

`CREATE SERVER` defines a new foreign server. The user who defines the server becomes its owner.

A foreign server typically encapsulates connection information that a foreign-data wrapper uses to access an external data resource. Additional user-specific connection information may be specified by means of user mappings.

The server name must be unique within the database.

Creating a server requires `USAGE` privilege on the foreign-data wrapper being used.

Parameters

`IF NOT EXISTS`

Do not throw an error if a server with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing server is anything like the one that would have been created.

`server_name`

The name of the foreign server to be created.

`server_type`

Optional server type, potentially useful to foreign-data wrappers.

`server_version`

Optional server version, potentially useful to foreign-data wrappers.

`fdw_name`

The name of the foreign-data wrapper that manages the server.

`OPTIONS ( option 'value' [, ... ] )`

This clause specifies the options for the server. The options typically define the connection details of the server, but the actual names and values are dependent on the server's foreign-data wrapper.

Notes

When using the dblink module, a foreign server's name can be used as an argument of the dblink_connect function to indicate the connection parameters. It is necessary to have the `USAGE` privilege on the foreign server to be able to use it in this way.

If the foreign server supports sort pushdown, it is necessary for it to have the same sort ordering as the local server.

Examples

Create a server `myserver` that uses the foreign-data wrapper `postgres_fdw`:

```
CREATE SERVER myserver FOREIGN DATA WRAPPER postgres_fdw OPTIONS (host 'foo', dbname
 'foodb', port '5432');
```

See postgres_fdw for more details.

Compatibility

`CREATE SERVER` conforms to ISO/IEC 9075-9 (SQL/MED).

See Also

ALTER SERVER, DROP SERVER, CREATE FOREIGN DATA WRAPPER, CREATE FOREIGN TABLE, CREATE USER MAPPING

CREATE STATISTICS

CREATE STATISTICS — define extended statistics

Synopsis

```
CREATE STATISTICS [ IF NOT EXISTS ] statistics_name
    ON ( expression )
    FROM table_name

CREATE STATISTICS [ IF NOT EXISTS ] statistics_name
    [ ( statistics_kind [, ... ] ) ]
    ON { column_name | ( expression ) }, { column_name | ( expression ) } [, ...]
    FROM table_name
```

Description

`CREATE STATISTICS` will create a new extended statistics object tracking data about the specified table, foreign table or materialized view. The statistics object will be created in the current database and will be owned by the user issuing the command.

The `CREATE STATISTICS` command has two basic forms. The first form allows univariate statistics for a single expression to be collected, providing benefits similar to an expression index without the overhead of index maintenance. This form does not allow the statistics kind to be specified, since the various statistics kinds refer only to multivariate statistics. The second form of the command allows multivariate statistics on multiple columns and/or expressions to be collected, optionally specifying which statistics kinds to include. This form will also automatically cause univariate statistics to be collected on any expressions included in the list.

If a schema name is given (for example, `CREATE STATISTICS myschema.mystat ...`) then the statistics object is created in the specified schema. Otherwise it is created in the current schema. The name of the statistics object must be distinct from the name of any other statistics object in the same schema.

Parameters

`IF NOT EXISTS`

Do not throw an error if a statistics object with the same name already exists. A notice is issued in this case. Note that only the name of the statistics object is considered here, not the details of its definition.

`statistics_name`

The name (optionally schema-qualified) of the statistics object to be created.

`statistics_kind`

A multivariate statistics kind to be computed in this statistics object. Currently supported kinds are `ndistinct`, which enables n-distinct statistics, `dependencies`, which enables functional dependency statistics, and `mcv` which enables most-common values lists. If this clause is omitted, all supported statistics kinds are included in the statistics object. Univariate expression statistics are built automatically if the statistics definition includes any complex expressions rather than just simple column references. For more information, see Section 14.2.2 and Section 71.2.

`column_name`

The name of a table column to be covered by the computed statistics. This is only allowed when building multivariate statistics. At least two column names or expressions must be specified, and their order is not significant.

expression

An expression to be covered by the computed statistics. This may be used to build univariate statistics on a single expression, or as part of a list of multiple column names and/or expressions to build multivariate statistics. In the latter case, separate univariate statistics are built automatically for each expression in the list.

table_name

The name (optionally schema-qualified) of the table containing the column(s) the statistics are computed on; see ANALYZE for an explanation of the handling of inheritance and partitions.

Notes

You must be the owner of a table to create a statistics object reading it. Once created, however, the ownership of the statistics object is independent of the underlying table(s).

Expression statistics are per-expression and are similar to creating an index on the expression, except that they avoid the overhead of index maintenance. Expression statistics are built automatically for each expression in the statistics object definition.

Extended statistics are not currently used by the planner for selectivity estimations made for table joins. This limitation will likely be removed in a future version of PostgreSQL.

Examples

Create table `t1` with two functionally dependent columns, i.e., knowledge of a value in the first column is sufficient for determining the value in the other column. Then functional dependency statistics are built on those columns:

```
CREATE TABLE t1 (
    a   int,
    b   int
);

INSERT INTO t1 SELECT i/100, i/500
                FROM generate_series(1,1000000) s(i);

ANALYZE t1;

-- the number of matching rows will be drastically underestimated:
EXPLAIN ANALYZE SELECT * FROM t1 WHERE (a = 1) AND (b = 0);

CREATE STATISTICS s1 (dependencies) ON a, b FROM t1;

ANALYZE t1;

-- now the row count estimate is more accurate:
EXPLAIN ANALYZE SELECT * FROM t1 WHERE (a = 1) AND (b = 0);
```

Without functional-dependency statistics, the planner would assume that the two `WHERE` conditions are independent, and would multiply their selectivities together to arrive at a much-too-small row count estimate. With such statistics, the planner recognizes that the `WHERE` conditions are redundant and does not underestimate the row count.

Create table `t2` with two perfectly correlated columns (containing identical data), and an MCV list on those columns:

```
CREATE TABLE t2 (
    a   int,
    b   int
);
```

```
INSERT INTO t2 SELECT mod(i,100), mod(i,100)
                 FROM generate_series(1,1000000) s(i);

CREATE STATISTICS s2 (mcv) ON a, b FROM t2;

ANALYZE t2;

-- valid combination (found in MCV)
EXPLAIN ANALYZE SELECT * FROM t2 WHERE (a = 1) AND (b = 1);

-- invalid combination (not found in MCV)
EXPLAIN ANALYZE SELECT * FROM t2 WHERE (a = 1) AND (b = 2);
```

The MCV list gives the planner more detailed information about the specific values that commonly appear in the table, as well as an upper bound on the selectivities of combinations of values that do not appear in the table, allowing it to generate better estimates in both cases.

Create table `t3` with a single timestamp column, and run queries using expressions on that column. Without extended statistics, the planner has no information about the data distribution for the expressions, and uses default estimates. The planner also does not realize that the value of the date truncated to the month is fully determined by the value of the date truncated to the day. Then expression and ndistinct statistics are built on those two expressions:

```
CREATE TABLE t3 (
    a   timestamp
);

INSERT INTO t3 SELECT i FROM generate_series('2020-01-01'::timestamp,
                                             '2020-12-31'::timestamp,
                                             '1 minute'::interval) s(i);

ANALYZE t3;

-- the number of matching rows will be drastically underestimated:
EXPLAIN ANALYZE SELECT * FROM t3
  WHERE date_trunc('month', a) = '2020-01-01'::timestamp;

EXPLAIN ANALYZE SELECT * FROM t3
  WHERE date_trunc('day', a) BETWEEN '2020-01-01'::timestamp
                                 AND '2020-06-30'::timestamp;

EXPLAIN ANALYZE SELECT date_trunc('month', a), date_trunc('day', a)
   FROM t3 GROUP BY 1, 2;

-- build ndistinct statistics on the pair of expressions (per-expression
-- statistics are built automatically)
CREATE STATISTICS s3 (ndistinct) ON date_trunc('month', a), date_trunc('day', a) FROM
 t3;

ANALYZE t3;

-- now the row count estimates are more accurate:
EXPLAIN ANALYZE SELECT * FROM t3
  WHERE date_trunc('month', a) = '2020-01-01'::timestamp;

EXPLAIN ANALYZE SELECT * FROM t3
  WHERE date_trunc('day', a) BETWEEN '2020-01-01'::timestamp
                                 AND '2020-06-30'::timestamp;
```

```
EXPLAIN ANALYZE SELECT date_trunc('month', a), date_trunc('day', a)
   FROM t3 GROUP BY 1, 2;
```

Without expression and ndistinct statistics, the planner has no information about the number of distinct values for the expressions, and has to rely on default estimates. The equality and range conditions are assumed to have 0.5% selectivity, and the number of distinct values in the expression is assumed to be the same as for the column (i.e. unique). This results in a significant underestimate of the row count in the first two queries. Moreover, the planner has no information about the relationship between the expressions, so it assumes the two `WHERE` and `GROUP BY` conditions are independent, and multiplies their selectivities together to arrive at a severe overestimate of the group count in the aggregate query. This is further exacerbated by the lack of accurate statistics for the expressions, forcing the planner to use a default ndistinct estimate for the expression derived from ndistinct for the column. With such statistics, the planner recognizes that the conditions are correlated, and arrives at much more accurate estimates.

Compatibility

There is no `CREATE STATISTICS` command in the SQL standard.

See Also

ALTER STATISTICS, DROP STATISTICS

CREATE SUBSCRIPTION

CREATE SUBSCRIPTION — define a new subscription

Synopsis

```
CREATE SUBSCRIPTION subscription_name
    CONNECTION 'conninfo'
    PUBLICATION publication_name [, ...]
    [ WITH ( subscription_parameter [= value] [, ... ] ) ]
```

Description

`CREATE SUBSCRIPTION` adds a new subscription for the current database. The subscription name must be distinct from the name of any existing subscription in the database.

The subscription represents a replication connection to the publisher. As such this command does not only add definitions in the local catalogs but also creates a replication slot on the publisher.

A logical replication worker will be started to replicate data for the new subscription at the commit of the transaction where this command is run.

Additional information about subscriptions and logical replication as a whole is available at Section 30.2 and Chapter 30.

Parameters

subscription_name

The name of the new subscription.

`CONNECTION '`*conninfo*`'`

The connection string to the publisher. For details see Section 36.1.1.

`PUBLICATION` *publication_name*

Names of the publications on the publisher to subscribe to.

`WITH (` *subscription_parameter* `[=` *value*`] [, ... ] )`

This clause specifies optional parameters for a subscription. The following parameters are supported:

`copy_data` (`boolean`)

Specifies whether the existing data in the publications that are being subscribed to should be copied once the replication starts. The default is `true`.

`create_slot` (`boolean`)

Specifies whether the command should create the replication slot on the publisher. The default is `true`.

`enabled` (`boolean`)

Specifies whether the subscription should be actively replicating, or whether it should be just setup but not started yet. The default is `true`.

`slot_name` (`string`)

Name of the replication slot to use. The default behavior is to use the name of the subscription for the slot name.

When slot_name is set to NONE, there will be no replication slot associated with the subscription. This can be used if the replication slot will be created later manually. Such subscriptions must also have both enabled and create_slot set to false.

synchronous_commit (enum)

The value of this parameter overrides the synchronous_commit setting within this subscription's apply worker processes. The default value is off.

It is safe to use off for logical replication: If the subscriber loses transactions because of missing synchronization, the data will be sent again from the publisher.

A different setting might be appropriate when doing synchronous logical replication. The logical replication workers report the positions of writes and flushes to the publisher, and when using synchronous replication, the publisher will wait for the actual flush. This means that setting synchronous_commit for the subscriber to off when the subscription is used for synchronous replication might increase the latency for COMMIT on the publisher. In this scenario, it can be advantageous to set synchronous_commit to local or higher.

binary (boolean)

Specifies whether the subscription will request the publisher to send the data in binary format (as opposed to text). The default is false. Even when this option is enabled, only data types that have binary send and receive functions will be transferred in binary.

When doing cross-version replication, it could happen that the publisher has a binary send function for some data type, but the subscriber lacks a binary receive function for the type. In such a case, data transfer will fail, and the binary option cannot be used.

connect (boolean)

Specifies whether the CREATE SUBSCRIPTION should connect to the publisher at all. Setting this to false will change default values of enabled, create_slot and copy_data to false.

It is not allowed to combine connect set to false and enabled, create_slot, or copy_data set to true.

Since no connection is made when this option is set to false, the tables are not subscribed, and so after you enable the subscription nothing will be replicated. It is required to run ALTER SUBSCRIPTION ... REFRESH PUBLICATION in order for tables to be subscribed.

streaming (boolean)

Specifies whether streaming of in-progress transactions should be enabled for this subscription. By default, all transactions are fully decoded on the publisher, and only then sent to the subscriber as a whole.

Notes

See Section 30.7 for details on how to configure access control between the subscription and the publication instance.

When creating a replication slot (the default behavior), CREATE SUBSCRIPTION cannot be executed inside a transaction block.

Creating a subscription that connects to the same database cluster (for example, to replicate between databases in the same cluster or to replicate within the same database) will only succeed if the replication slot is not created as part of the same command. Otherwise, the CREATE SUBSCRIPTION call will hang. To make this work, create the replication slot separately (using the function pg_create_logical_replication_slot with the plugin name pgoutput) and create the subscription using the parameter create_slot = false. This is an implementation restriction that might be lifted in a future release.

Examples

Create a subscription to a remote server that replicates tables in the publications `mypublication` and `insert_only` and starts replicating immediately on commit:

```
CREATE SUBSCRIPTION mysub
         CONNECTION 'host=192.168.1.50 port=5432 user=foo dbname=foodb'
        PUBLICATION mypublication, insert_only;
```

Create a subscription to a remote server that replicates tables in the `insert_only` publication and does not start replicating until enabled at a later time.

```
CREATE SUBSCRIPTION mysub
         CONNECTION 'host=192.168.1.50 port=5432 user=foo dbname=foodb'
        PUBLICATION insert_only
               WITH (enabled = false);
```

Compatibility

`CREATE SUBSCRIPTION` is a Postgres Pro extension.

See Also

ALTER SUBSCRIPTION, DROP SUBSCRIPTION, CREATE PUBLICATION, ALTER PUBLICATION

CREATE TABLE

CREATE TABLE — define a new table

Synopsis

```
CREATE [ [ GLOBAL | LOCAL ] { TEMPORARY | TEMP } | UNLOGGED | CONSTANT ] TABLE [ IF NOT
 EXISTS ] table_name ( [
  { column_name data_type [ COMPRESSION compression_method ] [ COLLATE collation ]
 [ column_constraint [ ... ] ]
    | table_constraint
    | LIKE source_table [ like_option ... ] }
    [, ... ]
] )
[ INHERITS ( parent_table [, ... ] ) ]
[ PARTITION BY { RANGE | LIST | HASH } ( { column_name | ( expression ) }
 [ pg_pathman_partitioning_clause ] [ COLLATE collation ] [ opclass ] [, ... ] )
 [ USING partition_backend ] ]
[ USING method ]
[ WITH ( storage_parameter [= value] [, ... ] ) | WITHOUT OIDS ]
[ ON COMMIT { PRESERVE ROWS | DELETE ROWS | DROP } ]
[ TABLESPACE tablespace_name ]

CREATE [ [ GLOBAL | LOCAL ] { TEMPORARY | TEMP } | UNLOGGED | CONSTANT ] TABLE [ IF NOT
 EXISTS ] table_name
    OF type_name [ (
  { column_name [ WITH OPTIONS ] [ column_constraint [ ... ] ]
    | table_constraint }
    [, ... ]
) ]
[ PARTITION BY { RANGE | LIST | HASH } ( { column_name | ( expression ) }
 [ pg_pathman_partitioning_clause ] [ COLLATE collation ] [ opclass ] [, ... ] )
 [ USING partition_backend ] ]
[ USING method ]
[ WITH ( storage_parameter [= value] [, ... ] ) | WITHOUT OIDS ]
[ ON COMMIT { PRESERVE ROWS | DELETE ROWS | DROP } ]
[ TABLESPACE tablespace_name ]

CREATE [ [ GLOBAL | LOCAL ] { TEMPORARY | TEMP } | UNLOGGED ] TABLE [ IF NOT
 EXISTS ] table_name
    PARTITION OF parent_table [ (
  { column_name [ WITH OPTIONS ] [ column_constraint [ ... ] ]
    | table_constraint }
    [, ... ]
) ] { FOR VALUES partition_bound_spec | DEFAULT }
[ PARTITION BY { RANGE | LIST | HASH } ( { column_name | ( expression ) }
 [ COLLATE collation ] [ opclass ] [, ... ] ) [ USING partition_backend ] ]
[ USING method ]
[ WITH ( storage_parameter [= value] [, ... ] ) | WITHOUT OIDS ]
[ ON COMMIT { PRESERVE ROWS | DELETE ROWS | DROP } ]
[ TABLESPACE tablespace_name ]

where column_constraint is:

[ CONSTRAINT constraint_name ]
{ NOT NULL |
```

```
  NULL |
  CHECK ( expression ) [ NO INHERIT ] |
  DEFAULT default_expr |
  GENERATED ALWAYS AS ( generation_expr ) STORED |
  GENERATED { ALWAYS | BY DEFAULT } AS IDENTITY [ ( sequence_options ) ] |
  UNIQUE index_parameters |
  PRIMARY KEY index_parameters |
  REFERENCES reftable [ ( refcolumn ) ] [ MATCH FULL | MATCH PARTIAL | MATCH SIMPLE ]
    [ ON DELETE referential_action ] [ ON UPDATE referential_action ] }
[ DEFERRABLE | NOT DEFERRABLE ] [ INITIALLY DEFERRED | INITIALLY IMMEDIATE ]

and table_constraint is:

[ CONSTRAINT constraint_name ]
{ CHECK ( expression ) [ NO INHERIT ] |
  UNIQUE ( column_name [, ... ] ) index_parameters |
  PRIMARY KEY ( column_name [, ... ] ) index_parameters |
  EXCLUDE [ USING index_method ] ( exclude_element WITH operator
 [, ... ] ) index_parameters [ WHERE ( predicate ) ] |
  FOREIGN KEY ( column_name [, ... ] ) REFERENCES reftable [ ( refcolumn [, ... ] ) ]
    [ MATCH FULL | MATCH PARTIAL | MATCH SIMPLE ] [ ON DELETE referential_action ] [ ON
 UPDATE referential_action ] }
[ DEFERRABLE | NOT DEFERRABLE ] [ INITIALLY DEFERRED | INITIALLY IMMEDIATE ]

and like_option is:

{ INCLUDING | EXCLUDING } { COMMENTS | COMPRESSION | CONSTRAINTS | DEFAULTS | GENERATED
 | IDENTITY | INDEXES | STATISTICS | STORAGE | ALL }

and partition_bound_spec is:

IN ( partition_bound_expr [, ...] ) |
FROM ( { partition_bound_expr | MINVALUE | MAXVALUE } [, ...] )
  TO ( { partition_bound_expr | MINVALUE | MAXVALUE } [, ...] ) |
WITH ( MODULUS numeric_literal, REMAINDER numeric_literal )

and pg_pathman_partitioning_clause is:

PARTITIONS (partition_count) |
(PARTITION partition_name [ TABLESPACE tablespace_name ] [, ... ] ) |
[ INTERVAL (value) ] (PARTITION partition_name VALUES LESS THAN (value)
 [ TABLESPACE tablespace_name ] [, ... ] )

index_parameters in UNIQUE, PRIMARY KEY, and EXCLUDE constraints are:

[ INCLUDE ( column_name [, ... ] ) ]
[ WITH ( storage_parameter [= value] [, ... ] ) ]
[ USING INDEX TABLESPACE tablespace_name ]

exclude_element in an EXCLUDE constraint is:

{ column_name | ( expression ) } [ COLLATE collation ] [ opclass [ ( opclass_parameter
 = value [, ... ] ) ] ] [ ASC | DESC ] [ NULLS { FIRST | LAST } ]
```

Description

`CREATE TABLE` will create a new, initially empty table in the current database. The table will be owned by the user issuing the command.

If a schema name is given (for example, `CREATE TABLE myschema.mytable ...`) then the table is created in the specified schema. Otherwise it is created in the current schema. Temporary tables exist in a special schema, so a schema name cannot be given when creating a temporary table. The name of the table must be distinct from the name of any other table, sequence, index, view, or foreign table in the same schema.

`CREATE TABLE` also automatically creates a data type that represents the composite type corresponding to one row of the table. Therefore, tables cannot have the same name as any existing data type in the same schema.

The optional constraint clauses specify constraints (tests) that new or updated rows must satisfy for an insert or update operation to succeed. A constraint is an SQL object that helps define the set of valid values in the table in various ways.

There are two ways to define constraints: table constraints and column constraints. A column constraint is defined as part of a column definition. A table constraint definition is not tied to a particular column, and it can encompass more than one column. Every column constraint can also be written as a table constraint; a column constraint is only a notational convenience for use when the constraint only affects one column.

To be able to create a table, you must have `USAGE` privilege on all column types or the type in the `OF` clause, respectively.

Parameters

`TEMPORARY` or `TEMP`

If specified, the table is created as a temporary table. Temporary tables are automatically dropped at the end of a session, or optionally at the end of the current transaction (see `ON COMMIT` below). The default search_path includes the temporary schema first and so identically named existing permanent tables are not chosen for new plans while the temporary table exists, unless they are referenced with schema-qualified names. Any indexes created on a temporary table are automatically temporary as well.

Unlike for permanent tables, we extend the physical file for a temporary table only when the table does not fit into `temp_buffers` cache anymore. Thus, the total and on-disk size of a temporary table can differ. Blocks are not allocated in advance, so we may run out of free space on disk when trying to evict a temporary buffer from cache. If the available disk space is smaller than `temp_buffers` size, an error occurs. This case is quite unusual, though.

The autovacuum daemon cannot access and therefore cannot vacuum or analyze temporary tables. For this reason, appropriate vacuum and analyze operations should be performed via session SQL commands. For example, if a temporary table is going to be used in complex queries, it is wise to run `ANALYZE` on the temporary table after it is populated.

Optionally, `GLOBAL` or `LOCAL` can be written before `TEMPORARY` or `TEMP`. This presently makes no difference in Postgres Pro and is deprecated; see Compatibility below.

`UNLOGGED`

If specified, the table is created as an unlogged table. Data written to unlogged tables is not written to the write-ahead log (see Chapter 29), which makes them considerably faster than ordinary tables. However, they are not crash-safe: an unlogged table is automatically truncated after a crash or unclean shutdown. The contents of an unlogged table are also not replicated to standby servers. Any indexes created on an unlogged table are automatically unlogged as well.

`CONSTANT`

If specified, the table is created as read-only. No data can be modified or added to constant tables, and they are not processed by autovacuum. Constant tables cannot be changed to read-write mode, so there is no much sense to create them as constant; use CREATE TABLE AS or ALTER TABLE instead.

`IF NOT EXISTS`

Do not throw an error if a relation with the same name already exists. A notice is issued in this case. Note that there is no guarantee that the existing relation is anything like the one that would have been created.

table_name

The name (optionally schema-qualified) of the table to be created.

`OF` *type_name*

Creates a *typed table*, which takes its structure from the specified composite type (name optionally schema-qualified). A typed table is tied to its type; for example the table will be dropped if the type is dropped (with `DROP TYPE ... CASCADE`).

When a typed table is created, then the data types of the columns are determined by the underlying composite type and are not specified by the `CREATE TABLE` command. But the `CREATE TABLE` command can add defaults and constraints to the table and can specify storage parameters.

column_name

The name of a column to be created in the new table.

data_type

The data type of the column. This can include array specifiers. For more information on the data types supported by Postgres Pro, refer to Chapter 8.

`COLLATE` *collation*

The `COLLATE` clause assigns a collation to the column (which must be of a collatable data type). If not specified, the column data type's default collation is used.

`COMPRESSION` *compression_method*

The `COMPRESSION` clause sets the compression method for the column. Compression is supported only for variable-width data types, and is used only when the column's storage mode is `main` or `extended`. (See ALTER TABLE for information on column storage modes.) Setting this property for a partitioned table has no direct effect, because such tables have no storage of their own, but the configured value will be inherited by newly-created partitions. The supported compression methods are `pglz` and `lz4`. (`lz4` is available only if `--with-lz4` was used when building Postgres Pro.) In addition, *compression_method* can be `default` to explicitly specify the default behavior, which is to consult the default_toast_compression setting at the time of data insertion to determine the method to use.

`INHERITS ( parent_table [, ... ] )`

The optional `INHERITS` clause specifies a list of tables from which the new table automatically inherits all columns. Parent tables can be plain tables or foreign tables.

Use of `INHERITS` creates a persistent relationship between the new child table and its parent table(s). Schema modifications to the parent(s) normally propagate to children as well, and by default the data of the child table is included in scans of the parent(s).

If the same column name exists in more than one parent table, an error is reported unless the data types of the columns match in each of the parent tables. If there is no conflict, then the duplicate columns are merged to form a single column in the new table. If the column name list of the new table contains a column name that is also inherited, the data type must likewise match the inherited column(s), and the column definitions are merged into one. If the new table explicitly specifies a default value for the column, this default overrides any defaults from inherited declarations of the column. Otherwise, any parents that specify default values for the column must all specify the same default, or an error will be reported.

CHECK constraints are merged in essentially the same way as columns: if multiple parent tables and/or the new table definition contain identically-named CHECK constraints, these constraints must all have the same check expression, or an error will be reported. Constraints having the same name and expression will be merged into one copy. A constraint marked NO INHERIT in a parent will not be considered. Notice that an unnamed CHECK constraint in the new table will never be merged, since a unique name will always be chosen for it.

Column STORAGE settings are also copied from parent tables.

If a column in the parent table is an identity column, that property is not inherited. A column in the child table can be declared identity column if desired.

PARTITION BY { RANGE | LIST | HASH } ({ *column_name* | (*expression*) } [*pg_pathman_partitioning_clause*] [*opclass*] [, ...]) [USING *partition_backend*]

The optional PARTITION BY clause specifies a strategy of partitioning the table. The table thus created is called a *partitioned* table. The parenthesized list of columns or expressions forms the *partition key* for the table. When using range or hash partitioning, the partition key can include multiple columns or expressions (up to 32, but this limit can be altered when building Postgres Pro), but for list partitioning, the partition key must consist of a single column or expression.

Range and list partitioning require a btree operator class, while hash partitioning requires a hash operator class. If no operator class is specified explicitly, the default operator class of the appropriate type will be used; if no default operator class exists, an error will be raised. When hash partitioning is used, the operator class used must implement support function 2 (see Section 40.16.3 for details).

A partitioned table is divided into sub-tables (called partitions), which are created using separate CREATE TABLE commands. The partitioned table is itself empty. A data row inserted into the table is routed to a partition based on the value of columns or expressions in the partition key. If no existing partition matches the values in the new row, an error will be reported, unless you use pg_pathman for partitioning as explained below.

Partitioned tables do not support EXCLUDE constraints; however, you can define these constraints on individual partitions.

See Section 5.11 for more discussion on table partitioning.

Optionally, you can choose the backend that performs partitioning by specifying the USING *partition_backend* clause, where *partition_backend* can be one of the following:

- internal — use Postgres Pro Enterprise core functionality for partitioning, as explained in Section 5.11.2.
- pg_pathman — use the pg_pathman extension, which supports range and hash partitioning.

If you omit this clause, the backend for partitioning is defined by the partition_backend parameter. The default value is internal, which enables declarative partitioning implementation provided by Postgres Pro core.

Do not confuse USING *partition_backend* with the USING *method* clause, which cannot be used when creating partitioned tables.

Starting from Postgres Pro 12, using pg_pathman is not recommended.

When using pg_pathman for partitioning, you must provide the *pg_pathman_partitioning_clause*. Depending on the chosen partitioning strategy, this clause can be one of the following:

PARTITIONS (*partition_count*)

Specifies the number of partitions to create using hash partitioning.

(PARTITION *partition_name* [TABLESPACE *tablespace_name*] [, ...])

Specifies the exact names of partitions to create using hash partitioning.

[INTERVAL (*value*)] (PARTITION *partition_name* VALUES LESS THAN (*value*) [TABLESPACE *tablespace_name*] [, ...])

Defines partition bounds and the names of partitions to create when using range partitioning strategy. The created partition will comprise the range of values defined by the VALUES LESS THAN clause, excluding the specified *value*. Note that this value must be of the same type as the partition key.

The optional INTERVAL clause specifies the interval that will be used to create new partitions if you insert data outside of the existing data range. If INTERVAL is not specified, pg_pathman cannot create new partitions automatically. If you omit this clause, you can later enable automatic partition creation using the SET INTERVAL form of the ALTER TABLE command. The value defining the interval must be of the same type as the partition key.

PARTITION OF *parent_table* { FOR VALUES *partition_bound_spec* | DEFAULT }

Creates the table as a *partition* of the specified parent table. The table can be created either as a partition for specific values using FOR VALUES or as a default partition using DEFAULT. Any indexes, constraints and user-defined row-level triggers that exist in the parent table are cloned on the new partition. This clause is not supported by pg_pathman.

The *partition_bound_spec* must correspond to the partitioning method and partition key of the parent table, and must not overlap with any existing partition of that parent. The form with IN is used for list partitioning, the form with FROM and TO is used for range partitioning, and the form with WITH is used for hash partitioning.

partition_bound_expr is any variable-free expression (subqueries, window functions, aggregate functions, and set-returning functions are not allowed). Its data type must match the data type of the corresponding partition key column. The expression is evaluated once at table creation time, so it can even contain volatile expressions such as CURRENT_TIMESTAMP.

When creating a list partition, NULL can be specified to signify that the partition allows the partition key column to be null. However, there cannot be more than one such list partition for a given parent table. NULL cannot be specified for range partitions.

When creating a range partition, the lower bound specified with FROM is an inclusive bound, whereas the upper bound specified with TO is an exclusive bound. That is, the values specified in the FROM list are valid values of the corresponding partition key columns for this partition, whereas those in the TO list are not. Note that this statement must be understood according to the rules of row-wise comparison (Section 9.24.5). For example, given PARTITION BY RANGE (x,y), a partition bound FROM (1, 2) TO (3, 4) allows x=1 with any y>=2, x=2 with any non-null y, and x=3 with any y<4.

The special values MINVALUE and MAXVALUE may be used when creating a range partition to indicate that there is no lower or upper bound on the column's value. For example, a partition defined using FROM (MINVALUE) TO (10) allows any values less than 10, and a partition defined using FROM (10) TO (MAXVALUE) allows any values greater than or equal to 10.

When creating a range partition involving more than one column, it can also make sense to use MAXVALUE as part of the lower bound, and MINVALUE as part of the upper bound. For example, a partition defined using FROM (0, MAXVALUE) TO (10, MAXVALUE) allows any rows where the first partition key column is greater than 0 and less than or equal to 10. Similarly, a partition defined using FROM ('a', MINVALUE) TO ('b', MINVALUE) allows any rows where the first partition key column starts with "a".

Note that if MINVALUE or MAXVALUE is used for one column of a partitioning bound, the same value must be used for all subsequent columns. For example, (10, MINVALUE, 0) is not a valid bound; you should write (10, MINVALUE, MINVALUE).

Also note that some element types, such as timestamp, have a notion of "infinity", which is just another value that can be stored. This is different from MINVALUE and MAXVALUE, which are not real val-

ues that can be stored, but rather they are ways of saying that the value is unbounded. MAXVALUE can be thought of as being greater than any other value, including "infinity" and MINVALUE as being less than any other value, including "minus infinity". Thus the range FROM ('infinity') TO (MAXVALUE) is not an empty range; it allows precisely one value to be stored — "infinity".

If DEFAULT is specified, the table will be created as the default partition of the parent table. This option is not available for hash-partitioned tables. A partition key value not fitting into any other partition of the given parent will be routed to the default partition.

When a table has an existing DEFAULT partition and a new partition is added to it, the default partition must be scanned to verify that it does not contain any rows which properly belong in the new partition. If the default partition contains a large number of rows, this may be slow. The scan will be skipped if the default partition is a foreign table or if it has a constraint which proves that it cannot contain rows which should be placed in the new partition.

When creating a hash partition, a modulus and remainder must be specified. The modulus must be a positive integer, and the remainder must be a non-negative integer less than the modulus. Typically, when initially setting up a hash-partitioned table, you should choose a modulus equal to the number of partitions and assign every table the same modulus and a different remainder (see examples, below). However, it is not required that every partition have the same modulus, only that every modulus which occurs among the partitions of a hash-partitioned table is a factor of the next larger modulus. This allows the number of partitions to be increased incrementally without needing to move all the data at once. For example, suppose you have a hash-partitioned table with 8 partitions, each of which has modulus 8, but find it necessary to increase the number of partitions to 16. You can detach one of the modulus-8 partitions, create two new modulus-16 partitions covering the same portion of the key space (one with a remainder equal to the remainder of the detached partition, and the other with a remainder equal to that value plus 8), and repopulate them with data. You can then repeat this -- perhaps at a later time -- for each modulus-8 partition until none remain. While this may still involve a large amount of data movement at each step, it is still better than having to create a whole new table and move all the data at once.

A partition must have the same column names and types as the partitioned table to which it belongs. Modifications to the column names or types of a partitioned table will automatically propagate to all partitions. CHECK constraints will be inherited automatically by every partition, but an individual partition may specify additional CHECK constraints; additional constraints with the same name and condition as in the parent will be merged with the parent constraint. Defaults may be specified separately for each partition. But note that a partition's default value is not applied when inserting a tuple through a partitioned table.

Rows inserted into a partitioned table will be automatically routed to the correct partition. If no suitable partition exists, an error will occur.

Operations such as TRUNCATE which normally affect a table and all of its inheritance children will cascade to all partitions, but may also be performed on an individual partition.

Note that creating a partition using PARTITION OF requires taking an ACCESS EXCLUSIVE lock on the parent partitioned table. Likewise, dropping a partition with DROP TABLE requires taking an ACCESS EXCLUSIVE lock on the parent table. It is possible to use ALTER TABLE ATTACH/DETACH PARTITION to perform these operations with a weaker lock, thus reducing interference with concurrent operations on the partitioned table.

LIKE *source_table* [*like_option* ...]

The LIKE clause specifies a table from which the new table automatically copies all column names, their data types, and their not-null constraints.

Unlike INHERITS, the new table and original table are completely decoupled after creation is complete. Changes to the original table will not be applied to the new table, and it is not possible to include data of the new table in scans of the original table.

Also unlike INHERITS, columns and constraints copied by LIKE are not merged with similarly named columns and constraints. If the same name is specified explicitly or in another LIKE clause, an error is signaled.

The optional *like_option* clauses specify which additional properties of the original table to copy. Specifying INCLUDING copies the property, specifying EXCLUDING omits the property. EXCLUDING is the default. If multiple specifications are made for the same kind of object, the last one is used. The available options are:

INCLUDING COMMENTS

Comments for the copied columns, constraints, and indexes will be copied. The default behavior is to exclude comments, resulting in the copied columns and constraints in the new table having no comments.

INCLUDING COMPRESSION

Compression method of the columns will be copied. The default behavior is to exclude compression methods, resulting in columns having the default compression method.

INCLUDING CONSTRAINTS

CHECK constraints will be copied. No distinction is made between column constraints and table constraints. Not-null constraints are always copied to the new table.

INCLUDING DEFAULTS

Default expressions for the copied column definitions will be copied. Otherwise, default expressions are not copied, resulting in the copied columns in the new table having null defaults. Note that copying defaults that call database-modification functions, such as nextval, may create a functional linkage between the original and new tables.

INCLUDING GENERATED

Any generation expressions of copied column definitions will be copied. By default, new columns will be regular base columns.

INCLUDING IDENTITY

Any identity specifications of copied column definitions will be copied. A new sequence is created for each identity column of the new table, separate from the sequences associated with the old table.

INCLUDING INDEXES

Indexes, PRIMARY KEY, UNIQUE, and EXCLUDE constraints on the original table will be created on the new table. Names for the new indexes and constraints are chosen according to the default rules, regardless of how the originals were named. (This behavior avoids possible duplicate-name failures for the new indexes.)

INCLUDING STATISTICS

Extended statistics are copied to the new table.

INCLUDING STORAGE

STORAGE settings for the copied column definitions will be copied. The default behavior is to exclude STORAGE settings, resulting in the copied columns in the new table having type-specific default settings. For more on STORAGE settings, see Section 70.2.

INCLUDING ALL

INCLUDING ALL is an abbreviated form selecting all the available individual options. (It could be useful to write individual EXCLUDING clauses after INCLUDING ALL to select all but some specific options.)

The LIKE clause can also be used to copy column definitions from views, foreign tables, or composite types. Inapplicable options (e.g., INCLUDING INDEXES from a view) are ignored.

CONSTRAINT *constraint_name*

An optional name for a column or table constraint. If the constraint is violated, the constraint name is present in error messages, so constraint names like col must be positive can be used to communicate helpful constraint information to client applications. (Double-quotes are needed to specify constraint names that contain spaces.) If a constraint name is not specified, the system generates a name.

NOT NULL

The column is not allowed to contain null values.

NULL

The column is allowed to contain null values. This is the default.

This clause is only provided for compatibility with non-standard SQL databases. Its use is discouraged in new applications.

CHECK (*expression*) [NO INHERIT]

The CHECK clause specifies an expression producing a Boolean result which new or updated rows must satisfy for an insert or update operation to succeed. Expressions evaluating to TRUE or UNKNOWN succeed. Should any row of an insert or update operation produce a FALSE result, an error exception is raised and the insert or update does not alter the database. A check constraint specified as a column constraint should reference that column's value only, while an expression appearing in a table constraint can reference multiple columns.

Currently, CHECK expressions cannot contain subqueries nor refer to variables other than columns of the current row (see Section 5.4.1). The system column tableoid may be referenced, but not any other system column.

A constraint marked with NO INHERIT will not propagate to child tables.

When a table has multiple CHECK constraints, they will be tested for each row in alphabetical order by name, after checking NOT NULL constraints. (PostgreSQL versions before 9.5 did not honor any particular firing order for CHECK constraints.)

DEFAULT *default_expr*

The DEFAULT clause assigns a default data value for the column whose column definition it appears within. The value is any variable-free expression (in particular, cross-references to other columns in the current table are not allowed). Subqueries are not allowed either. The data type of the default expression must match the data type of the column.

The default expression will be used in any insert operation that does not specify a value for the column. If there is no default for a column, then the default is null.

GENERATED ALWAYS AS (*generation_expr*) STORED

This clause creates the column as a *generated column*. The column cannot be written to, and when read the result of the specified expression will be returned.

The keyword STORED is required to signify that the column will be computed on write and will be stored on disk.

The generation expression can refer to other columns in the table, but not other generated columns. Any functions and operators used must be immutable. References to other tables are not allowed.

`GENERATED { ALWAYS | BY DEFAULT } AS IDENTITY [ ( sequence_options ) ]`

This clause creates the column as an *identity column*. It will have an implicit sequence attached to it and the column in new rows will automatically have values from the sequence assigned to it. Such a column is implicitly `NOT NULL`.

The clauses `ALWAYS` and `BY DEFAULT` determine how explicitly user-specified values are handled in `INSERT` and `UPDATE` commands.

In an `INSERT` command, if `ALWAYS` is selected, a user-specified value is only accepted if the `INSERT` statement specifies `OVERRIDING SYSTEM VALUE`. If `BY DEFAULT` is selected, then the user-specified value takes precedence. See INSERT for details. (In the `COPY` command, user-specified values are always used regardless of this setting.)

In an `UPDATE` command, if `ALWAYS` is selected, any update of the column to any value other than `DEFAULT` will be rejected. If `BY DEFAULT` is selected, the column can be updated normally. (There is no `OVERRIDING` clause for the `UPDATE` command.)

The optional *sequence_options* clause can be used to override the options of the sequence. See CREATE SEQUENCE for details.

`UNIQUE` (column constraint)
`UNIQUE ( column_name [, ... ] ) [ INCLUDE ( column_name [, ...]) ]` (table constraint)

The `UNIQUE` constraint specifies that a group of one or more columns of a table can contain only unique values. The behavior of a unique table constraint is the same as that of a unique column constraint, with the additional capability to span multiple columns. The constraint therefore enforces that any two rows must differ in at least one of these columns.

For the purpose of a unique constraint, null values are not considered equal.

Each unique constraint should name a set of columns that is different from the set of columns named by any other unique or primary key constraint defined for the table. (Otherwise, redundant unique constraints will be discarded.)

When establishing a unique constraint for a multi-level partition hierarchy, all the columns in the partition key of the target partitioned table, as well as those of all its descendant partitioned tables, must be included in the constraint definition.

Adding a unique constraint will automatically create a unique btree index on the column or group of columns used in the constraint.

The optional `INCLUDE` clause adds to that index one or more columns that are simply “payload”: uniqueness is not enforced on them, and the index cannot be searched on the basis of those columns. However they can be retrieved by an index-only scan. Note that although the constraint is not enforced on included columns, it still depends on them. Consequently, some operations on such columns (e.g., `DROP COLUMN`) can cause cascaded constraint and index deletion.

`PRIMARY KEY` (column constraint)
`PRIMARY KEY ( column_name [, ... ] ) [ INCLUDE ( column_name [, ...]) ]` (table constraint)

The `PRIMARY KEY` constraint specifies that a column or columns of a table can contain only unique (non-duplicate), nonnull values. Only one primary key can be specified for a table, whether as a column constraint or a table constraint.

The primary key constraint should name a set of columns that is different from the set of columns named by any unique constraint defined for the same table. (Otherwise, the unique constraint is redundant and will be discarded.)

`PRIMARY KEY` enforces the same data constraints as a combination of `UNIQUE` and `NOT NULL`. However, identifying a set of columns as the primary key also provides metadata about the design of the

schema, since a primary key implies that other tables can rely on this set of columns as a unique identifier for rows.

When placed on a partitioned table, `PRIMARY KEY` constraints share the restrictions previously described for `UNIQUE` constraints.

Adding a `PRIMARY KEY` constraint will automatically create a unique btree index on the column or group of columns used in the constraint.

The optional `INCLUDE` clause adds to that index one or more columns that are simply "payload": uniqueness is not enforced on them, and the index cannot be searched on the basis of those columns. However they can be retrieved by an index-only scan. Note that although the constraint is not enforced on included columns, it still depends on them. Consequently, some operations on such columns (e.g., `DROP COLUMN`) can cause cascaded constraint and index deletion.

`EXCLUDE [ USING` *index_method* `] (` *exclude_element* `WITH` *operator* `[, ... ] ) ` *index_parameters* `[ WHERE ( ` *predicate* ` ) ]`

The `EXCLUDE` clause defines an exclusion constraint, which guarantees that if any two rows are compared on the specified column(s) or expression(s) using the specified operator(s), not all of these comparisons will return `TRUE`. If all of the specified operators test for equality, this is equivalent to a `UNIQUE` constraint, although an ordinary unique constraint will be faster. However, exclusion constraints can specify constraints that are more general than simple equality. For example, you can specify a constraint that no two rows in the table contain overlapping circles (see Section 8.8) by using the `&&` operator. The operator(s) are required to be commutative.

Exclusion constraints are implemented using an index, so each specified operator must be associated with an appropriate operator class (see Section 11.10) for the index access method *index_method*. Each *exclude_element* defines a column of the index, so it can optionally specify a collation, an operator class, operator class parameters, and/or ordering options; these are described fully under CREATE INDEX.

The access method must support `amgettuple` (see Chapter 62); at present this means GIN cannot be used. Although it's allowed, there is little point in using B-tree or hash indexes with an exclusion constraint, because this does nothing that an ordinary unique constraint doesn't do better. So in practice the access method will always be GiST or SP-GiST.

The *predicate* allows you to specify an exclusion constraint on a subset of the table; internally this creates a partial index. Note that parentheses are required around the predicate.

`REFERENCES` *reftable* `[ ( ` *refcolumn* ` ) ] [ MATCH` *matchtype* `] [ ON DELETE` *referential_action* `] [ ON UPDATE` *referential_action* `]` (column constraint)
`FOREIGN KEY ( ` *column_name* `[, ... ] ) REFERENCES` *reftable* `[ ( ` *refcolumn* `[, ... ] ) ] [ MATCH` *matchtype* `] [ ON DELETE` *referential_action* `] [ ON UPDATE` *referential_action* `]` (table constraint)

These clauses specify a foreign key constraint, which requires that a group of one or more columns of the new table must only contain values that match values in the referenced column(s) of some row of the referenced table. If the *refcolumn* list is omitted, the primary key of the *reftable* is used. Otherwise, the *refcolumn* list must refer to the columns of a non-deferrable unique or primary key constraint or be the columns of a non-partial unique index. The user must have `REFERENCES` permission on the referenced table (either the whole table, or the specific referenced columns). The addition of a foreign key constraint requires a `SHARE ROW EXCLUSIVE` lock on the referenced table. Note that foreign key constraints cannot be defined between temporary tables and permanent tables.

A value inserted into the referencing column(s) is matched against the values of the referenced table and referenced columns using the given match type. There are three match types: `MATCH FULL`, `MATCH PARTIAL`, and `MATCH SIMPLE` (which is the default). `MATCH FULL` will not allow one column of a multicolumn foreign key to be null unless all foreign key columns are null; if they are all null, the row is not required to have a match in the referenced table. `MATCH SIMPLE` allows any of the foreign key

columns to be null; if any of them are null, the row is not required to have a match in the referenced table. MATCH PARTIAL is not yet implemented. (Of course, NOT NULL constraints can be applied to the referencing column(s) to prevent these cases from arising.)

In addition, when the data in the referenced columns is changed, certain actions are performed on the data in this table's columns. The ON DELETE clause specifies the action to perform when a referenced row in the referenced table is being deleted. Likewise, the ON UPDATE clause specifies the action to perform when a referenced column in the referenced table is being updated to a new value. If the row is updated, but the referenced column is not actually changed, no action is done. Referential actions other than the NO ACTION check cannot be deferred, even if the constraint is declared deferrable. There are the following possible actions for each clause:

NO ACTION

Produce an error indicating that the deletion or update would create a foreign key constraint violation. If the constraint is deferred, this error will be produced at constraint check time if there still exist any referencing rows. This is the default action.

RESTRICT

Produce an error indicating that the deletion or update would create a foreign key constraint violation. This is the same as NO ACTION except that the check is not deferrable.

CASCADE

Delete any rows referencing the deleted row, or update the values of the referencing column(s) to the new values of the referenced columns, respectively.

SET NULL

Set the referencing column(s) to null.

SET DEFAULT

Set the referencing column(s) to their default values. (There must be a row in the referenced table matching the default values, if they are not null, or the operation will fail.)

If the referenced column(s) are changed frequently, it might be wise to add an index to the referencing column(s) so that referential actions associated with the foreign key constraint can be performed more efficiently.

DEFERRABLE
NOT DEFERRABLE

This controls whether the constraint can be deferred. A constraint that is not deferrable will be checked immediately after every command. Checking of constraints that are deferrable can be postponed until the end of the transaction (using the SET CONSTRAINTS command). NOT DEFERRABLE is the default. Currently, only UNIQUE, PRIMARY KEY, EXCLUDE, and REFERENCES (foreign key) constraints accept this clause. NOT NULL and CHECK constraints are not deferrable. Note that deferrable constraints cannot be used as conflict arbitrators in an INSERT statement that includes an ON CONFLICT DO UPDATE clause.

INITIALLY IMMEDIATE
INITIALLY DEFERRED

If a constraint is deferrable, this clause specifies the default time to check the constraint. If the constraint is INITIALLY IMMEDIATE, it is checked after each statement. This is the default. If the constraint is INITIALLY DEFERRED, it is checked only at the end of the transaction. The constraint check time can be altered with the SET CONSTRAINTS command.

USING *method*

This optional clause specifies the table access method to use to store the contents for the new table; the method needs be an access method of type TABLE. See Chapter 61 for more information. If this

option is not specified, the default table access method is chosen for the new table. See default_table_access_method for more information.

`WITH ( storage_parameter [= value] [, ... ] )`

This clause specifies optional storage parameters for a table or index; see Storage Parameters below for more information. For backward-compatibility the `WITH` clause for a table can also include `OIDS=FALSE` to specify that rows of the new table should not contain OIDs (object identifiers), `OIDS=TRUE` is not supported anymore.

`WITHOUT OIDS`

This is backward-compatible syntax for declaring a table `WITHOUT OIDS`, creating a table `WITH OIDS` is not supported anymore.

`ON COMMIT`

The behavior of temporary tables at the end of a transaction block can be controlled using `ON COMMIT`. The three options are:

`PRESERVE ROWS`

No special action is taken at the ends of transactions. This is the default behavior.

`DELETE ROWS`

All rows in the temporary table will be deleted at the end of each transaction block. Essentially, an automatic `TRUNCATE` is done at each commit. When used on a partitioned table, this is not cascaded to its partitions.

`DROP`

The temporary table will be dropped at the end of the current transaction block. When used on a partitioned table, this action drops its partitions and when used on tables with inheritance children, it drops the dependent children.

`TABLESPACE tablespace_name`

The *tablespace_name* is the name of the tablespace in which the new table is to be created. If not specified, default_tablespace is consulted, or temp_tablespaces if the table is temporary. For partitioned tables, since no storage is required for the table itself, the tablespace specified overrides `default_tablespace` as the default tablespace to use for any newly created partitions when no other tablespace is explicitly specified.

`USING INDEX TABLESPACE tablespace_name`

This clause allows selection of the tablespace in which the index associated with a `UNIQUE`, `PRIMARY KEY`, or `EXCLUDE` constraint will be created. If not specified, default_tablespace is consulted, or temp_tablespaces if the table is temporary.

Storage Parameters

The `WITH` clause can specify *storage parameters* for tables, and for indexes associated with a `UNIQUE`, `PRIMARY KEY`, or `EXCLUDE` constraint. Storage parameters for indexes are documented in CREATE INDEX. The storage parameters currently available for tables are listed below. For many of these parameters, as shown, there is an additional parameter with the same name prefixed with `toast.`, which controls the behavior of the table's secondary TOAST table, if any (see Section 70.2 for more information about TOAST). If a table parameter value is set and the equivalent `toast.` parameter is not, the TOAST table will use the table's parameter value. Specifying these parameters for partitioned tables is not supported, but you may specify them for individual leaf partitions.

`fillfactor` (`integer`)

The fillfactor for a table is a percentage between 10 and 100. 100 (complete packing) is the default. When a smaller fillfactor is specified, `INSERT` operations pack table pages only to the indicated per-

centage; the remaining space on each page is reserved for updating rows on that page. This gives UPDATE a chance to place the updated copy of a row on the same page as the original, which is more efficient than placing it on a different page, and makes heap-only tuple updates more likely. For a table whose entries are never updated, complete packing is the best choice, but in heavily updated tables smaller fillfactors are appropriate. This parameter cannot be set for TOAST tables.

toast_tuple_target (integer)

The toast_tuple_target specifies the minimum tuple length required before we try to compress and/or move long column values into TOAST tables, and is also the target length we try to reduce the length below once toasting begins. This affects columns marked as External (for move), Main (for compression), or Extended (for both) and applies only to new tuples. There is no effect on existing rows. By default this parameter is set to allow at least 4 tuples per block, which with the default block size will be 2040 bytes. Valid values are between 128 bytes and the (block size - header), by default 8160 bytes. Changing this value may not be useful for very short or very long rows. Note that the default setting is often close to optimal, and it is possible that setting this parameter could have negative effects in some cases. This parameter cannot be set for TOAST tables.

parallel_workers (integer)

This sets the number of workers that should be used to assist a parallel scan of this table. If not set, the system will determine a value based on the relation size. The actual number of workers chosen by the planner or by utility statements that use parallel scans may be less, for example due to the setting of max_worker_processes.

autovacuum_enabled, toast.autovacuum_enabled (boolean)

Enables or disables the autovacuum daemon for a particular table. If true, the autovacuum daemon will perform automatic VACUUM and/or ANALYZE operations on this table following the rules discussed in Section 24.1.6. If false, this table will not be autovacuumed, except to shrink pg_xact and pg_multixact. See Section 24.1.5 for more about that. Note that the autovacuum daemon does not run at all (except to shrink pg_xact and pg_multixact) if the autovacuum parameter is false; setting individual tables' storage parameters does not override that. Therefore there is seldom much point in explicitly setting this storage parameter to true, only to false.

vacuum_index_cleanup, toast.vacuum_index_cleanup (enum)

Forces or disables index cleanup when VACUUM is run on this table. The default value is AUTO. With OFF, index cleanup is disabled, with ON it is enabled, and with AUTO a decision is made dynamically, each time VACUUM runs. The dynamic behavior allows VACUUM to avoid needlessly scanning indexes to remove very few dead tuples. Forcibly disabling all index cleanup can speed up VACUUM very significantly, but may also lead to severely bloated indexes if table modifications are frequent. The INDEX_CLEANUP parameter of VACUUM, if specified, overrides the value of this option.

vacuum_truncate, toast.vacuum_truncate (boolean)

Enables or disables vacuum to try to truncate off any empty pages at the end of this table. The default value is true. If true, VACUUM and autovacuum do the truncation and the disk space for the truncated pages is returned to the operating system. Note that the truncation requires ACCESS EXCLUSIVE lock on the table. The TRUNCATE parameter of VACUUM, if specified, overrides the value of this option.

autovacuum_vacuum_threshold, toast.autovacuum_vacuum_threshold (integer)

Per-table value for autovacuum_vacuum_threshold parameter.

autovacuum_vacuum_scale_factor, toast.autovacuum_vacuum_scale_factor (floating point)

Per-table value for autovacuum_vacuum_scale_factor parameter.

autovacuum_vacuum_insert_threshold, toast.autovacuum_vacuum_insert_threshold (integer)

Per-table value for autovacuum_vacuum_insert_threshold parameter. The special value of -1 may be used to disable insert vacuums on the table.

`autovacuum_vacuum_insert_scale_factor`, `toast.autovacuum_vacuum_insert_scale_factor` (`floating point`)

Per-table value for autovacuum_vacuum_insert_scale_factor parameter.

`autovacuum_analyze_threshold` (`integer`)

Per-table value for autovacuum_analyze_threshold parameter.

`autovacuum_analyze_scale_factor` (`floating point`)

Per-table value for autovacuum_analyze_scale_factor parameter.

`autovacuum_vacuum_cost_delay`, `toast.autovacuum_vacuum_cost_delay` (`floating point`)

Per-table value for autovacuum_vacuum_cost_delay parameter.

`autovacuum_vacuum_cost_limit`, `toast.autovacuum_vacuum_cost_limit` (`integer`)

Per-table value for autovacuum_vacuum_cost_limit parameter.

`autovacuum_freeze_min_age`, `toast.autovacuum_freeze_min_age` (`integer`)

Per-table value for vacuum_freeze_min_age parameter. Note that autovacuum will ignore per-table `autovacuum_freeze_min_age` parameters that are larger than half the system-wide autovacuum_freeze_max_age setting.

`autovacuum_freeze_max_age`, `toast.autovacuum_freeze_max_age` (`integer`)

Per-table value for autovacuum_freeze_max_age parameter. Note that autovacuum will ignore per-table `autovacuum_freeze_max_age` parameters that are larger than the system-wide setting (it can only be set smaller).

`autovacuum_freeze_table_age`, `toast.autovacuum_freeze_table_age` (`integer`)

Per-table value for vacuum_freeze_table_age parameter.

`autovacuum_multixact_freeze_min_age`, `toast.autovacuum_multixact_freeze_min_age` (`integer`)

Per-table value for vacuum_multixact_freeze_min_age parameter. Note that autovacuum will ignore per-table `autovacuum_multixact_freeze_min_age` parameters that are larger than half the system-wide autovacuum_multixact_freeze_max_age setting.

`autovacuum_multixact_freeze_max_age`, `toast.autovacuum_multixact_freeze_max_age` (`integer`)

Per-table value for autovacuum_multixact_freeze_max_age parameter. Note that autovacuum will ignore per-table `autovacuum_multixact_freeze_max_age` parameters that are larger than the system-wide setting (it can only be set smaller).

`autovacuum_multixact_freeze_table_age`, `toast.autovacuum_multixact_freeze_table_age` (`integer`)

Per-table value for vacuum_multixact_freeze_table_age parameter.

`log_autovacuum_min_duration`, `toast.log_autovacuum_min_duration` (`integer`)

Per-table value for log_autovacuum_min_duration parameter.

`user_catalog_table` (`boolean`)

Declare the table as an additional catalog table for purposes of logical replication. See Section 51.6.2 for details. This parameter cannot be set for TOAST tables.

Notes

Postgres Pro automatically creates an index for each unique constraint and primary key constraint to enforce uniqueness. Thus, it is not necessary to create an index explicitly for primary key columns. (See CREATE INDEX for more information.)

Unique constraints and primary keys are not inherited in the current implementation. This makes the combination of inheritance and unique constraints rather dysfunctional.

A table cannot have more than 1600 columns. (In practice, the effective limit is usually lower because of tuple-length constraints.)

Examples

Create table `films` and table `distributors`:

```
CREATE TABLE films (
    code        char(5) CONSTRAINT firstkey PRIMARY KEY,
    title       varchar(40) NOT NULL,
    did         integer NOT NULL,
    date_prod   date,
    kind        varchar(10),
    len         interval hour to minute
);

CREATE TABLE distributors (
     did    integer PRIMARY KEY GENERATED BY DEFAULT AS IDENTITY,
     name   varchar(40) NOT NULL CHECK (name <> '')
);
```

Create a table with a 2-dimensional array:

```
CREATE TABLE array_int (
    vector  int[][]
);
```

Define a unique table constraint for the table `films`. Unique table constraints can be defined on one or more columns of the table:

```
CREATE TABLE films (
    code        char(5),
    title       varchar(40),
    did         integer,
    date_prod   date,
    kind        varchar(10),
    len         interval hour to minute,
    CONSTRAINT production UNIQUE(date_prod)
);
```

Define a check column constraint:

```
CREATE TABLE distributors (
    did     integer CHECK (did > 100),
    name    varchar(40)
);
```

Define a check table constraint:

```
CREATE TABLE distributors (
    did     integer,
    name    varchar(40),
    CONSTRAINT con1 CHECK (did > 100 AND name <> '')
);
```

Define a primary key table constraint for the table `films`:

```
CREATE TABLE films (
    code        char(5),
```

```
    title       varchar(40),
    did         integer,
    date_prod   date,
    kind        varchar(10),
    len         interval hour to minute,
    CONSTRAINT code_title PRIMARY KEY(code,title)
);
```

Define a primary key constraint for table `distributors`. The following two examples are equivalent, the first using the table constraint syntax, the second the column constraint syntax:

```
CREATE TABLE distributors (
    did     integer,
    name    varchar(40),
    PRIMARY KEY(did)
);

CREATE TABLE distributors (
    did     integer PRIMARY KEY,
    name    varchar(40)
);
```

Assign a literal constant default value for the column `name`, arrange for the default value of column `did` to be generated by selecting the next value of a sequence object, and make the default value of `modtime` be the time at which the row is inserted:

```
CREATE TABLE distributors (
    name      varchar(40) DEFAULT 'Luso Films',
    did       integer DEFAULT nextval('distributors_serial'),
    modtime   timestamp DEFAULT current_timestamp
);
```

Define two `NOT NULL` column constraints on the table `distributors`, one of which is explicitly given a name:

```
CREATE TABLE distributors (
    did     integer CONSTRAINT no_null NOT NULL,
    name    varchar(40) NOT NULL
);
```

Define a unique constraint for the `name` column:

```
CREATE TABLE distributors (
    did     integer,
    name    varchar(40) UNIQUE
);
```

The same, specified as a table constraint:

```
CREATE TABLE distributors (
    did     integer,
    name    varchar(40),
    UNIQUE(name)
);
```

Create the same table, specifying 70% fill factor for both the table and its unique index:

```
CREATE TABLE distributors (
    did     integer,
    name    varchar(40),
    UNIQUE(name) WITH (fillfactor=70)
)
```

```
WITH (fillfactor=70);
```

Create table `circles` with an exclusion constraint that prevents any two circles from overlapping:

```
CREATE TABLE circles (
    c circle,
    EXCLUDE USING gist (c WITH &&)
);
```

Create table `cinemas` in tablespace `diskvol1`:

```
CREATE TABLE cinemas (
        id serial,
        name text,
        location text
) TABLESPACE diskvol1;
```

Create a composite type and a typed table:

```
CREATE TYPE employee_type AS (name text, salary numeric);

CREATE TABLE employees OF employee_type (
    PRIMARY KEY (name),
    salary WITH OPTIONS DEFAULT 1000
);
```

Create a range partitioned table:

```
CREATE TABLE measurement (
    logdate         date not null,
    peaktemp        int,
    unitsales       int
) PARTITION BY RANGE (logdate);
```

Create a range partitioned table with multiple columns in the partition key:

```
CREATE TABLE measurement_year_month (
    logdate         date not null,
    peaktemp        int,
    unitsales       int
) PARTITION BY RANGE (EXTRACT(YEAR FROM logdate), EXTRACT(MONTH FROM logdate));
```

Create a list partitioned table:

```
CREATE TABLE cities (
    city_id      bigserial not null,
    name         text not null,
    population   bigint
) PARTITION BY LIST (left(lower(name), 1));
```

Create a hash partitioned table:

```
CREATE TABLE orders (
    order_id     bigint not null,
    cust_id      bigint not null,
    status       text
) PARTITION BY HASH (order_id);
```

Create partition of a range partitioned table:

```
CREATE TABLE measurement_y2016m07
    PARTITION OF measurement (
    unitsales DEFAULT 0
```

```
) FOR VALUES FROM ('2016-07-01') TO ('2016-08-01');
```

Create a few partitions of a range partitioned table with multiple columns in the partition key:

```
CREATE TABLE measurement_ym_older
    PARTITION OF measurement_year_month
    FOR VALUES FROM (MINVALUE, MINVALUE) TO (2016, 11);

CREATE TABLE measurement_ym_y2016m11
    PARTITION OF measurement_year_month
    FOR VALUES FROM (2016, 11) TO (2016, 12);

CREATE TABLE measurement_ym_y2016m12
    PARTITION OF measurement_year_month
    FOR VALUES FROM (2016, 12) TO (2017, 01);

CREATE TABLE measurement_ym_y2017m01
    PARTITION OF measurement_year_month
    FOR VALUES FROM (2017, 01) TO (2017, 02);
```

Create partition of a list partitioned table:

```
CREATE TABLE cities_ab
    PARTITION OF cities (
    CONSTRAINT city_id_nonzero CHECK (city_id != 0)
) FOR VALUES IN ('a', 'b');
```

Create partition of a list partitioned table that is itself further partitioned and then add a partition to it:

```
CREATE TABLE cities_ab
    PARTITION OF cities (
    CONSTRAINT city_id_nonzero CHECK (city_id != 0)
) FOR VALUES IN ('a', 'b') PARTITION BY RANGE (population);

CREATE TABLE cities_ab_10000_to_100000
    PARTITION OF cities_ab FOR VALUES FROM (10000) TO (100000);
```

Create partitions of a hash partitioned table:

```
CREATE TABLE orders_p1 PARTITION OF orders
    FOR VALUES WITH (MODULUS 4, REMAINDER 0);
CREATE TABLE orders_p2 PARTITION OF orders
    FOR VALUES WITH (MODULUS 4, REMAINDER 1);
CREATE TABLE orders_p3 PARTITION OF orders
    FOR VALUES WITH (MODULUS 4, REMAINDER 2);
CREATE TABLE orders_p4 PARTITION OF orders
    FOR VALUES WITH (MODULUS 4, REMAINDER 3);
```

Create a default partition:

```
CREATE TABLE cities_partdef
    PARTITION OF cities DEFAULT;
```

Create a range-partitioned table using `pg_pathman`:

```
CREATE TABLE journal (
    id      SERIAL NOT NULL,
    dt      TIMESTAMP NOT NULL,
    msg     TEXT
) PARTITION BY RANGE (id)
(
    PARTITION journal_100 VALUES LESS THAN (100),
```

```
    PARTITION journal_200 VALUES LESS THAN (200)
);
```

Create a range-partitioned table using `pg_pathman` and enable automatic partition creation with interval 50:

```
CREATE TABLE journal (
    id      SERIAL NOT NULL,
    dt      TIMESTAMP NOT NULL,
    msg     TEXT
) PARTITION BY RANGE (id)
INTERVAL (50)
(
    PARTITION journal_100 VALUES LESS THAN (100),
    PARTITION journal_200 VALUES LESS THAN (200)
);
```

Create a hash-partitioned table with five partitions using `pg_pathman`:

```
CREATE TABLE journal(id serial NOT NULL)
    PARTITION BY HASH (id) PARTITIONS (5);
```

Compatibility

The `CREATE TABLE` command conforms to the SQL standard, with exceptions listed below.

Temporary Tables

Although the syntax of `CREATE TEMPORARY TABLE` resembles that of the SQL standard, the effect is not the same. In the standard, temporary tables are defined just once and automatically exist (starting with empty contents) in every session that needs them. Postgres Pro instead requires each session to issue its own `CREATE TEMPORARY TABLE` command for each temporary table to be used. This allows different sessions to use the same temporary table name for different purposes, whereas the standard's approach constrains all instances of a given temporary table name to have the same table structure.

The standard's definition of the behavior of temporary tables is widely ignored. Postgres Pro's behavior on this point is similar to that of several other SQL databases.

The SQL standard also distinguishes between global and local temporary tables, where a local temporary table has a separate set of contents for each SQL module within each session, though its definition is still shared across sessions. Since Postgres Pro does not support SQL modules, this distinction is not relevant in Postgres Pro.

For compatibility's sake, Postgres Pro will accept the `GLOBAL` and `LOCAL` keywords in a temporary table declaration, but they currently have no effect. Use of these keywords is discouraged, since future versions of Postgres Pro might adopt a more standard-compliant interpretation of their meaning.

The `ON COMMIT` clause for temporary tables also resembles the SQL standard, but has some differences. If the `ON COMMIT` clause is omitted, SQL specifies that the default behavior is `ON COMMIT DELETE ROWS`. However, the default behavior in Postgres Pro is `ON COMMIT PRESERVE ROWS`. The `ON COMMIT DROP` option does not exist in SQL.

Non-Deferred Uniqueness Constraints

When a `UNIQUE` or `PRIMARY KEY` constraint is not deferrable, Postgres Pro checks for uniqueness immediately whenever a row is inserted or modified. The SQL standard says that uniqueness should be enforced only at the end of the statement; this makes a difference when, for example, a single command updates multiple key values. To obtain standard-compliant behavior, declare the constraint as `DEFERRABLE` but not deferred (i.e., `INITIALLY IMMEDIATE`). Be aware that this can be significantly slower than immediate uniqueness checking.

Column Check Constraints

The SQL standard says that CHECK column constraints can only refer to the column they apply to; only CHECK table constraints can refer to multiple columns. Postgres Pro does not enforce this restriction; it treats column and table check constraints alike.

EXCLUDE Constraint

The EXCLUDE constraint type is a Postgres Pro extension.

Foreign Key Constraints

It is a PostgreSQL extension that a foreign key constraint may reference columns of a unique index instead of columns of a primary key or unique constraint.

NULL "Constraint"

The NULL "constraint" (actually a non-constraint) is a Postgres Pro extension to the SQL standard that is included for compatibility with some other database systems (and for symmetry with the NOT NULL constraint). Since it is the default for any column, its presence is simply noise.

Constraint Naming

The SQL standard says that table and domain constraints must have names that are unique across the schema containing the table or domain. Postgres Pro is laxer: it only requires constraint names to be unique across the constraints attached to a particular table or domain. However, this extra freedom does not exist for index-based constraints (UNIQUE, PRIMARY KEY, and EXCLUDE constraints), because the associated index is named the same as the constraint, and index names must be unique across all relations within the same schema.

Currently, Postgres Pro does not record names for NOT NULL constraints at all, so they are not subject to the uniqueness restriction. This might change in a future release.

Inheritance

Multiple inheritance via the INHERITS clause is a Postgres Pro language extension. SQL:1999 and later define single inheritance using a different syntax and different semantics. SQL:1999-style inheritance is not yet supported by Postgres Pro.

Zero-Column Tables

Postgres Pro allows a table of no columns to be created (for example, CREATE TABLE foo();). This is an extension from the SQL standard, which does not allow zero-column tables. Zero-column tables are not in themselves very useful, but disallowing them creates odd special cases for ALTER TABLE DROP COLUMN, so it seems cleaner to ignore this spec restriction.

Multiple Identity Columns

Postgres Pro allows a table to have more than one identity column. The standard specifies that a table can have at most one identity column. This is relaxed mainly to give more flexibility for doing schema changes or migrations. Note that the INSERT command supports only one override clause that applies to the entire statement, so having multiple identity columns with different behaviors is not well supported.

Generated Columns

The option STORED is not standard but is also used by other SQL implementations. The SQL standard does not specify the storage of generated columns.

LIKE Clause

While a LIKE clause exists in the SQL standard, many of the options that Postgres Pro accepts for it are not in the standard, and some of the standard's options are not implemented by Postgres Pro.

`WITH` Clause

The `WITH` clause is a Postgres Pro extension; storage parameters are not in the standard.

Tablespaces

The Postgres Pro concept of tablespaces is not part of the standard. Hence, the clauses `TABLESPACE` and `USING INDEX TABLESPACE` are extensions.

Typed Tables

Typed tables implement a subset of the SQL standard. According to the standard, a typed table has columns corresponding to the underlying composite type as well as one other column that is the “self-referencing column”. Postgres Pro does not support self-referencing columns explicitly.

`PARTITION BY` Clause

The `PARTITION BY` clause is a Postgres Pro extension.

`PARTITION OF` Clause

The `PARTITION OF` clause is a Postgres Pro extension.

See Also

ALTER TABLE, DROP TABLE, CREATE TABLE AS, CREATE TABLESPACE, CREATE TYPE

CREATE TABLE AS

CREATE TABLE AS — define a new table from the results of a query

Synopsis

```
CREATE [ [ GLOBAL | LOCAL ] { TEMPORARY | TEMP } | UNLOGGED | CONSTANT ] TABLE [ IF NOT
 EXISTS ] table_name
    [ (column_name [, ...] ) ]
    [ USING method ]
    [ WITH ( storage_parameter [= value] [, ... ] ) | WITHOUT OIDS ]
    [ ON COMMIT { PRESERVE ROWS | DELETE ROWS | DROP } ]
    [ TABLESPACE tablespace_name ]
    AS query
    [ WITH [ NO ] DATA ]
```

Description

`CREATE TABLE AS` creates a table and fills it with data computed by a `SELECT` command. The table columns have the names and data types associated with the output columns of the `SELECT` (except that you can override the column names by giving an explicit list of new column names).

`CREATE TABLE AS` bears some resemblance to creating a view, but it is really quite different: it creates a new table and evaluates the query just once to fill the new table initially. The new table will not track subsequent changes to the source tables of the query. In contrast, a view re-evaluates its defining `SELECT` statement whenever it is queried.

`CREATE TABLE AS` requires `CREATE` privilege on the schema used for the table.

Parameters

`GLOBAL` or `LOCAL`

Ignored for compatibility. Use of these keywords is deprecated; refer to CREATE TABLE for details.

`TEMPORARY` or `TEMP`

If specified, the table is created as a temporary table. Refer to CREATE TABLE for details.

`UNLOGGED`

If specified, the table is created as an unlogged table. Refer to CREATE TABLE for details.

`CONSTANT`

If specified, the table is created as read-only. No data can be modified or added to constant tables, and they are not processed by autovacuum. Constant tables cannot be changed to read-write mode.

`IF NOT EXISTS`

Do not throw an error if a relation with the same name already exists; simply issue a notice and leave the table unmodified.

`table_name`

The name (optionally schema-qualified) of the table to be created.

`column_name`

The name of a column in the new table. If column names are not provided, they are taken from the output column names of the query.

`USING method`

This optional clause specifies the table access method to use to store the contents for the new table; the method needs be an access method of type `TABLE`. See Chapter 61 for more information. If this option is not specified, the default table access method is chosen for the new table. See default_table_access_method for more information.

`WITH ( storage_parameter [= value] [, ... ] )`

This clause specifies optional storage parameters for the new table; see Storage Parameters in the CREATE TABLE documentation for more information. For backward-compatibility the `WITH` clause for a table can also include `OIDS=FALSE` to specify that rows of the new table should contain no OIDs (object identifiers), `OIDS=TRUE` is not supported anymore.

`WITHOUT OIDS`

This is backward-compatible syntax for declaring a table `WITHOUT OIDS`, creating a table `WITH OIDS` is not supported anymore.

`ON COMMIT`

The behavior of temporary tables at the end of a transaction block can be controlled using `ON COMMIT`. The three options are:

`PRESERVE ROWS`

No special action is taken at the ends of transactions. This is the default behavior.

`DELETE ROWS`

All rows in the temporary table will be deleted at the end of each transaction block. Essentially, an automatic `TRUNCATE` is done at each commit.

`DROP`

The temporary table will be dropped at the end of the current transaction block.

`TABLESPACE tablespace_name`

The *tablespace_name* is the name of the tablespace in which the new table is to be created. If not specified, default_tablespace is consulted, or temp_tablespaces if the table is temporary.

query

A `SELECT`, `TABLE`, or `VALUES` command, or an `EXECUTE` command that runs a prepared `SELECT`, `TABLE`, or `VALUES` query.

`WITH [ NO ] DATA`

This clause specifies whether or not the data produced by the query should be copied into the new table. If not, only the table structure is copied. The default is to copy the data.

Notes

This command is functionally similar to SELECT INTO, but it is preferred since it is less likely to be confused with other uses of the `SELECT INTO` syntax. Furthermore, `CREATE TABLE AS` offers a superset of the functionality offered by `SELECT INTO`.

Examples

Create a new table `films_recent` consisting of only recent entries from the table `films`:

```
CREATE TABLE films_recent AS
  SELECT * FROM films WHERE date_prod >= '2002-01-01';
```

To copy a table completely, the short form using the `TABLE` command can also be used:

```
CREATE TABLE films2 AS
  TABLE films;
```

Create a new temporary table `films_recent`, consisting of only recent entries from the table `films`, using a prepared statement. The new table will be dropped at commit:

```
PREPARE recentfilms(date) AS
  SELECT * FROM films WHERE date_prod > $1;
CREATE TEMP TABLE films_recent ON COMMIT DROP AS
  EXECUTE recentfilms('2002-01-01');
```

Compatibility

`CREATE TABLE AS` conforms to the SQL standard. The following are nonstandard extensions:

- The standard requires parentheses around the subquery clause; in Postgres Pro, these parentheses are optional.
- In the standard, the `WITH [ NO ] DATA` clause is required; in Postgres Pro it is optional.
- Postgres Pro handles temporary tables in a way rather different from the standard; see CREATE TABLE for details.
- The `WITH` clause is a Postgres Pro extension; storage parameters are not in the standard.
- The Postgres Pro concept of tablespaces is not part of the standard. Hence, the clause `TABLESPACE` is an extension.

See Also

CREATE MATERIALIZED VIEW, CREATE TABLE, EXECUTE, SELECT, SELECT INTO, VALUES

CREATE TABLESPACE

CREATE TABLESPACE — define a new tablespace

Synopsis

```
CREATE TABLESPACE tablespace_name
    [ OWNER { new_owner | CURRENT_ROLE | CURRENT_USER | SESSION_USER } ]
    LOCATION 'directory'
    [ WITH ( tablespace_option = value [, ... ] ) ]
```

Description

`CREATE TABLESPACE` registers a new cluster-wide tablespace. The tablespace name must be distinct from the name of any existing tablespace in the database cluster.

A tablespace allows superusers to define an alternative location on the file system where the data files containing database objects (such as tables and indexes) can reside.

A user with appropriate privileges can pass *tablespace_name* to `CREATE DATABASE`, `CREATE TABLE`, `CREATE INDEX` or `ADD CONSTRAINT` to have the data files for these objects stored within the specified tablespace.

> **Warning**
>
> A tablespace cannot be used independently of the cluster in which it is defined; see Section 22.6.

Parameters

tablespace_name

The name of a tablespace to be created. The name cannot begin with `pg_`, as such names are reserved for system tablespaces.

user_name

The name of the user who will own the tablespace. If omitted, defaults to the user executing the command. Only superusers can create tablespaces, but they can assign ownership of tablespaces to non-superusers.

directory

The directory that will be used for the tablespace. The directory must exist (`CREATE TABLESPACE` will not create it), should be empty, and must be owned by the Postgres Pro system user. The directory must be specified by an absolute path name.

tablespace_option

A tablespace parameter to be set or reset. Currently, the only available parameters are `seq_page_cost`, `random_page_cost`, `effective_io_concurrency`, `maintenance_io_concurrency` and `compression`. Setting cost value for a particular tablespace will override the planner's usual estimate of the cost of reading pages from tables in that tablespace, and the executor's prefetching behavior, as established by the configuration parameters of the same name (see seq_page_cost, random_page_cost, effective_io_concurrency, maintenance_io_concurrency). This may be useful if one tablespace is located on a disk which is faster or slower than the remainder of the I/O subsystem. Compression is discussed in section Chapter 33.

Notes

Tablespaces are only supported on systems that support symbolic links.

`CREATE TABLESPACE` cannot be executed inside a transaction block.

Examples

To create a tablespace `dbspace` at file system location `/data/dbs`, first create the directory using operating system facilities and set the correct ownership:

```
mkdir /data/dbs
chown postgres:postgres /data/dbs
```

Then issue the tablespace creation command inside Postgres Pro:

```
CREATE TABLESPACE dbspace LOCATION '/data/dbs';
```

To create a tablespace owned by a different database user, use a command like this:

```
CREATE TABLESPACE indexspace OWNER genevieve LOCATION '/data/indexes';
```

Compatibility

`CREATE TABLESPACE` is a Postgres Pro extension.

See Also

CREATE DATABASE, CREATE TABLE, CREATE INDEX, DROP TABLESPACE, ALTER TABLESPACE

CREATE TEXT SEARCH CONFIGURATION

CREATE TEXT SEARCH CONFIGURATION — define a new text search configuration

Synopsis

```
CREATE TEXT SEARCH CONFIGURATION name (
    PARSER = parser_name |
    COPY = source_config
)
```

Description

`CREATE TEXT SEARCH CONFIGURATION` creates a new text search configuration. A text search configuration specifies a text search parser that can divide a string into tokens, plus dictionaries that can be used to determine which tokens are of interest for searching.

If only the parser is specified, then the new text search configuration initially has no mappings from token types to dictionaries, and therefore will ignore all words. Subsequent `ALTER TEXT SEARCH CONFIGURATION` commands must be used to create mappings to make the configuration useful. Alternatively, an existing text search configuration can be copied.

If a schema name is given then the text search configuration is created in the specified schema. Otherwise it is created in the current schema.

The user who defines a text search configuration becomes its owner.

Refer to Chapter 12 for further information.

Parameters

name

The name of the text search configuration to be created. The name can be schema-qualified.

parser_name

The name of the text search parser to use for this configuration.

source_config

The name of an existing text search configuration to copy.

Notes

The `PARSER` and `COPY` options are mutually exclusive, because when an existing configuration is copied, its parser selection is copied too.

Compatibility

There is no `CREATE TEXT SEARCH CONFIGURATION` statement in the SQL standard.

See Also

ALTER TEXT SEARCH CONFIGURATION, DROP TEXT SEARCH CONFIGURATION

CREATE TEXT SEARCH DICTIONARY

CREATE TEXT SEARCH DICTIONARY — define a new text search dictionary

Synopsis

```
CREATE TEXT SEARCH DICTIONARY name (
    TEMPLATE = template
    [, option = value [, ... ]]
)
```

Description

`CREATE TEXT SEARCH DICTIONARY` creates a new text search dictionary. A text search dictionary specifies a way of recognizing interesting or uninteresting words for searching. A dictionary depends on a text search template, which specifies the functions that actually perform the work. Typically the dictionary provides some options that control the detailed behavior of the template's functions.

If a schema name is given then the text search dictionary is created in the specified schema. Otherwise it is created in the current schema.

The user who defines a text search dictionary becomes its owner.

Refer to Chapter 12 for further information.

Parameters

name

The name of the text search dictionary to be created. The name can be schema-qualified.

template

The name of the text search template that will define the basic behavior of this dictionary.

option

The name of a template-specific option to be set for this dictionary.

value

The value to use for a template-specific option. If the value is not a simple identifier or number, it must be quoted (but you can always quote it, if you wish).

The options can appear in any order.

Examples

The following example command creates a Snowball-based dictionary with a nonstandard list of stop words.

```
CREATE TEXT SEARCH DICTIONARY my_russian (
    template = snowball,
    language = russian,
    stopwords = myrussian
);
```

Compatibility

There is no `CREATE TEXT SEARCH DICTIONARY` statement in the SQL standard.

See Also

ALTER TEXT SEARCH DICTIONARY, DROP TEXT SEARCH DICTIONARY

CREATE TEXT SEARCH PARSER

CREATE TEXT SEARCH PARSER — define a new text search parser

Synopsis

```
CREATE TEXT SEARCH PARSER name (
    START = start_function ,
    GETTOKEN = gettoken_function ,
    END = end_function ,
    LEXTYPES = lextypes_function
    [, HEADLINE = headline_function ]
)
```

Description

`CREATE TEXT SEARCH PARSER` creates a new text search parser. A text search parser defines a method for splitting a text string into tokens and assigning types (categories) to the tokens. A parser is not particularly useful by itself, but must be bound into a text search configuration along with some text search dictionaries to be used for searching.

If a schema name is given then the text search parser is created in the specified schema. Otherwise it is created in the current schema.

You must be a superuser to use `CREATE TEXT SEARCH PARSER`. (This restriction is made because an erroneous text search parser definition could confuse or even crash the server.)

Refer to Chapter 12 for further information.

Parameters

name

The name of the text search parser to be created. The name can be schema-qualified.

start_function

The name of the start function for the parser.

gettoken_function

The name of the get-next-token function for the parser.

end_function

The name of the end function for the parser.

lextypes_function

The name of the lextypes function for the parser (a function that returns information about the set of token types it produces).

headline_function

The name of the headline function for the parser (a function that summarizes a set of tokens).

The function names can be schema-qualified if necessary. Argument types are not given, since the argument list for each type of function is predetermined. All except the headline function are required.

The arguments can appear in any order, not only the one shown above.

Compatibility

There is no `CREATE TEXT SEARCH PARSER` statement in the SQL standard.

See Also

ALTER TEXT SEARCH PARSER, DROP TEXT SEARCH PARSER

CREATE TEXT SEARCH TEMPLATE

CREATE TEXT SEARCH TEMPLATE — define a new text search template

Synopsis

```
CREATE TEXT SEARCH TEMPLATE name (
    [ INIT = init_function , ]
    LEXIZE = lexize_function
)
```

Description

`CREATE TEXT SEARCH TEMPLATE` creates a new text search template. Text search templates define the functions that implement text search dictionaries. A template is not useful by itself, but must be instantiated as a dictionary to be used. The dictionary typically specifies parameters to be given to the template functions.

If a schema name is given then the text search template is created in the specified schema. Otherwise it is created in the current schema.

You must be a superuser to use `CREATE TEXT SEARCH TEMPLATE`. This restriction is made because an erroneous text search template definition could confuse or even crash the server. The reason for separating templates from dictionaries is that a template encapsulates the “unsafe” aspects of defining a dictionary. The parameters that can be set when defining a dictionary are safe for unprivileged users to set, and so creating a dictionary need not be a privileged operation.

Refer to Chapter 12 for further information.

Parameters

name

The name of the text search template to be created. The name can be schema-qualified.

init_function

The name of the init function for the template.

lexize_function

The name of the lexize function for the template.

The function names can be schema-qualified if necessary. Argument types are not given, since the argument list for each type of function is predetermined. The lexize function is required, but the init function is optional.

The arguments can appear in any order, not only the one shown above.

Compatibility

There is no `CREATE TEXT SEARCH TEMPLATE` statement in the SQL standard.

See Also

ALTER TEXT SEARCH TEMPLATE, DROP TEXT SEARCH TEMPLATE

CREATE TRANSFORM

CREATE TRANSFORM — define a new transform

Synopsis

```
CREATE [ OR REPLACE ] TRANSFORM FOR type_name LANGUAGE lang_name (
    FROM SQL WITH FUNCTION from_sql_function_name [ (argument_type [, ...]) ],
    TO SQL WITH FUNCTION to_sql_function_name [ (argument_type [, ...]) ]
);
```

Description

`CREATE TRANSFORM` defines a new transform. `CREATE OR REPLACE TRANSFORM` will either create a new transform, or replace an existing definition.

A transform specifies how to adapt a data type to a procedural language. For example, when writing a function in PL/Python using the `hstore` type, PL/Python has no prior knowledge how to present `hstore` values in the Python environment. Language implementations usually default to using the text representation, but that is inconvenient when, for example, an associative array or a list would be more appropriate.

A transform specifies two functions:

- A "from SQL" function that converts the type from the SQL environment to the language. This function will be invoked on the arguments of a function written in the language.
- A "to SQL" function that converts the type from the language to the SQL environment. This function will be invoked on the return value of a function written in the language.

It is not necessary to provide both of these functions. If one is not specified, the language-specific default behavior will be used if necessary. (To prevent a transformation in a certain direction from happening at all, you could also write a transform function that always errors out.)

To be able to create a transform, you must own and have `USAGE` privilege on the type, have `USAGE` privilege on the language, and own and have `EXECUTE` privilege on the from-SQL and to-SQL functions, if specified.

Parameters

type_name

The name of the data type of the transform.

lang_name

The name of the language of the transform.

from_sql_function_name[(*argument_type* [, ...])]

The name of the function for converting the type from the SQL environment to the language. It must take one argument of type `internal` and return type `internal`. The actual argument will be of the type for the transform, and the function should be coded as if it were. (But it is not allowed to declare an SQL-level function returning `internal` without at least one argument of type `internal`.) The actual return value will be something specific to the language implementation. If no argument list is specified, the function name must be unique in its schema.

to_sql_function_name[(*argument_type* [, ...])]

The name of the function for converting the type from the language to the SQL environment. It must take one argument of type `internal` and return the type that is the type for the transform. The actual argument value will be something specific to the language implementation. If no argument list is specified, the function name must be unique in its schema.

Notes

Use DROP TRANSFORM to remove transforms.

Examples

To create a transform for type hstore and language plpythonu, first set up the type and the language:

```
CREATE TYPE hstore ...;

CREATE EXTENSION plpythonu;
```

Then create the necessary functions:

```
CREATE FUNCTION hstore_to_plpython(val internal) RETURNS internal
LANGUAGE C STRICT IMMUTABLE
AS ...;

CREATE FUNCTION plpython_to_hstore(val internal) RETURNS hstore
LANGUAGE C STRICT IMMUTABLE
AS ...;
```

And finally create the transform to connect them all together:

```
CREATE TRANSFORM FOR hstore LANGUAGE plpythonu (
    FROM SQL WITH FUNCTION hstore_to_plpython(internal),
    TO SQL WITH FUNCTION plpython_to_hstore(internal)
);
```

In practice, these commands would be wrapped up in an extension.

The contrib section contains a number of extensions that provide transforms, which can serve as real-world examples.

Compatibility

This form of CREATE TRANSFORM is a Postgres Pro extension. There is a CREATE TRANSFORM command in the SQL standard, but it is for adapting data types to client languages. That usage is not supported by Postgres Pro.

See Also

CREATE FUNCTION, CREATE LANGUAGE, CREATE TYPE, DROP TRANSFORM

CREATE TRIGGER

CREATE TRIGGER — define a new trigger

Synopsis

```
CREATE [ OR REPLACE ] [ CONSTRAINT ] TRIGGER name { BEFORE | AFTER | INSTEAD OF }
 { event [ OR ... ] }
    ON table_name
    [ FROM referenced_table_name ]
    [ NOT DEFERRABLE | [ DEFERRABLE ] [ INITIALLY IMMEDIATE | INITIALLY DEFERRED ] ]
    [ REFERENCING { { OLD | NEW } TABLE [ AS ] transition_relation_name } [ ... ] ]
    [ FOR [ EACH ] { ROW | STATEMENT } ]
    [ WHEN ( condition ) ]
    EXECUTE { FUNCTION | PROCEDURE } function_name ( arguments )

where event can be one of:

    INSERT
    UPDATE [ OF column_name [, ... ] ]
    DELETE
    TRUNCATE
```

Description

`CREATE TRIGGER` creates a new trigger. `CREATE OR REPLACE TRIGGER` will either create a new trigger, or replace an existing trigger. The trigger will be associated with the specified table, view, or foreign table and will execute the specified function *`function_name`* when certain operations are performed on that table.

To replace the current definition of an existing trigger, use `CREATE OR REPLACE TRIGGER`, specifying the existing trigger's name and parent table. All other properties are replaced.

The trigger can be specified to fire before the operation is attempted on a row (before constraints are checked and the `INSERT`, `UPDATE`, or `DELETE` is attempted); or after the operation has completed (after constraints are checked and the `INSERT`, `UPDATE`, or `DELETE` has completed); or instead of the operation (in the case of inserts, updates or deletes on a view). If the trigger fires before or instead of the event, the trigger can skip the operation for the current row, or change the row being inserted (for `INSERT` and `UPDATE` operations only). If the trigger fires after the event, all changes, including the effects of other triggers, are “visible” to the trigger.

A trigger that is marked `FOR EACH ROW` is called once for every row that the operation modifies. For example, a `DELETE` that affects 10 rows will cause any `ON DELETE` triggers on the target relation to be called 10 separate times, once for each deleted row. In contrast, a trigger that is marked `FOR EACH STATEMENT` only executes once for any given operation, regardless of how many rows it modifies (in particular, an operation that modifies zero rows will still result in the execution of any applicable `FOR EACH STATEMENT` triggers).

Triggers that are specified to fire `INSTEAD OF` the trigger event must be marked `FOR EACH ROW`, and can only be defined on views. `BEFORE` and `AFTER` triggers on a view must be marked as `FOR EACH STATEMENT`.

In addition, triggers may be defined to fire for `TRUNCATE`, though only `FOR EACH STATEMENT`.

The following table summarizes which types of triggers may be used on tables, views, and foreign tables:

When	Event	Row-level	Statement-level
BEFORE	INSERT/UPDATE/DELETE	Tables and foreign tables	Tables, views, and foreign tables

When	Event	Row-level	Statement-level
	TRUNCATE	—	Tables
AFTER	INSERT/UPDATE/DELETE	Tables and foreign tables	Tables, views, and foreign tables
	TRUNCATE	—	Tables
INSTEAD OF	INSERT/UPDATE/DELETE	Views	—
	TRUNCATE	—	—

Also, a trigger definition can specify a Boolean WHEN condition, which will be tested to see whether the trigger should be fired. In row-level triggers the WHEN condition can examine the old and/or new values of columns of the row. Statement-level triggers can also have WHEN conditions, although the feature is not so useful for them since the condition cannot refer to any values in the table.

If multiple triggers of the same kind are defined for the same event, they will be fired in alphabetical order by name.

When the CONSTRAINT option is specified, this command creates a *constraint trigger*. This is the same as a regular trigger except that the timing of the trigger firing can be adjusted using SET CONSTRAINTS. Constraint triggers must be AFTER ROW triggers on plain tables (not foreign tables). They can be fired either at the end of the statement causing the triggering event, or at the end of the containing transaction; in the latter case they are said to be *deferred*. A pending deferred-trigger firing can also be forced to happen immediately by using SET CONSTRAINTS. Constraint triggers are expected to raise an exception when the constraints they implement are violated.

The REFERENCING option enables collection of *transition relations*, which are row sets that include all of the rows inserted, deleted, or modified by the current SQL statement. This feature lets the trigger see a global view of what the statement did, not just one row at a time. This option is only allowed for an AFTER trigger that is not a constraint trigger; also, if the trigger is an UPDATE trigger, it must not specify a *column_name* list. OLD TABLE may only be specified once, and only for a trigger that can fire on UPDATE or DELETE; it creates a transition relation containing the *before-images* of all rows updated or deleted by the statement. Similarly, NEW TABLE may only be specified once, and only for a trigger that can fire on UPDATE or INSERT; it creates a transition relation containing the *after-images* of all rows updated or inserted by the statement.

SELECT does not modify any rows so you cannot create SELECT triggers. Rules and views may provide workable solutions to problems that seem to need SELECT triggers.

Refer to Chapter 41 for more information about triggers.

Parameters

name

The name to give the new trigger. This must be distinct from the name of any other trigger for the same table. The name cannot be schema-qualified — the trigger inherits the schema of its table. For a constraint trigger, this is also the name to use when modifying the trigger's behavior using SET CONSTRAINTS.

BEFORE
AFTER
INSTEAD OF

Determines whether the function is called before, after, or instead of the event. A constraint trigger can only be specified as AFTER.

event

One of INSERT, UPDATE, DELETE, or TRUNCATE; this specifies the event that will fire the trigger. Multiple events can be specified using OR, except when transition relations are requested.

For UPDATE events, it is possible to specify a list of columns using this syntax:

```
UPDATE OF column_name1 [, column_name2 ... ]
```

The trigger will only fire if at least one of the listed columns is mentioned as a target of the UPDATE command or if one of the listed columns is a generated column that depends on a column that is the target of the UPDATE.

INSTEAD OF UPDATE events do not allow a list of columns. A column list cannot be specified when requesting transition relations, either.

table_name

The name (optionally schema-qualified) of the table, view, or foreign table the trigger is for.

referenced_table_name

The (possibly schema-qualified) name of another table referenced by the constraint. This option is used for foreign-key constraints and is not recommended for general use. This can only be specified for constraint triggers.

DEFERRABLE
NOT DEFERRABLE
INITIALLY IMMEDIATE
INITIALLY DEFERRED

The default timing of the trigger. See the CREATE TABLE documentation for details of these constraint options. This can only be specified for constraint triggers.

REFERENCING

This keyword immediately precedes the declaration of one or two relation names that provide access to the transition relations of the triggering statement.

OLD TABLE
NEW TABLE

This clause indicates whether the following relation name is for the before-image transition relation or the after-image transition relation.

transition_relation_name

The (unqualified) name to be used within the trigger for this transition relation.

FOR EACH ROW
FOR EACH STATEMENT

This specifies whether the trigger function should be fired once for every row affected by the trigger event, or just once per SQL statement. If neither is specified, FOR EACH STATEMENT is the default. Constraint triggers can only be specified FOR EACH ROW.

condition

A Boolean expression that determines whether the trigger function will actually be executed. If WHEN is specified, the function will only be called if the *condition* returns true. In FOR EACH ROW triggers, the WHEN condition can refer to columns of the old and/or new row values by writing OLD.*column_name* or NEW.*column_name* respectively. Of course, INSERT triggers cannot refer to OLD and DELETE triggers cannot refer to NEW.

INSTEAD OF triggers do not support WHEN conditions.

Currently, WHEN expressions cannot contain subqueries.

Note that for constraint triggers, evaluation of the WHEN condition is not deferred, but occurs immediately after the row update operation is performed. If the condition does not evaluate to true then the trigger is not queued for deferred execution.

function_name

A user-supplied function that is declared as taking no arguments and returning type `trigger`, which is executed when the trigger fires.

In the syntax of `CREATE TRIGGER`, the keywords `FUNCTION` and `PROCEDURE` are equivalent, but the referenced function must in any case be a function, not a procedure. The use of the keyword `PROCEDURE` here is historical and deprecated.

arguments

An optional comma-separated list of arguments to be provided to the function when the trigger is executed. The arguments are literal string constants. Simple names and numeric constants can be written here, too, but they will all be converted to strings. Please check the description of the implementation language of the trigger function to find out how these arguments can be accessed within the function; it might be different from normal function arguments.

Notes

To create or replace a trigger on a table, the user must have the `TRIGGER` privilege on the table. The user must also have `EXECUTE` privilege on the trigger function.

Use `DROP TRIGGER` to remove a trigger.

Creating a row-level trigger on a partitioned table will cause an identical “clone” trigger to be created on each of its existing partitions; and any partitions created or attached later will have an identical trigger, too. If there is a conflictingly-named trigger on a child partition already, an error occurs unless `CREATE OR REPLACE TRIGGER` is used, in which case that trigger is replaced with a clone trigger. When a partition is detached from its parent, its clone triggers are removed.

A column-specific trigger (one defined using the `UPDATE OF` *column_name* syntax) will fire when any of its columns are listed as targets in the `UPDATE` command's `SET` list. It is possible for a column's value to change even when the trigger is not fired, because changes made to the row's contents by `BEFORE UPDATE` triggers are not considered. Conversely, a command such as `UPDATE ... SET x = x ...` will fire a trigger on column `x`, even though the column's value did not change.

In a `BEFORE` trigger, the `WHEN` condition is evaluated just before the function is or would be executed, so using `WHEN` is not materially different from testing the same condition at the beginning of the trigger function. Note in particular that the `NEW` row seen by the condition is the current value, as possibly modified by earlier triggers. Also, a `BEFORE` trigger's `WHEN` condition is not allowed to examine the system columns of the `NEW` row (such as `ctid`), because those won't have been set yet.

In an `AFTER` trigger, the `WHEN` condition is evaluated just after the row update occurs, and it determines whether an event is queued to fire the trigger at the end of statement. So when an `AFTER` trigger's `WHEN` condition does not return true, it is not necessary to queue an event nor to re-fetch the row at end of statement. This can result in significant speedups in statements that modify many rows, if the trigger only needs to be fired for a few of the rows.

In some cases it is possible for a single SQL command to fire more than one kind of trigger. For instance an `INSERT` with an `ON CONFLICT DO UPDATE` clause may cause both insert and update operations, so it will fire both kinds of triggers as needed. The transition relations supplied to triggers are specific to their event type; thus an `INSERT` trigger will see only the inserted rows, while an `UPDATE` trigger will see only the updated rows.

Row updates or deletions caused by foreign-key enforcement actions, such as `ON UPDATE CASCADE` or `ON DELETE SET NULL`, are treated as part of the SQL command that caused them (note that such actions are never deferred). Relevant triggers on the affected table will be fired, so that this provides another way in which an SQL command might fire triggers not directly matching its type. In simple cases, triggers that request transition relations will see all changes caused in their table by a single original SQL command as a single transition relation. However, there are cases in which the presence of an `AFTER ROW` trigger

that requests transition relations will cause the foreign-key enforcement actions triggered by a single SQL command to be split into multiple steps, each with its own transition relation(s). In such cases, any statement-level triggers that are present will be fired once per creation of a transition relation set, ensuring that the triggers see each affected row in a transition relation once and only once.

Statement-level triggers on a view are fired only if the action on the view is handled by a row-level `INSTEAD OF` trigger. If the action is handled by an `INSTEAD` rule, then whatever statements are emitted by the rule are executed in place of the original statement naming the view, so that the triggers that will be fired are those on tables named in the replacement statements. Similarly, if the view is automatically updatable, then the action is handled by automatically rewriting the statement into an action on the view's base table, so that the base table's statement-level triggers are the ones that are fired.

Modifying a partitioned table or a table with inheritance children fires statement-level triggers attached to the explicitly named table, but not statement-level triggers for its partitions or child tables. In contrast, row-level triggers are fired on the rows in affected partitions or child tables, even if they are not explicitly named in the query. If a statement-level trigger has been defined with transition relations named by a `REFERENCING` clause, then before and after images of rows are visible from all affected partitions or child tables. In the case of inheritance children, the row images include only columns that are present in the table that the trigger is attached to.

Currently, row-level triggers with transition relations cannot be defined on partitions or inheritance child tables. Also, triggers on partitioned tables may not be `INSTEAD OF`.

Currently, the `OR REPLACE` option is not supported for constraint triggers.

Replacing an existing trigger within a transaction that has already performed updating actions on the trigger's table is not recommended. Trigger firing decisions, or portions of firing decisions, that have already been made will not be reconsidered, so the effects could be surprising.

There are a few built-in trigger functions that can be used to solve common problems without having to write your own trigger code; see Section 9.28.

Examples

Execute the function `check_account_update` whenever a row of the table `accounts` is about to be updated:

```
CREATE TRIGGER check_update
    BEFORE UPDATE ON accounts
    FOR EACH ROW
    EXECUTE FUNCTION check_account_update();
```

Modify that trigger definition to only execute the function if column `balance` is specified as a target in the `UPDATE` command:

```
CREATE OR REPLACE TRIGGER check_update
    BEFORE UPDATE OF balance ON accounts
    FOR EACH ROW
    EXECUTE FUNCTION check_account_update();
```

This form only executes the function if column `balance` has in fact changed value:

```
CREATE TRIGGER check_update
    BEFORE UPDATE ON accounts
    FOR EACH ROW
    WHEN (OLD.balance IS DISTINCT FROM NEW.balance)
    EXECUTE FUNCTION check_account_update();
```

Call a function to log updates of `accounts`, but only if something changed:

```
CREATE TRIGGER log_update
    AFTER UPDATE ON accounts
    FOR EACH ROW
```

```
    WHEN (OLD.* IS DISTINCT FROM NEW.*)
    EXECUTE FUNCTION log_account_update();
```

Execute the function `view_insert_row` for each row to insert rows into the tables underlying a view:

```
CREATE TRIGGER view_insert
    INSTEAD OF INSERT ON my_view
    FOR EACH ROW
    EXECUTE FUNCTION view_insert_row();
```

Execute the function `check_transfer_balances_to_zero` for each statement to confirm that the `transfer` rows offset to a net of zero:

```
CREATE TRIGGER transfer_insert
    AFTER INSERT ON transfer
    REFERENCING NEW TABLE AS inserted
    FOR EACH STATEMENT
    EXECUTE FUNCTION check_transfer_balances_to_zero();
```

Execute the function `check_matching_pairs` for each row to confirm that changes are made to matching pairs at the same time (by the same statement):

```
CREATE TRIGGER paired_items_update
    AFTER UPDATE ON paired_items
    REFERENCING NEW TABLE AS newtab OLD TABLE AS oldtab
    FOR EACH ROW
    EXECUTE FUNCTION check_matching_pairs();
```

Section 41.4 contains a complete example of a trigger function written in C.

Compatibility

The `CREATE TRIGGER` statement in Postgres Pro implements a subset of the SQL standard. The following functionalities are currently missing:

- While transition table names for `AFTER` triggers are specified using the `REFERENCING` clause in the standard way, the row variables used in `FOR EACH ROW` triggers may not be specified in a `REFERENCING` clause. They are available in a manner that is dependent on the language in which the trigger function is written, but is fixed for any one language. Some languages effectively behave as though there is a `REFERENCING` clause containing `OLD ROW AS OLD NEW ROW AS NEW`.
- The standard allows transition tables to be used with column-specific `UPDATE` triggers, but then the set of rows that should be visible in the transition tables depends on the trigger's column list. This is not currently implemented by Postgres Pro.
- Postgres Pro only allows the execution of a user-defined function for the triggered action. The standard allows the execution of a number of other SQL commands, such as `CREATE TABLE`, as the triggered action. This limitation is not hard to work around by creating a user-defined function that executes the desired commands.

SQL specifies that multiple triggers should be fired in time-of-creation order. Postgres Pro uses name order, which was judged to be more convenient.

SQL specifies that `BEFORE DELETE` triggers on cascaded deletes fire *after* the cascaded `DELETE` completes. The Postgres Pro behavior is for `BEFORE DELETE` to always fire before the delete action, even a cascading one. This is considered more consistent. There is also nonstandard behavior if `BEFORE` triggers modify rows or prevent updates during an update that is caused by a referential action. This can lead to constraint violations or stored data that does not honor the referential constraint.

The ability to specify multiple actions for a single trigger using `OR` is a Postgres Pro extension of the SQL standard.

The ability to fire triggers for `TRUNCATE` is a Postgres Pro extension of the SQL standard, as is the ability to define statement-level triggers on views.

`CREATE CONSTRAINT TRIGGER` is a Postgres Pro extension of the SQL standard. So is the `OR REPLACE` option.

See Also

ALTER TRIGGER, DROP TRIGGER, CREATE FUNCTION, SET CONSTRAINTS

CREATE TYPE

CREATE TYPE — define a new data type

Synopsis

```
CREATE TYPE name AS
    ( [ attribute_name data_type [ COLLATE collation ] [, ... ] ] )

CREATE TYPE name AS ENUM
    ( [ 'label' [, ... ] ] )

CREATE TYPE name AS RANGE (
    SUBTYPE = subtype
    [ , SUBTYPE_OPCLASS = subtype_operator_class ]
    [ , COLLATION = collation ]
    [ , CANONICAL = canonical_function ]
    [ , SUBTYPE_DIFF = subtype_diff_function ]
    [ , MULTIRANGE_TYPE_NAME = multirange_type_name ]
)

CREATE TYPE name (
    INPUT = input_function,
    OUTPUT = output_function
    [ , RECEIVE = receive_function ]
    [ , SEND = send_function ]
    [ , TYPMOD_IN = type_modifier_input_function ]
    [ , TYPMOD_OUT = type_modifier_output_function ]
    [ , ANALYZE = analyze_function ]
    [ , SUBSCRIPT = subscript_function ]
    [ , INTERNALLENGTH = { internallength | VARIABLE } ]
    [ , PASSEDBYVALUE ]
    [ , ALIGNMENT = alignment ]
    [ , STORAGE = storage ]
    [ , LIKE = like_type ]
    [ , CATEGORY = category ]
    [ , PREFERRED = preferred ]
    [ , DEFAULT = default ]
    [ , ELEMENT = element ]
    [ , DELIMITER = delimiter ]
    [ , COLLATABLE = collatable ]
)

CREATE TYPE name
```

Description

`CREATE TYPE` registers a new data type for use in the current database. The user who defines a type becomes its owner.

If a schema name is given then the type is created in the specified schema. Otherwise it is created in the current schema. The type name must be distinct from the name of any existing type or domain in the same schema. (Because tables have associated data types, the type name must also be distinct from the name of any existing table in the same schema.)

There are five forms of `CREATE TYPE`, as shown in the syntax synopsis above. They respectively create a *composite type*, an *enum type*, a *range type*, a *base type*, or a *shell type*. The first four of these are

discussed in turn below. A shell type is simply a placeholder for a type to be defined later; it is created by issuing CREATE TYPE with no parameters except for the type name. Shell types are needed as forward references when creating range types and base types, as discussed in those sections.

Composite Types

The first form of CREATE TYPE creates a composite type. The composite type is specified by a list of attribute names and data types. An attribute's collation can be specified too, if its data type is collatable. A composite type is essentially the same as the row type of a table, but using CREATE TYPE avoids the need to create an actual table when all that is wanted is to define a type. A stand-alone composite type is useful, for example, as the argument or return type of a function.

To be able to create a composite type, you must have USAGE privilege on all attribute types.

Enumerated Types

The second form of CREATE TYPE creates an enumerated (enum) type, as described in Section 8.7. Enum types take a list of quoted labels, each of which must be less than NAMEDATALEN bytes long (64 bytes in a standard Postgres Pro build). (It is possible to create an enumerated type with zero labels, but such a type cannot be used to hold values before at least one label is added using ALTER TYPE.)

Range Types

The third form of CREATE TYPE creates a new range type, as described in Section 8.17.

The range type's *subtype* can be any type with an associated b-tree operator class (to determine the ordering of values for the range type). Normally the subtype's default b-tree operator class is used to determine ordering; to use a non-default operator class, specify its name with *subtype_opclass*. If the subtype is collatable, and you want to use a non-default collation in the range's ordering, specify the desired collation with the *collation* option.

The optional *canonical* function must take one argument of the range type being defined, and return a value of the same type. This is used to convert range values to a canonical form, when applicable. See Section 8.17.8 for more information. Creating a *canonical* function is a bit tricky, since it must be defined before the range type can be declared. To do this, you must first create a shell type, which is a placeholder type that has no properties except a name and an owner. This is done by issuing the command CREATE TYPE *name*, with no additional parameters. Then the function can be declared using the shell type as argument and result, and finally the range type can be declared using the same name. This automatically replaces the shell type entry with a valid range type.

The optional *subtype_diff* function must take two values of the *subtype* type as argument, and return a double precision value representing the difference between the two given values. While this is optional, providing it allows much greater efficiency of GiST indexes on columns of the range type. See Section 8.17.8 for more information.

The optional *multirange_type_name* parameter specifies the name of the corresponding multirange type. If not specified, this name is chosen automatically as follows. If the range type name contains the substring range, then the multirange type name is formed by replacement of the range substring with multirange in the range type name. Otherwise, the multirange type name is formed by appending a _multirange suffix to the range type name.

Base Types

The fourth form of CREATE TYPE creates a new base type (scalar type). To create a new base type, you must be a superuser. (This restriction is made because an erroneous type definition could confuse or even crash the server.)

The parameters can appear in any order, not only that illustrated above, and most are optional. You must register two or more functions (using CREATE FUNCTION) before defining the type. The support functions *input_function* and *output_function* are required, while the functions *receive_function*,

send_function, *type_modifier_input_function*, *type_modifier_output_function*, *analyze_function*, and *subscript_function* are optional. Generally these functions have to be coded in C or another low-level language.

The *input_function* converts the type's external textual representation to the internal representation used by the operators and functions defined for the type. *output_function* performs the reverse transformation. The input function can be declared as taking one argument of type `cstring`, or as taking three arguments of types `cstring`, `oid`, `integer`. The first argument is the input text as a C string, the second argument is the type's own OID (except for array types, which instead receive their element type's OID), and the third is the `typmod` of the destination column, if known (-1 will be passed if not). The input function must return a value of the data type itself. Usually, an input function should be declared STRICT; if it is not, it will be called with a NULL first parameter when reading a NULL input value. The function must still return NULL in this case, unless it raises an error. (This case is mainly meant to support domain input functions, which might need to reject NULL inputs.) The output function must be declared as taking one argument of the new data type. The output function must return type `cstring`. Output functions are not invoked for NULL values.

The optional *receive_function* converts the type's external binary representation to the internal representation. If this function is not supplied, the type cannot participate in binary input. The binary representation should be chosen to be cheap to convert to internal form, while being reasonably portable. (For example, the standard integer data types use network byte order as the external binary representation, while the internal representation is in the machine's native byte order.) The receive function should perform adequate checking to ensure that the value is valid. The receive function can be declared as taking one argument of type `internal`, or as taking three arguments of types `internal`, `oid`, `integer`. The first argument is a pointer to a `StringInfo` buffer holding the received byte string; the optional arguments are the same as for the text input function. The receive function must return a value of the data type itself. Usually, a receive function should be declared STRICT; if it is not, it will be called with a NULL first parameter when reading a NULL input value. The function must still return NULL in this case, unless it raises an error. (This case is mainly meant to support domain receive functions, which might need to reject NULL inputs.) Similarly, the optional *send_function* converts from the internal representation to the external binary representation. If this function is not supplied, the type cannot participate in binary output. The send function must be declared as taking one argument of the new data type. The send function must return type `bytea`. Send functions are not invoked for NULL values.

You should at this point be wondering how the input and output functions can be declared to have results or arguments of the new type, when they have to be created before the new type can be created. The answer is that the type should first be defined as a *shell type*, which is a placeholder type that has no properties except a name and an owner. This is done by issuing the command `CREATE TYPE` *name*, with no additional parameters. Then the C I/O functions can be defined referencing the shell type. Finally, `CREATE TYPE` with a full definition replaces the shell entry with a complete, valid type definition, after which the new type can be used normally.

The optional *type_modifier_input_function* and *type_modifier_output_function* are needed if the type supports modifiers, that is optional constraints attached to a type declaration, such as `char(5)` or `numeric(30,2)`. Postgres Pro allows user-defined types to take one or more simple constants or identifiers as modifiers. However, this information must be capable of being packed into a single non-negative integer value for storage in the system catalogs. The *type_modifier_input_function* is passed the declared modifier(s) in the form of a `cstring` array. It must check the values for validity (throwing an error if they are wrong), and if they are correct, return a single non-negative `integer` value that will be stored as the column “typmod”. Type modifiers will be rejected if the type does not have a *type_modifier_input_function*. The *type_modifier_output_function* converts the internal integer typmod value back to the correct form for user display. It must return a `cstring` value that is the exact string to append to the type name; for example `numeric`'s function might return `(30,2)`. It is allowed to omit the *type_modifier_output_function*, in which case the default display format is just the stored typmod integer value enclosed in parentheses.

The optional *analyze_function* performs type-specific statistics collection for columns of the data type. By default, `ANALYZE` will attempt to gather statistics using the type's “equals” and “less-than” operators,

if there is a default b-tree operator class for the type. For non-scalar types this behavior is likely to be unsuitable, so it can be overridden by specifying a custom analysis function. The analysis function must be declared to take a single argument of type `internal`, and return a `boolean` result.

The optional *`subscript_function`* allows the data type to be subscripted in SQL commands. Specifying this function does not cause the type to be considered a “true” array type; for example, it will not be a candidate for the result type of `ARRAY[]` constructs. But if subscripting a value of the type is a natural notation for extracting data from it, then a *`subscript_function`* can be written to define what that means. The subscript function must be declared to take a single argument of type `internal`, and return an `internal` result, which is a pointer to a struct of methods (functions) that implement subscripting. The detailed API for subscript functions appears in *`src/include/nodes/subscripting.h`*. Additional information appears in Array Types below.

While the details of the new type's internal representation are only known to the I/O functions and other functions you create to work with the type, there are several properties of the internal representation that must be declared to Postgres Pro. Foremost of these is *`internallength`*. Base data types can be fixed-length, in which case *`internallength`* is a positive integer, or variable-length, indicated by setting *`internallength`* to `VARIABLE`. (Internally, this is represented by setting `typlen` to -1.) The internal representation of all variable-length types must start with a 4-byte integer giving the total length of this value of the type. (Note that the length field is often encoded, as described in Section 70.2; it's unwise to access it directly.)

The optional flag `PASSEDBYVALUE` indicates that values of this data type are passed by value, rather than by reference. Types passed by value must be fixed-length, and their internal representation cannot be larger than the size of the `Datum` type (4 bytes on some machines, 8 bytes on others).

The *`alignment`* parameter specifies the storage alignment required for the data type. The allowed values equate to alignment on 1, 2, 4, or 8 byte boundaries. Note that variable-length types must have an alignment of at least 4, since they necessarily contain an `int4` as their first component.

The *`storage`* parameter allows selection of storage strategies for variable-length data types. (Only `plain` is allowed for fixed-length types.) `plain` specifies that data of the type will always be stored in-line and not compressed. `extended` specifies that the system will first try to compress a long data value, and will move the value out of the main table row if it's still too long. `external` allows the value to be moved out of the main table, but the system will not try to compress it. `main` allows compression, but discourages moving the value out of the main table. (Data items with this storage strategy might still be moved out of the main table if there is no other way to make a row fit, but they will be kept in the main table preferentially over `extended` and `external` items.)

All *`storage`* values other than `plain` imply that the functions of the data type can handle values that have been *toasted*, as described in Section 70.2 and Section 40.13.1. The specific other value given merely determines the default TOAST storage strategy for columns of a toastable data type; users can pick other strategies for individual columns using `ALTER TABLE SET STORAGE`.

The *`like_type`* parameter provides an alternative method for specifying the basic representation properties of a data type: copy them from some existing type. The values of *`internallength`*, *`passedbyvalue`*, *`alignment`*, and *`storage`* are copied from the named type. (It is possible, though usually undesirable, to override some of these values by specifying them along with the `LIKE` clause.) Specifying representation this way is especially useful when the low-level implementation of the new type “piggybacks” on an existing type in some fashion.

The *`category`* and *`preferred`* parameters can be used to help control which implicit cast will be applied in ambiguous situations. Each data type belongs to a category named by a single ASCII character, and each type is either “preferred” or not within its category. The parser will prefer casting to preferred types (but only from other types within the same category) when this rule is helpful in resolving overloaded functions or operators. For more details see Chapter 10. For types that have no implicit casts to or from any other types, it is sufficient to leave these settings at the defaults. However, for a group of related types that have implicit casts, it is often helpful to mark them all as belonging to a category and select one or two of the “most general” types as being preferred within the category. The *`category`* parameter

is especially useful when adding a user-defined type to an existing built-in category, such as the numeric or string types. However, it is also possible to create new entirely-user-defined type categories. Select any ASCII character other than an upper-case letter to name such a category.

A default value can be specified, in case a user wants columns of the data type to default to something other than the null value. Specify the default with the `DEFAULT` key word. (Such a default can be overridden by an explicit `DEFAULT` clause attached to a particular column.)

To indicate that a type is a fixed-length array type, specify the type of the array elements using the `ELEMENT` key word. For example, to define an array of 4-byte integers (`int4`), specify `ELEMENT = int4`. For more details, see Array Types below.

To indicate the delimiter to be used between values in the external representation of arrays of this type, *`delimiter`* can be set to a specific character. The default delimiter is the comma (`,`). Note that the delimiter is associated with the array element type, not the array type itself.

If the optional Boolean parameter *`collatable`* is true, column definitions and expressions of the type may carry collation information through use of the `COLLATE` clause. It is up to the implementations of the functions operating on the type to actually make use of the collation information; this does not happen automatically merely by marking the type collatable.

Array Types

Whenever a user-defined type is created, Postgres Pro automatically creates an associated array type, whose name consists of the element type's name prepended with an underscore, and truncated if necessary to keep it less than `NAMEDATALEN` bytes long. (If the name so generated collides with an existing type name, the process is repeated until a non-colliding name is found.) This implicitly-created array type is variable length and uses the built-in input and output functions `array_in` and `array_out`. Furthermore, this type is what the system uses for constructs such as `ARRAY[]` over the user-defined type. The array type tracks any changes in its element type's owner or schema, and is dropped if the element type is.

You might reasonably ask why there is an `ELEMENT` option, if the system makes the correct array type automatically. The main case where it's useful to use `ELEMENT` is when you are making a fixed-length type that happens to be internally an array of a number of identical things, and you want to allow these things to be accessed directly by subscripting, in addition to whatever operations you plan to provide for the type as a whole. For example, type `point` is represented as just two floating-point numbers, which can be accessed using `point[0]` and `point[1]`. Note that this facility only works for fixed-length types whose internal form is exactly a sequence of identical fixed-length fields. For historical reasons (i.e., this is clearly wrong but it's far too late to change it), subscripting of fixed-length array types starts from zero, rather than from one as for variable-length arrays.

Specifying the `SUBSCRIPT` option allows a data type to be subscripted, even though the system does not otherwise regard it as an array type. The behavior just described for fixed-length arrays is actually implemented by the `SUBSCRIPT` handler function `raw_array_subscript_handler`, which is used automatically if you specify `ELEMENT` for a fixed-length type without also writing `SUBSCRIPT`.

When specifying a custom `SUBSCRIPT` function, it is not necessary to specify `ELEMENT` unless the `SUBSCRIPT` handler function needs to consult `typelem` to find out what to return. Be aware that specifying `ELEMENT` causes the system to assume that the new type contains, or is somehow physically dependent on, the element type; thus for example changing properties of the element type won't be allowed if there are any columns of the dependent type.

Parameters

`name`

The name (optionally schema-qualified) of a type to be created.

`attribute_name`

The name of an attribute (column) for the composite type.

data_type

The name of an existing data type to become a column of the composite type.

collation

The name of an existing collation to be associated with a column of a composite type, or with a range type.

label

A string literal representing the textual label associated with one value of an enum type.

subtype

The name of the element type that the range type will represent ranges of.

subtype_operator_class

The name of a b-tree operator class for the subtype.

canonical_function

The name of the canonicalization function for the range type.

subtype_diff_function

The name of a difference function for the subtype.

multirange_type_name

The name of the corresponding multirange type.

input_function

The name of a function that converts data from the type's external textual form to its internal form.

output_function

The name of a function that converts data from the type's internal form to its external textual form.

receive_function

The name of a function that converts data from the type's external binary form to its internal form.

send_function

The name of a function that converts data from the type's internal form to its external binary form.

type_modifier_input_function

The name of a function that converts an array of modifier(s) for the type into internal form.

type_modifier_output_function

The name of a function that converts the internal form of the type's modifier(s) to external textual form.

analyze_function

The name of a function that performs statistical analysis for the data type.

subscript_function

The name of a function that defines what subscripting a value of the data type does.

internallength

A numeric constant that specifies the length in bytes of the new type's internal representation. The default assumption is that it is variable-length.

alignment

The storage alignment requirement of the data type. If specified, it must be `char`, `int2`, `int4`, or `double`; the default is `int4`.

storage

The storage strategy for the data type. If specified, must be `plain`, `external`, `extended`, or `main`; the default is `plain`.

like_type

The name of an existing data type that the new type will have the same representation as. The values of *internallength*, *passedbyvalue*, *alignment*, and *storage* are copied from that type, unless overridden by explicit specification elsewhere in this `CREATE TYPE` command.

category

The category code (a single ASCII character) for this type. The default is `'U'` for "user-defined type". Other standard category codes can be found in Table 54.65. You may also choose other ASCII characters in order to create custom categories.

preferred

True if this type is a preferred type within its type category, else false. The default is false. Be very careful about creating a new preferred type within an existing type category, as this could cause surprising changes in behavior.

default

The default value for the data type. If this is omitted, the default is null.

element

The type being created is an array; this specifies the type of the array elements.

delimiter

The delimiter character to be used between values in arrays made of this type.

collatable

True if this type's operations can use collation information. The default is false.

Notes

Because there are no restrictions on use of a data type once it's been created, creating a base type or range type is tantamount to granting public execute permission on the functions mentioned in the type definition. This is usually not an issue for the sorts of functions that are useful in a type definition. But you might want to think twice before designing a type in a way that would require "secret" information to be used while converting it to or from external form.

Before PostgreSQL version 8.3, the name of a generated array type was always exactly the element type's name with one underscore character (_) prepended. (Type names were therefore restricted in length to one fewer character than other names.) While this is still usually the case, the array type name may vary from this in case of maximum-length names or collisions with user type names that begin with underscore. Writing code that depends on this convention is therefore deprecated. Instead, use `pg_type.typarray` to locate the array type associated with a given type.

It may be advisable to avoid using type and table names that begin with underscore. While the server will change generated array type names to avoid collisions with user-given names, there is still risk of confusion, particularly with old client software that may assume that type names beginning with underscores always represent arrays.

Before PostgreSQL version 8.2, the shell-type creation syntax `CREATE TYPE name` did not exist. The way to create a new base type was to create its input function first. In this approach, Postgres Pro will first see the name of the new data type as the return type of the input function. The shell type is implicitly created in this situation, and then it can be referenced in the definitions of the remaining I/O functions. This approach still works, but is deprecated and might be disallowed in some future release. Also, to avoid accidentally cluttering the catalogs with shell types as a result of simple typos in function definitions, a shell type will only be made this way when the input function is written in C.

Examples

This example creates a composite type and uses it in a function definition:

```
CREATE TYPE compfoo AS (f1 int, f2 text);

CREATE FUNCTION getfoo() RETURNS SETOF compfoo AS $$
    SELECT fooid, fooname FROM foo
$$ LANGUAGE SQL;
```

This example creates an enumerated type and uses it in a table definition:

```
CREATE TYPE bug_status AS ENUM ('new', 'open', 'closed');

CREATE TABLE bug (
    id serial,
    description text,
    status bug_status
);
```

This example creates a range type:

```
CREATE TYPE float8_range AS RANGE (subtype = float8, subtype_diff = float8mi);
```

This example creates the base data type `box` and then uses the type in a table definition:

```
CREATE TYPE box;

CREATE FUNCTION my_box_in_function(cstring) RETURNS box AS ... ;
CREATE FUNCTION my_box_out_function(box) RETURNS cstring AS ... ;

CREATE TYPE box (
    INTERNALLENGTH = 16,
    INPUT = my_box_in_function,
    OUTPUT = my_box_out_function
);

CREATE TABLE myboxes (
    id integer,
    description box
);
```

If the internal structure of `box` were an array of four `float4` elements, we might instead use:

```
CREATE TYPE box (
    INTERNALLENGTH = 16,
    INPUT = my_box_in_function,
    OUTPUT = my_box_out_function,
    ELEMENT = float4
);
```

which would allow a box value's component numbers to be accessed by subscripting. Otherwise the type behaves the same as before.

This example creates a large object type and uses it in a table definition:

```
CREATE TYPE bigobj (
    INPUT = lo_filein, OUTPUT = lo_fileout,
    INTERNALLENGTH = VARIABLE
);
CREATE TABLE big_objs (
    id integer,
    obj bigobj
);
```

More examples, including suitable input and output functions, are in Section 40.13.

Compatibility

The first form of the `CREATE TYPE` command, which creates a composite type, conforms to the SQL standard. The other forms are Postgres Pro extensions. The `CREATE TYPE` statement in the SQL standard also defines other forms that are not implemented in Postgres Pro.

The ability to create a composite type with zero attributes is a Postgres Pro-specific deviation from the standard (analogous to the same case in `CREATE TABLE`).

See Also

ALTER TYPE, CREATE DOMAIN, CREATE FUNCTION, DROP TYPE

CREATE USER

CREATE USER — define a new database role

Synopsis

```
CREATE USER name [ [ WITH ] option [ ... ] ]

where option can be:

      SUPERUSER | NOSUPERUSER
    | CREATEDB | NOCREATEDB
    | CREATEROLE | NOCREATEROLE
    | INHERIT | NOINHERIT
    | LOGIN | NOLOGIN
    | REPLICATION | NOREPLICATION
    | BYPASSRLS | NOBYPASSRLS
    | CONNECTION LIMIT connlimit
    | [ ENCRYPTED ] PASSWORD 'password' | PASSWORD NULL
    | VALID UNTIL 'timestamp'
    | IN ROLE role_name [, ...]
    | IN GROUP role_name [, ...]
    | ROLE role_name [, ...]
    | ADMIN role_name [, ...]
    | USER role_name [, ...]
    | SYSID uid
    | PROFILE profile_name
```

Description

`CREATE USER` is now an alias for `CREATE ROLE`. The only difference is that when the command is spelled `CREATE USER`, `LOGIN` is assumed by default, whereas `NOLOGIN` is assumed when the command is spelled `CREATE ROLE`.

Compatibility

The `CREATE USER` statement is a Postgres Pro extension. The SQL standard leaves the definition of users to the implementation.

See Also

CREATE ROLE

CREATE USER MAPPING

CREATE USER MAPPING — define a new mapping of a user to a foreign server

Synopsis

```
CREATE USER MAPPING [ IF NOT EXISTS ] FOR { user_name | USER | CURRENT_ROLE |
 CURRENT_USER | PUBLIC }
    SERVER server_name
    [ OPTIONS ( option 'value' [ , ... ] ) ]
```

Description

`CREATE USER MAPPING` defines a mapping of a user to a foreign server. A user mapping typically encapsulates connection information that a foreign-data wrapper uses together with the information encapsulated by a foreign server to access an external data resource.

The owner of a foreign server can create user mappings for that server for any user. Also, a user can create a user mapping for their own user name if `USAGE` privilege on the server has been granted to the user.

Parameters

`IF NOT EXISTS`

Do not throw an error if a mapping of the given user to the given foreign server already exists. A notice is issued in this case. Note that there is no guarantee that the existing user mapping is anything like the one that would have been created.

`user_name`

The name of an existing user that is mapped to foreign server. `CURRENT_ROLE`, `CURRENT_USER`, and `USER` match the name of the current user. When `PUBLIC` is specified, a so-called public mapping is created that is used when no user-specific mapping is applicable.

`server_name`

The name of an existing server for which the user mapping is to be created.

`OPTIONS ( option 'value' [, ... ] )`

This clause specifies the options of the user mapping. The options typically define the actual user name and password of the mapping. Option names must be unique. The allowed option names and values are specific to the server's foreign-data wrapper.

Examples

Create a user mapping for user `bob`, server `foo`:

```
CREATE USER MAPPING FOR bob SERVER foo OPTIONS (user 'bob', password 'secret');
```

Compatibility

`CREATE USER MAPPING` conforms to ISO/IEC 9075-9 (SQL/MED).

See Also

ALTER USER MAPPING, DROP USER MAPPING, CREATE FOREIGN DATA WRAPPER, CREATE SERVER

CREATE VIEW

CREATE VIEW — define a new view

Synopsis

```
CREATE [ OR REPLACE ] [ TEMP | TEMPORARY ] [ RECURSIVE ] VIEW name [ ( column_name
 [, ...] ) ]
    [ WITH ( view_option_name [= view_option_value] [, ... ] ) ]
    AS query
    [ WITH [ CASCADED | LOCAL ] CHECK OPTION ]
```

Description

`CREATE VIEW` defines a view of a query. The view is not physically materialized. Instead, the query is run every time the view is referenced in a query.

`CREATE OR REPLACE VIEW` is similar, but if a view of the same name already exists, it is replaced. The new query must generate the same columns that were generated by the existing view query (that is, the same column names in the same order and with the same data types), but it may add additional columns to the end of the list. The calculations giving rise to the output columns may be completely different.

If a schema name is given (for example, `CREATE VIEW myschema.myview ...`) then the view is created in the specified schema. Otherwise it is created in the current schema. Temporary views exist in a special schema, so a schema name cannot be given when creating a temporary view. The name of the view must be distinct from the name of any other view, table, sequence, index or foreign table in the same schema.

Parameters

`TEMPORARY` or `TEMP`

If specified, the view is created as a temporary view. Temporary views are automatically dropped at the end of the current session. Existing permanent relations with the same name are not visible to the current session while the temporary view exists, unless they are referenced with schema-qualified names.

If any of the tables referenced by the view are temporary, the view is created as a temporary view (whether `TEMPORARY` is specified or not).

`RECURSIVE`

Creates a recursive view. The syntax

```
CREATE RECURSIVE VIEW [ schema . ] view_name (column_names) AS SELECT ...;
```

is equivalent to

```
CREATE VIEW [ schema . ] view_name AS WITH RECURSIVE view_name (column_names) AS
 (SELECT ...) SELECT column_names FROM view_name;
```

A view column name list must be specified for a recursive view.

`name`

The name (optionally schema-qualified) of a view to be created.

`column_name`

An optional list of names to be used for columns of the view. If not given, the column names are deduced from the query.

`WITH ( view_option_name [= view_option_value] [, ... ] )`

This clause specifies optional parameters for a view; the following parameters are supported:

`check_option` (`enum`)

This parameter may be either `local` or `cascaded`, and is equivalent to specifying `WITH [ CASCADED | LOCAL ] CHECK OPTION` (see below). This option can be changed on existing views using `ALTER VIEW`.

`security_barrier` (`boolean`)

This should be used if the view is intended to provide row-level security. See Section 43.5 for full details.

query

A `SELECT` or `VALUES` command which will provide the columns and rows of the view.

`WITH [ CASCADED | LOCAL ] CHECK OPTION`

This option controls the behavior of automatically updatable views. When this option is specified, `INSERT` and `UPDATE` commands on the view will be checked to ensure that new rows satisfy the view-defining condition (that is, the new rows are checked to ensure that they are visible through the view). If they are not, the update will be rejected. If the `CHECK OPTION` is not specified, `INSERT` and `UPDATE` commands on the view are allowed to create rows that are not visible through the view. The following check options are supported:

`LOCAL`

New rows are only checked against the conditions defined directly in the view itself. Any conditions defined on underlying base views are not checked (unless they also specify the `CHECK OPTION`).

`CASCADED`

New rows are checked against the conditions of the view and all underlying base views. If the `CHECK OPTION` is specified, and neither `LOCAL` nor `CASCADED` is specified, then `CASCADED` is assumed.

The `CHECK OPTION` may not be used with `RECURSIVE` views.

Note that the `CHECK OPTION` is only supported on views that are automatically updatable, and do not have `INSTEAD OF` triggers or `INSTEAD` rules. If an automatically updatable view is defined on top of a base view that has `INSTEAD OF` triggers, then the `LOCAL CHECK OPTION` may be used to check the conditions on the automatically updatable view, but the conditions on the base view with `INSTEAD OF` triggers will not be checked (a cascaded check option will not cascade down to a trigger-updatable view, and any check options defined directly on a trigger-updatable view will be ignored). If the view or any of its base relations has an `INSTEAD` rule that causes the `INSERT` or `UPDATE` command to be rewritten, then all check options will be ignored in the rewritten query, including any checks from automatically updatable views defined on top of the relation with the `INSTEAD` rule.

Notes

Use the `DROP VIEW` statement to drop views.

Be careful that the names and types of the view's columns will be assigned the way you want. For example:

```
CREATE VIEW vista AS SELECT 'Hello World';
```

is bad form because the column name defaults to `?column?`; also, the column data type defaults to `text`, which might not be what you wanted. Better style for a string literal in a view's result is something like:

```
CREATE VIEW vista AS SELECT text 'Hello World' AS hello;
```

Access to tables referenced in the view is determined by permissions of the view owner. In some cases, this can be used to provide secure but restricted access to the underlying tables. However, not all views

are secure against tampering; see Section 43.5 for details. Functions called in the view are treated the same as if they had been called directly from the query using the view. Therefore the user of a view must have permissions to call all functions used by the view.

When CREATE OR REPLACE VIEW is used on an existing view, only the view's defining SELECT rule is changed. Other view properties, including ownership, permissions, and non-SELECT rules, remain unchanged. You must own the view to replace it (this includes being a member of the owning role).

Updatable Views

Simple views are automatically updatable: the system will allow INSERT, UPDATE and DELETE statements to be used on the view in the same way as on a regular table. A view is automatically updatable if it satisfies all of the following conditions:

- The view must have exactly one entry in its FROM list, which must be a table or another updatable view.
- The view definition must not contain WITH, DISTINCT, GROUP BY, HAVING, LIMIT, or OFFSET clauses at the top level.
- The view definition must not contain set operations (UNION, INTERSECT or EXCEPT) at the top level.
- The view's select list must not contain any aggregates, window functions or set-returning functions.

An automatically updatable view may contain a mix of updatable and non-updatable columns. A column is updatable if it is a simple reference to an updatable column of the underlying base relation; otherwise the column is read-only, and an error will be raised if an INSERT or UPDATE statement attempts to assign a value to it.

If the view is automatically updatable the system will convert any INSERT, UPDATE or DELETE statement on the view into the corresponding statement on the underlying base relation. INSERT statements that have an ON CONFLICT UPDATE clause are fully supported.

If an automatically updatable view contains a WHERE condition, the condition restricts which rows of the base relation are available to be modified by UPDATE and DELETE statements on the view. However, an UPDATE is allowed to change a row so that it no longer satisfies the WHERE condition, and thus is no longer visible through the view. Similarly, an INSERT command can potentially insert base-relation rows that do not satisfy the WHERE condition and thus are not visible through the view (ON CONFLICT UPDATE may similarly affect an existing row not visible through the view). The CHECK OPTION may be used to prevent INSERT and UPDATE commands from creating such rows that are not visible through the view.

If an automatically updatable view is marked with the security_barrier property then all the view's WHERE conditions (and any conditions using operators which are marked as LEAKPROOF) will always be evaluated before any conditions that a user of the view has added. See Section 43.5 for full details. Note that, due to this, rows which are not ultimately returned (because they do not pass the user's WHERE conditions) may still end up being locked. EXPLAIN can be used to see which conditions are applied at the relation level (and therefore do not lock rows) and which are not.

A more complex view that does not satisfy all these conditions is read-only by default: the system will not allow an insert, update, or delete on the view. You can get the effect of an updatable view by creating INSTEAD OF triggers on the view, which must convert attempted inserts, etc. on the view into appropriate actions on other tables. For more information see CREATE TRIGGER. Another possibility is to create rules (see CREATE RULE), but in practice triggers are easier to understand and use correctly.

Note that the user performing the insert, update or delete on the view must have the corresponding insert, update or delete privilege on the view. In addition the view's owner must have the relevant privileges on the underlying base relations, but the user performing the update does not need any permissions on the underlying base relations (see Section 43.5).

Examples

Create a view consisting of all comedy films:

```
CREATE VIEW comedies AS
    SELECT *
    FROM films
    WHERE kind = 'Comedy';
```

This will create a view containing the columns that are in the `film` table at the time of view creation. Though `*` was used to create the view, columns added later to the table will not be part of the view.

Create a view with `LOCAL CHECK OPTION`:

```
CREATE VIEW universal_comedies AS
    SELECT *
    FROM comedies
    WHERE classification = 'U'
    WITH LOCAL CHECK OPTION;
```

This will create a view based on the `comedies` view, showing only films with `kind = 'Comedy'` and `classification = 'U'`. Any attempt to `INSERT` or `UPDATE` a row in the view will be rejected if the new row doesn't have `classification = 'U'`, but the film `kind` will not be checked.

Create a view with `CASCADED CHECK OPTION`:

```
CREATE VIEW pg_comedies AS
    SELECT *
    FROM comedies
    WHERE classification = 'PG'
    WITH CASCADED CHECK OPTION;
```

This will create a view that checks both the `kind` and `classification` of new rows.

Create a view with a mix of updatable and non-updatable columns:

```
CREATE VIEW comedies AS
    SELECT f.*,
           country_code_to_name(f.country_code) AS country,
           (SELECT avg(r.rating)
            FROM user_ratings r
            WHERE r.film_id = f.id) AS avg_rating
    FROM films f
    WHERE f.kind = 'Comedy';
```

This view will support `INSERT`, `UPDATE` and `DELETE`. All the columns from the `films` table will be updatable, whereas the computed columns `country` and `avg_rating` will be read-only.

Create a recursive view consisting of the numbers from 1 to 100:

```
CREATE RECURSIVE VIEW public.nums_1_100 (n) AS
    VALUES (1)
UNION ALL
    SELECT n+1 FROM nums_1_100 WHERE n < 100;
```

Notice that although the recursive view's name is schema-qualified in this `CREATE`, its internal self-reference is not schema-qualified. This is because the implicitly-created CTE's name cannot be schema-qualified.

Compatibility

`CREATE OR REPLACE VIEW` is a Postgres Pro language extension. So is the concept of a temporary view. The `WITH ( ... )` clause is an extension as well.

See Also

ALTER VIEW, DROP VIEW, CREATE MATERIALIZED VIEW

DEALLOCATE

DEALLOCATE — deallocate a prepared statement

Synopsis

```
DEALLOCATE [ PREPARE ] { name | ALL }
```

Description

`DEALLOCATE` is used to deallocate a previously prepared SQL statement. If you do not explicitly deallocate a prepared statement, it is deallocated when the session ends.

For more information on prepared statements, see PREPARE.

Parameters

`PREPARE`

This key word is ignored.

`name`

The name of the prepared statement to deallocate.

`ALL`

Deallocate all prepared statements.

Compatibility

The SQL standard includes a `DEALLOCATE` statement, but it is only for use in embedded SQL.

See Also

EXECUTE, PREPARE

DECLARE

DECLARE — define a cursor

Synopsis

```
DECLARE name [ BINARY ] [ ASENSITIVE | INSENSITIVE ] [ [ NO ] SCROLL ]
    CURSOR [ { WITH | WITHOUT } HOLD ] FOR query
```

Description

`DECLARE` allows a user to create cursors, which can be used to retrieve a small number of rows at a time out of a larger query. After the cursor is created, rows are fetched from it using `FETCH`.

> **Note**
>
> This page describes usage of cursors at the SQL command level. If you are trying to use cursors inside a PL/pgSQL function, the rules are different — see Section 45.7.

Parameters

name

The name of the cursor to be created.

`BINARY`

Causes the cursor to return data in binary rather than in text format.

`ASENSITIVE`
`INSENSITIVE`

Cursor sensitivity determines whether changes to the data underlying the cursor, done in the same transaction, after the cursor has been declared, are visible in the cursor. `INSENSITIVE` means they are not visible, `ASENSITIVE` means the behavior is implementation-dependent. A third behavior, `SENSITIVE`, meaning that such changes are visible in the cursor, is not available in PostgreSQL. In PostgreSQL, all cursors are insensitive; so these key words have no effect and are only accepted for compatibility with the SQL standard.

Specifying `INSENSITIVE` together with `FOR UPDATE` or `FOR SHARE` is an error.

`SCROLL`
`NO SCROLL`

`SCROLL` specifies that the cursor can be used to retrieve rows in a nonsequential fashion (e.g., backward). Depending upon the complexity of the query's execution plan, specifying `SCROLL` might impose a performance penalty on the query's execution time. `NO SCROLL` specifies that the cursor cannot be used to retrieve rows in a nonsequential fashion. The default is to allow scrolling in some cases; this is not the same as specifying `SCROLL`. See Notes below for details.

`WITH HOLD`
`WITHOUT HOLD`

`WITH HOLD` specifies that the cursor can continue to be used after the transaction that created it successfully commits. `WITHOUT HOLD` specifies that the cursor cannot be used outside of the transaction that created it. If neither `WITHOUT HOLD` nor `WITH HOLD` is specified, `WITHOUT HOLD` is the default.

query

A `SELECT` or `VALUES` command which will provide the rows to be returned by the cursor.

The key words ASENSITIVE, BINARY, INSENSITIVE, and SCROLL can appear in any order.

Notes

Normal cursors return data in text format, the same as a SELECT would produce. The BINARY option specifies that the cursor should return data in binary format. This reduces conversion effort for both the server and client, at the cost of more programmer effort to deal with platform-dependent binary data formats. As an example, if a query returns a value of one from an integer column, you would get a string of 1 with a default cursor, whereas with a binary cursor you would get a 4-byte field containing the internal representation of the value (in big-endian byte order).

Binary cursors should be used carefully. Many applications, including psql, are not prepared to handle binary cursors and expect data to come back in the text format.

Note

When the client application uses the "extended query" protocol to issue a FETCH command, the Bind protocol message specifies whether data is to be retrieved in text or binary format. This choice overrides the way that the cursor is defined. The concept of a binary cursor as such is thus obsolete when using extended query protocol — any cursor can be treated as either text or binary.

Unless WITH HOLD is specified, the cursor created by this command can only be used within the current transaction. Thus, DECLARE without WITH HOLD is useless outside a transaction block: the cursor would survive only to the completion of the statement. Therefore Postgres Pro reports an error if such a command is used outside a transaction block. Use BEGIN and COMMIT (or ROLLBACK) to define a transaction block.

If WITH HOLD is specified and the transaction that created the cursor successfully commits, the cursor can continue to be accessed by subsequent transactions in the same session. (But if the creating transaction is aborted, the cursor is removed.) A cursor created with WITH HOLD is closed when an explicit CLOSE command is issued on it, or the session ends. In the current implementation, the rows represented by a held cursor are copied into a temporary file or memory area so that they remain available for subsequent transactions.

WITH HOLD may not be specified when the query includes FOR UPDATE or FOR SHARE.

The SCROLL option should be specified when defining a cursor that will be used to fetch backwards. This is required by the SQL standard. However, for compatibility with earlier versions, Postgres Pro will allow backward fetches without SCROLL, if the cursor's query plan is simple enough that no extra overhead is needed to support it. However, application developers are advised not to rely on using backward fetches from a cursor that has not been created with SCROLL. If NO SCROLL is specified, then backward fetches are disallowed in any case.

Backward fetches are also disallowed when the query includes FOR UPDATE or FOR SHARE; therefore SCROLL may not be specified in this case.

Caution

Scrollable cursors may give unexpected results if they invoke any volatile functions (see Section 40.7). When a previously fetched row is re-fetched, the functions might be re-executed, perhaps leading to results different from the first time. It's best to specify NO SCROLL for a query involving volatile functions. If that is not practical, one workaround is to declare the cursor SCROLL WITH HOLD and commit the transaction before reading any rows from it. This will force the entire output of the cursor to be materialized in temporary storage, so that volatile functions are executed exactly once for each row.

If the cursor's query includes FOR UPDATE or FOR SHARE, then returned rows are locked at the time they are first fetched, in the same way as for a regular SELECT command with these options. In addition, the returned rows will be the most up-to-date versions.

> **Caution**
>
> It is generally recommended to use FOR UPDATE if the cursor is intended to be used with UPDATE ... WHERE CURRENT OF or DELETE ... WHERE CURRENT OF. Using FOR UPDATE prevents other sessions from changing the rows between the time they are fetched and the time they are updated. Without FOR UPDATE, a subsequent WHERE CURRENT OF command will have no effect if the row was changed since the cursor was created.
>
> Another reason to use FOR UPDATE is that without it, a subsequent WHERE CURRENT OF might fail if the cursor query does not meet the SQL standard's rules for being “simply updatable” (in particular, the cursor must reference just one table and not use grouping or ORDER BY). Cursors that are not simply updatable might work, or might not, depending on plan choice details; so in the worst case, an application might work in testing and then fail in production. If FOR UPDATE is specified, the cursor is guaranteed to be updatable.
>
> The main reason not to use FOR UPDATE with WHERE CURRENT OF is if you need the cursor to be scrollable, or to be isolated from concurrent updates (that is, continue to show the old data). If this is a requirement, pay close heed to the caveats shown above.

The SQL standard only makes provisions for cursors in embedded SQL. The Postgres Pro server does not implement an OPEN statement for cursors; a cursor is considered to be open when it is declared. However, ECPG, the embedded SQL preprocessor for Postgres Pro, supports the standard SQL cursor conventions, including those involving DECLARE and OPEN statements.

You can see all available cursors by querying the pg_cursors system view.

Examples

To declare a cursor:

```
DECLARE liahona CURSOR FOR SELECT * FROM films;
```

See FETCH for more examples of cursor usage.

Compatibility

The SQL standard allows cursors only in embedded SQL and in modules. Postgres Pro permits cursors to be used interactively.

According to the SQL standard, changes made to insensitive cursors by UPDATE ... WHERE CURRENT OF and DELETE ... WHERE CURRENT OF statements are visible in that same cursor. PostgreSQL treats these statements like all other data changing statements in that they are not visible in insensitive cursors.

Binary cursors are a Postgres Pro extension.

See Also

CLOSE, FETCH, MOVE

DELETE

DELETE — delete rows of a table

Synopsis

```
[ WITH [ RECURSIVE ] with_query [, ...] ]
DELETE FROM [ ONLY ] table_name [ * ] [ [ AS ] alias ]
    [ USING from_item [, ...] ]
    [ WHERE condition | WHERE CURRENT OF cursor_name ]
    [ RETURNING { * | output_expression [ [ AS ] output_name ] } [, ...] ]
```

Description

`DELETE` deletes rows that satisfy the `WHERE` clause from the specified table. If the `WHERE` clause is absent, the effect is to delete all rows in the table. The result is a valid, but empty table.

> **Tip**
>
> `TRUNCATE` provides a faster mechanism to remove all rows from a table.

There are two ways to delete rows in a table using information contained in other tables in the database: using sub-selects, or specifying additional tables in the `USING` clause. Which technique is more appropriate depends on the specific circumstances.

The optional `RETURNING` clause causes `DELETE` to compute and return value(s) based on each row actually deleted. Any expression using the table's columns, and/or columns of other tables mentioned in `USING`, can be computed. The syntax of the `RETURNING` list is identical to that of the output list of `SELECT`.

You must have the `DELETE` privilege on the table to delete from it, as well as the `SELECT` privilege for any table in the `USING` clause or whose values are read in the *`condition`*.

Parameters

`with_query`

The `WITH` clause allows you to specify one or more subqueries that can be referenced by name in the `DELETE` query. See Section 7.8 and SELECT for details.

`table_name`

The name (optionally schema-qualified) of the table to delete rows from. If `ONLY` is specified before the table name, matching rows are deleted from the named table only. If `ONLY` is not specified, matching rows are also deleted from any tables inheriting from the named table. Optionally, `*` can be specified after the table name to explicitly indicate that descendant tables are included.

`alias`

A substitute name for the target table. When an alias is provided, it completely hides the actual name of the table. For example, given `DELETE FROM foo AS f`, the remainder of the `DELETE` statement must refer to this table as `f` not `foo`.

`from_item`

A table expression allowing columns from other tables to appear in the `WHERE` condition. This uses the same syntax as the `FROM` clause of a `SELECT` statement; for example, an alias for the table name can be specified. Do not repeat the target table as a *`from_item`* unless you wish to set up a self-join (in which case it must appear with an alias in the *`from_item`*).

condition

An expression that returns a value of type `boolean`. Only rows for which this expression returns `true` will be deleted.

cursor_name

The name of the cursor to use in a `WHERE CURRENT OF` condition. The row to be deleted is the one most recently fetched from this cursor. The cursor must be a non-grouping query on the `DELETE`'s target table. Note that `WHERE CURRENT OF` cannot be specified together with a Boolean condition. See DECLARE for more information about using cursors with `WHERE CURRENT OF`.

output_expression

An expression to be computed and returned by the `DELETE` command after each row is deleted. The expression can use any column names of the table named by *table_name* or table(s) listed in `USING`. Write `*` to return all columns.

output_name

A name to use for a returned column.

Outputs

On successful completion, a `DELETE` command returns a command tag of the form

```
DELETE count
```

The *count* is the number of rows deleted. Note that the number may be less than the number of rows that matched the *condition* when deletes were suppressed by a `BEFORE DELETE` trigger. If *count* is 0, no rows were deleted by the query (this is not considered an error).

If the `DELETE` command contains a `RETURNING` clause, the result will be similar to that of a `SELECT` statement containing the columns and values defined in the `RETURNING` list, computed over the row(s) deleted by the command.

Notes

Postgres Pro lets you reference columns of other tables in the `WHERE` condition by specifying the other tables in the `USING` clause. For example, to delete all films produced by a given producer, one can do:

```
DELETE FROM films USING producers
  WHERE producer_id = producers.id AND producers.name = 'foo';
```

What is essentially happening here is a join between `films` and `producers`, with all successfully joined `films` rows being marked for deletion. This syntax is not standard. A more standard way to do it is:

```
DELETE FROM films
  WHERE producer_id IN (SELECT id FROM producers WHERE name = 'foo');
```

In some cases the join style is easier to write or faster to execute than the sub-select style.

Examples

Delete all films but musicals:

```
DELETE FROM films WHERE kind <> 'Musical';
```

Clear the table `films`:

```
DELETE FROM films;
```

Delete completed tasks, returning full details of the deleted rows:

```
DELETE FROM tasks WHERE status = 'DONE' RETURNING *;
```

Delete the row of `tasks` on which the cursor `c_tasks` is currently positioned:

```
DELETE FROM tasks WHERE CURRENT OF c_tasks;
```

Compatibility

This command conforms to the SQL standard, except that the `USING` and `RETURNING` clauses are Postgres Pro extensions, as is the ability to use `WITH` with `DELETE`.

See Also

TRUNCATE

DISCARD

DISCARD — discard session state

Synopsis

```
DISCARD { ALL | PLANS | SEQUENCES | TEMPORARY | TEMP }
```

Description

`DISCARD` releases internal resources associated with a database session. This command is useful for partially or fully resetting the session's state. There are several subcommands to release different types of resources; the `DISCARD ALL` variant subsumes all the others, and also resets additional state.

Parameters

`PLANS`

Releases all cached query plans, forcing re-planning to occur the next time the associated prepared statement is used.

`SEQUENCES`

Discards all cached sequence-related state, including `currval()`/`lastval()` information and any preallocated sequence values that have not yet been returned by `nextval()`. (See CREATE SEQUENCE for a description of preallocated sequence values.)

`TEMPORARY` or `TEMP`

Drops all temporary tables created in the current session.

`ALL`

Releases all temporary resources associated with the current session and resets the session to its initial state. Currently, this has the same effect as executing the following sequence of statements:

```
CLOSE ALL;
SET SESSION AUTHORIZATION DEFAULT;
RESET ALL;
DEALLOCATE ALL;
UNLISTEN *;
SELECT pg_advisory_unlock_all();
DISCARD PLANS;
DISCARD TEMP;
DISCARD SEQUENCES;
```

Notes

`DISCARD ALL` cannot be executed inside a transaction block.

Compatibility

`DISCARD` is a Postgres Pro extension.

DO

DO — execute an anonymous code block

Synopsis

```
DO [ LANGUAGE lang_name ] code
```

Description

`DO` executes an anonymous code block, or in other words a transient anonymous function in a procedural language.

The code block is treated as though it were the body of a function with no parameters, returning `void`. It is parsed and executed a single time.

The optional `LANGUAGE` clause can be written either before or after the code block.

Parameters

code

The procedural language code to be executed. This must be specified as a string literal, just as in `CREATE FUNCTION`. Use of a dollar-quoted literal is recommended.

lang_name

The name of the procedural language the code is written in. If omitted, the default is `plpgsql`.

Notes

The procedural language to be used must already have been installed into the current database by means of `CREATE EXTENSION`. `plpgsql` is installed by default, but other languages are not.

The user must have `USAGE` privilege for the procedural language, or must be a superuser if the language is untrusted. This is the same privilege requirement as for creating a function in the language.

If `DO` is executed in a transaction block, then the procedure code cannot execute transaction control statements. Transaction control statements are only allowed if `DO` is executed in its own transaction.

Examples

Grant all privileges on all views in schema `public` to role `webuser`:

```
DO $$DECLARE r record;
BEGIN
    FOR r IN SELECT table_schema, table_name FROM information_schema.tables
             WHERE table_type = 'VIEW' AND table_schema = 'public'
    LOOP
        EXECUTE 'GRANT ALL ON ' || quote_ident(r.table_schema) || '.' ||
 quote_ident(r.table_name) || ' TO webuser';
    END LOOP;
END$$;
```

Compatibility

There is no `DO` statement in the SQL standard.

See Also

CREATE LANGUAGE

DROP ACCESS METHOD

DROP ACCESS METHOD — remove an access method

Synopsis

```
DROP ACCESS METHOD [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP ACCESS METHOD` removes an existing access method. Only superusers can drop access methods.

Parameters

`IF EXISTS`

Do not throw an error if the access method does not exist. A notice is issued in this case.

name

The name of an existing access method.

`CASCADE`

Automatically drop objects that depend on the access method (such as operator classes, operator families, and indexes), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the access method if any objects depend on it. This is the default.

Examples

Drop the access method `heptree`:

```
DROP ACCESS METHOD heptree;
```

Compatibility

`DROP ACCESS METHOD` is a Postgres Pro extension.

See Also

CREATE ACCESS METHOD

DROP AGGREGATE

DROP AGGREGATE — remove an aggregate function

Synopsis

```
DROP AGGREGATE [ IF EXISTS ] name ( aggregate_signature ) [, ...] [ CASCADE |
 RESTRICT ]

where aggregate_signature is:

* |
[ argmode ] [ argname ] argtype [ , ... ] |
[ [ argmode ] [ argname ] argtype [ , ... ] ] ORDER BY [ argmode ] [ argname ] argtype
 [ , ... ]
```

Description

`DROP AGGREGATE` removes an existing aggregate function. To execute this command the current user must be the owner of the aggregate function.

Parameters

`IF EXISTS`

Do not throw an error if the aggregate does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an existing aggregate function.

argmode

The mode of an argument: `IN` or `VARIADIC`. If omitted, the default is `IN`.

argname

The name of an argument. Note that `DROP AGGREGATE` does not actually pay any attention to argument names, since only the argument data types are needed to determine the aggregate function's identity.

argtype

An input data type on which the aggregate function operates. To reference a zero-argument aggregate function, write `*` in place of the list of argument specifications. To reference an ordered-set aggregate function, write `ORDER BY` between the direct and aggregated argument specifications.

`CASCADE`

Automatically drop objects that depend on the aggregate function (such as views using it), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the aggregate function if any objects depend on it. This is the default.

Notes

Alternative syntaxes for referencing ordered-set aggregates are described under ALTER AGGREGATE.

Examples

To remove the aggregate function `myavg` for type `integer`:

```
DROP AGGREGATE myavg(integer);
```

To remove the hypothetical-set aggregate function `myrank`, which takes an arbitrary list of ordering columns and a matching list of direct arguments:

```
DROP AGGREGATE myrank(VARIADIC "any" ORDER BY VARIADIC "any");
```

To remove multiple aggregate functions in one command:

```
DROP AGGREGATE myavg(integer), myavg(bigint);
```

Compatibility

There is no `DROP AGGREGATE` statement in the SQL standard.

See Also

ALTER AGGREGATE, CREATE AGGREGATE

DROP CAST

DROP CAST — remove a cast

Synopsis

```
DROP CAST [ IF EXISTS ] (source_type AS target_type) [ CASCADE | RESTRICT ]
```

Description

`DROP CAST` removes a previously defined cast.

To be able to drop a cast, you must own the source or the target data type. These are the same privileges that are required to create a cast.

Parameters

`IF EXISTS`

Do not throw an error if the cast does not exist. A notice is issued in this case.

`source_type`

The name of the source data type of the cast.

`target_type`

The name of the target data type of the cast.

`CASCADE`
`RESTRICT`

These key words do not have any effect, since there are no dependencies on casts.

Examples

To drop the cast from type `text` to type `int`:

```
DROP CAST (text AS int);
```

Compatibility

The `DROP CAST` command conforms to the SQL standard.

See Also

CREATE CAST

DROP COLLATION

DROP COLLATION — remove a collation

Synopsis

```
DROP COLLATION [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP COLLATION` removes a previously defined collation. To be able to drop a collation, you must own the collation.

Parameters

`IF EXISTS`

Do not throw an error if the collation does not exist. A notice is issued in this case.

name

The name of the collation. The collation name can be schema-qualified.

`CASCADE`

Automatically drop objects that depend on the collation, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the collation if any objects depend on it. This is the default.

Examples

To drop the collation named `german`:

```
DROP COLLATION german;
```

Compatibility

The `DROP COLLATION` command conforms to the SQL standard, apart from the `IF EXISTS` option, which is a Postgres Pro extension.

See Also

ALTER COLLATION, CREATE COLLATION

DROP CONVERSION

DROP CONVERSION — remove a conversion

Synopsis

```
DROP CONVERSION [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP CONVERSION` removes a previously defined conversion. To be able to drop a conversion, you must own the conversion.

Parameters

`IF EXISTS`

Do not throw an error if the conversion does not exist. A notice is issued in this case.

name

The name of the conversion. The conversion name can be schema-qualified.

`CASCADE`
`RESTRICT`

These key words do not have any effect, since there are no dependencies on conversions.

Examples

To drop the conversion named `myname`:

```
DROP CONVERSION myname;
```

Compatibility

There is no `DROP CONVERSION` statement in the SQL standard, but a `DROP TRANSLATION` statement that goes along with the `CREATE TRANSLATION` statement that is similar to the `CREATE CONVERSION` statement in Postgres Pro.

See Also

ALTER CONVERSION, CREATE CONVERSION

DROP DATABASE

DROP DATABASE — remove a database

Synopsis

```
DROP DATABASE [ IF EXISTS ] name [ [ WITH ] ( option [, ...] ) ]

where option can be:

    FORCE
```

Description

`DROP DATABASE` drops a database. It removes the catalog entries for the database and deletes the directory containing the data. It can only be executed by the database owner. It cannot be executed while you are connected to the target database. (Connect to `postgres` or any other database to issue this command.) Also, if anyone else is connected to the target database, this command will fail unless you use the `FORCE` option described below.

`DROP DATABASE` cannot be undone. Use it with care!

Parameters

`IF EXISTS`

Do not throw an error if the database does not exist. A notice is issued in this case.

name

The name of the database to remove.

`FORCE`

Attempt to terminate all existing connections to the target database. It doesn't terminate if prepared transactions, active logical replication slots or subscriptions are present in the target database.

This terminates background worker connections and connections that the current user has permission to terminate with `pg_terminate_backend`, described in Section 9.27.2. If connections would remain, this command will fail.

Notes

`DROP DATABASE` cannot be executed inside a transaction block.

This command cannot be executed while connected to the target database. Thus, it might be more convenient to use the program dropdb instead, which is a wrapper around this command.

Compatibility

There is no `DROP DATABASE` statement in the SQL standard.

See Also

CREATE DATABASE

DROP DOMAIN

DROP DOMAIN — remove a domain

Synopsis

```
DROP DOMAIN [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP DOMAIN` removes a domain. Only the owner of a domain can remove it.

Parameters

`IF EXISTS`

Do not throw an error if the domain does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an existing domain.

`CASCADE`

Automatically drop objects that depend on the domain (such as table columns), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the domain if any objects depend on it. This is the default.

Examples

To remove the domain `box`:

```
DROP DOMAIN box;
```

Compatibility

This command conforms to the SQL standard, except for the `IF EXISTS` option, which is a Postgres Pro extension.

See Also

CREATE DOMAIN, ALTER DOMAIN

DROP EVENT TRIGGER

DROP EVENT TRIGGER — remove an event trigger

Synopsis

```
DROP EVENT TRIGGER [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP EVENT TRIGGER` removes an existing event trigger. To execute this command, the current user must be the owner of the event trigger.

Parameters

`IF EXISTS`

Do not throw an error if the event trigger does not exist. A notice is issued in this case.

name

The name of the event trigger to remove.

`CASCADE`

Automatically drop objects that depend on the trigger, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the trigger if any objects depend on it. This is the default.

Examples

Destroy the trigger `snitch`:

```
DROP EVENT TRIGGER snitch;
```

Compatibility

There is no `DROP EVENT TRIGGER` statement in the SQL standard.

See Also

CREATE EVENT TRIGGER, ALTER EVENT TRIGGER

DROP EXTENSION

DROP EXTENSION — remove an extension

Synopsis

```
DROP EXTENSION [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP EXTENSION` removes extensions from the database. Dropping an extension causes its member objects, and other explicitly dependent routines (see ALTER ROUTINE, the `DEPENDS ON EXTENSION` *extension_name* action), to be dropped as well.

You must own the extension to use `DROP EXTENSION`.

Parameters

`IF EXISTS`

Do not throw an error if the extension does not exist. A notice is issued in this case.

name

The name of an installed extension.

`CASCADE`

Automatically drop objects that depend on the extension, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

This option prevents the specified extensions from being dropped if other objects, besides these extensions, their members, and their explicitly dependent routines, depend on them. This is the default.

Examples

To remove the extension `hstore` from the current database:

```
DROP EXTENSION hstore;
```

This command will fail if any of `hstore`'s objects are in use in the database, for example if any tables have columns of the `hstore` type. Add the `CASCADE` option to forcibly remove those dependent objects as well.

Compatibility

`DROP EXTENSION` is a Postgres Pro extension.

See Also

CREATE EXTENSION, ALTER EXTENSION

DROP FOREIGN DATA WRAPPER

DROP FOREIGN DATA WRAPPER — remove a foreign-data wrapper

Synopsis

```
DROP FOREIGN DATA WRAPPER [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP FOREIGN DATA WRAPPER` removes an existing foreign-data wrapper. To execute this command, the current user must be the owner of the foreign-data wrapper.

Parameters

`IF EXISTS`

Do not throw an error if the foreign-data wrapper does not exist. A notice is issued in this case.

name

The name of an existing foreign-data wrapper.

`CASCADE`

Automatically drop objects that depend on the foreign-data wrapper (such as foreign tables and servers), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the foreign-data wrapper if any objects depend on it. This is the default.

Examples

Drop the foreign-data wrapper `dbi`:

```
DROP FOREIGN DATA WRAPPER dbi;
```

Compatibility

`DROP FOREIGN DATA WRAPPER` conforms to ISO/IEC 9075-9 (SQL/MED). The `IF EXISTS` clause is a Postgres Pro extension.

See Also

CREATE FOREIGN DATA WRAPPER, ALTER FOREIGN DATA WRAPPER

DROP FOREIGN TABLE

DROP FOREIGN TABLE — remove a foreign table

Synopsis

```
DROP FOREIGN TABLE [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP FOREIGN TABLE` removes a foreign table. Only the owner of a foreign table can remove it.

Parameters

`IF EXISTS`

Do not throw an error if the foreign table does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of the foreign table to drop.

`CASCADE`

Automatically drop objects that depend on the foreign table (such as views), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the foreign table if any objects depend on it. This is the default.

Examples

To destroy two foreign tables, `films` and `distributors`:

```
DROP FOREIGN TABLE films, distributors;
```

Compatibility

This command conforms to ISO/IEC 9075-9 (SQL/MED), except that the standard only allows one foreign table to be dropped per command, and apart from the `IF EXISTS` option, which is a Postgres Pro extension.

See Also

ALTER FOREIGN TABLE, CREATE FOREIGN TABLE

DROP FUNCTION

DROP FUNCTION — remove a function

Synopsis

```
DROP FUNCTION [ IF EXISTS ] name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
  [, ...]
    [ CASCADE | RESTRICT ]
```

Description

`DROP FUNCTION` removes the definition of an existing function. To execute this command the user must be the owner of the function. The argument types to the function must be specified, since several different functions can exist with the same name and different argument lists.

Parameters

`IF EXISTS`

Do not throw an error if the function does not exist. A notice is issued in this case.

`name`

The name (optionally schema-qualified) of an existing function. If no argument list is specified, the name must be unique in its schema.

`argmode`

The mode of an argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN`. Note that `DROP FUNCTION` does not actually pay any attention to `OUT` arguments, since only the input arguments are needed to determine the function's identity. So it is sufficient to list the `IN`, `INOUT`, and `VARIADIC` arguments.

`argname`

The name of an argument. Note that `DROP FUNCTION` does not actually pay any attention to argument names, since only the argument data types are needed to determine the function's identity.

`argtype`

The data type(s) of the function's arguments (optionally schema-qualified), if any.

`CASCADE`

Automatically drop objects that depend on the function (such as operators or triggers), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the function if any objects depend on it. This is the default.

Examples

This command removes the square root function:

```
DROP FUNCTION sqrt(integer);
```

Drop multiple functions in one command:

```
DROP FUNCTION sqrt(integer), sqrt(bigint);
```

If the function name is unique in its schema, it can be referred to without an argument list:

```
DROP FUNCTION update_employee_salaries;
```

Note that this is different from

```
DROP FUNCTION update_employee_salaries();
```

which refers to a function with zero arguments, whereas the first variant can refer to a function with any number of arguments, including zero, as long as the name is unique.

Compatibility

This command conforms to the SQL standard, with these Postgres Pro extensions:

- The standard only allows one function to be dropped per command.
- The `IF EXISTS` option
- The ability to specify argument modes and names

See Also

CREATE FUNCTION, ALTER FUNCTION, DROP PROCEDURE, DROP ROUTINE

DROP GROUP

DROP GROUP — remove a database role

Synopsis

```
DROP GROUP [ IF EXISTS ] name [, ...]
```

Description

`DROP GROUP` is now an alias for `DROP ROLE`.

Compatibility

There is no `DROP GROUP` statement in the SQL standard.

See Also

DROP ROLE

DROP INDEX

DROP INDEX — remove an index

Synopsis

```
DROP INDEX [ CONCURRENTLY ] [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP INDEX` drops an existing index from the database system. To execute this command you must be the owner of the index.

Parameters

`CONCURRENTLY`

Drop the index without locking out concurrent selects, inserts, updates, and deletes on the index's table. A normal `DROP INDEX` acquires an `ACCESS EXCLUSIVE` lock on the table, blocking other accesses until the index drop can be completed. With this option, the command instead waits until conflicting transactions have completed.

There are several caveats to be aware of when using this option. Only one index name can be specified, and the `CASCADE` option is not supported. (Thus, an index that supports a `UNIQUE` or `PRIMARY KEY` constraint cannot be dropped this way.) Also, regular `DROP INDEX` commands can be performed within a transaction block, but `DROP INDEX CONCURRENTLY` cannot. Lastly, indexes on partitioned tables cannot be dropped using this option.

For temporary tables, `DROP INDEX` is always non-concurrent, as no other session can access them, and non-concurrent index drop is cheaper.

`IF EXISTS`

Do not throw an error if the index does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an index to remove.

`CASCADE`

Automatically drop objects that depend on the index, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the index if any objects depend on it. This is the default.

Examples

This command will remove the index `title_idx`:

```
DROP INDEX title_idx;
```

Compatibility

`DROP INDEX` is a Postgres Pro language extension. There are no provisions for indexes in the SQL standard.

See Also

CREATE INDEX

DROP LANGUAGE

DROP LANGUAGE — remove a procedural language

Synopsis

```
DROP [ PROCEDURAL ] LANGUAGE [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP LANGUAGE` removes the definition of a previously registered procedural language. You must be a superuser or the owner of the language to use `DROP LANGUAGE`.

> **Note**
>
> As of PostgreSQL 9.1, most procedural languages have been made into "extensions", and should therefore be removed with `DROP EXTENSION` not `DROP LANGUAGE`.

Parameters

`IF EXISTS`

Do not throw an error if the language does not exist. A notice is issued in this case.

name

The name of an existing procedural language.

`CASCADE`

Automatically drop objects that depend on the language (such as functions in the language), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the language if any objects depend on it. This is the default.

Examples

This command removes the procedural language `plsample`:

```
DROP LANGUAGE plsample;
```

Compatibility

There is no `DROP LANGUAGE` statement in the SQL standard.

See Also

ALTER LANGUAGE, CREATE LANGUAGE

DROP MATERIALIZED VIEW

DROP MATERIALIZED VIEW — remove a materialized view

Synopsis

```
DROP MATERIALIZED VIEW [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP MATERIALIZED VIEW` drops an existing materialized view. To execute this command you must be the owner of the materialized view.

Parameters

`IF EXISTS`

Do not throw an error if the materialized view does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of the materialized view to remove.

`CASCADE`

Automatically drop objects that depend on the materialized view (such as other materialized views, or regular views), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the materialized view if any objects depend on it. This is the default.

Examples

This command will remove the materialized view called `order_summary`:

```
DROP MATERIALIZED VIEW order_summary;
```

Compatibility

`DROP MATERIALIZED VIEW` is a Postgres Pro extension.

See Also

CREATE MATERIALIZED VIEW, ALTER MATERIALIZED VIEW, REFRESH MATERIALIZED VIEW

DROP OPERATOR

DROP OPERATOR — remove an operator

Synopsis

```
DROP OPERATOR [ IF EXISTS ] name ( { left_type | NONE } , right_type ) [, ...]
 [ CASCADE | RESTRICT ]
```

Description

`DROP OPERATOR` drops an existing operator from the database system. To execute this command you must be the owner of the operator.

Parameters

`IF EXISTS`

Do not throw an error if the operator does not exist. A notice is issued in this case.

`name`

The name (optionally schema-qualified) of an existing operator.

`left_type`

The data type of the operator's left operand; write `NONE` if the operator has no left operand.

`right_type`

The data type of the operator's right operand.

`CASCADE`

Automatically drop objects that depend on the operator (such as views using it), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the operator if any objects depend on it. This is the default.

Examples

Remove the power operator `a^b` for type `integer`:

```
DROP OPERATOR ^ (integer, integer);
```

Remove the bitwise-complement prefix operator `~b` for type `bit`:

```
DROP OPERATOR ~ (none, bit);
```

Remove multiple operators in one command:

```
DROP OPERATOR ~ (none, bit), ^ (integer, integer);
```

Compatibility

There is no `DROP OPERATOR` statement in the SQL standard.

See Also

CREATE OPERATOR, ALTER OPERATOR

DROP OPERATOR CLASS

DROP OPERATOR CLASS — remove an operator class

Synopsis

```
DROP OPERATOR CLASS [ IF EXISTS ] name USING index_method [ CASCADE | RESTRICT ]
```

Description

`DROP OPERATOR CLASS` drops an existing operator class. To execute this command you must be the owner of the operator class.

`DROP OPERATOR CLASS` does not drop any of the operators or functions referenced by the class. If there are any indexes depending on the operator class, you will need to specify `CASCADE` for the drop to complete.

Parameters

`IF EXISTS`

Do not throw an error if the operator class does not exist. A notice is issued in this case.

`name`

The name (optionally schema-qualified) of an existing operator class.

`index_method`

The name of the index access method the operator class is for.

`CASCADE`

Automatically drop objects that depend on the operator class (such as indexes), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the operator class if any objects depend on it. This is the default.

Notes

`DROP OPERATOR CLASS` will not drop the operator family containing the class, even if there is nothing else left in the family (in particular, in the case where the family was implicitly created by `CREATE OPERATOR CLASS`). An empty operator family is harmless, but for the sake of tidiness you might wish to remove the family with `DROP OPERATOR FAMILY`; or perhaps better, use `DROP OPERATOR FAMILY` in the first place.

Examples

Remove the B-tree operator class `widget_ops`:

```
DROP OPERATOR CLASS widget_ops USING btree;
```

This command will not succeed if there are any existing indexes that use the operator class. Add `CASCADE` to drop such indexes along with the operator class.

Compatibility

There is no `DROP OPERATOR CLASS` statement in the SQL standard.

See Also

ALTER OPERATOR CLASS, CREATE OPERATOR CLASS, DROP OPERATOR FAMILY

DROP OPERATOR FAMILY

DROP OPERATOR FAMILY — remove an operator family

Synopsis

```
DROP OPERATOR FAMILY [ IF EXISTS ] name USING index_method [ CASCADE | RESTRICT ]
```

Description

`DROP OPERATOR FAMILY` drops an existing operator family. To execute this command you must be the owner of the operator family.

`DROP OPERATOR FAMILY` includes dropping any operator classes contained in the family, but it does not drop any of the operators or functions referenced by the family. If there are any indexes depending on operator classes within the family, you will need to specify `CASCADE` for the drop to complete.

Parameters

`IF EXISTS`

Do not throw an error if the operator family does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an existing operator family.

index_method

The name of the index access method the operator family is for.

`CASCADE`

Automatically drop objects that depend on the operator family, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the operator family if any objects depend on it. This is the default.

Examples

Remove the B-tree operator family `float_ops`:

```
DROP OPERATOR FAMILY float_ops USING btree;
```

This command will not succeed if there are any existing indexes that use operator classes within the family. Add `CASCADE` to drop such indexes along with the operator family.

Compatibility

There is no `DROP OPERATOR FAMILY` statement in the SQL standard.

See Also

ALTER OPERATOR FAMILY, CREATE OPERATOR FAMILY, ALTER OPERATOR CLASS, CREATE OPERATOR CLASS, DROP OPERATOR CLASS

DROP OWNED

DROP OWNED — remove database objects owned by a database role

Synopsis

```
DROP OWNED BY { name | CURRENT_ROLE | CURRENT_USER | SESSION_USER } [, ...] [ CASCADE |
 RESTRICT ]
```

Description

`DROP OWNED` drops all the objects within the current database that are owned by one of the specified roles. Any privileges granted to the given roles on objects in the current database or on shared objects (databases, tablespaces) will also be revoked.

Parameters

name

The name of a role whose objects will be dropped, and whose privileges will be revoked.

`CASCADE`

Automatically drop objects that depend on the affected objects, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the objects owned by a role if any other database objects depend on one of the affected objects. This is the default.

Notes

`DROP OWNED` is often used to prepare for the removal of one or more roles. Because `DROP OWNED` only affects the objects in the current database, it is usually necessary to execute this command in each database that contains objects owned by a role that is to be removed.

Using the `CASCADE` option might make the command recurse to objects owned by other users.

The `REASSIGN OWNED` command is an alternative that reassigns the ownership of all the database objects owned by one or more roles. However, `REASSIGN OWNED` does not deal with privileges for other objects.

Databases and tablespaces owned by the role(s) will not be removed.

See Section 21.4 for more discussion.

Compatibility

The `DROP OWNED` command is a Postgres Pro extension.

See Also

REASSIGN OWNED, DROP ROLE

DROP POLICY

DROP POLICY — remove a row-level security policy from a table

Synopsis

```
DROP POLICY [ IF EXISTS ] name ON table_name [ CASCADE | RESTRICT ]
```

Description

`DROP POLICY` removes the specified policy from the table. Note that if the last policy is removed for a table and the table still has row-level security enabled via `ALTER TABLE`, then the default-deny policy will be used. `ALTER TABLE ... DISABLE ROW LEVEL SECURITY` can be used to disable row-level security for a table, whether policies for the table exist or not.

Parameters

`IF EXISTS`

Do not throw an error if the policy does not exist. A notice is issued in this case.

`name`

The name of the policy to drop.

`table_name`

The name (optionally schema-qualified) of the table that the policy is on.

`CASCADE`
`RESTRICT`

These key words do not have any effect, since there are no dependencies on policies.

Examples

To drop the policy called `p1` on the table named `my_table`:

```
DROP POLICY p1 ON my_table;
```

Compatibility

`DROP POLICY` is a Postgres Pro extension.

See Also

CREATE POLICY, ALTER POLICY

DROP PROCEDURE

DROP PROCEDURE — remove a procedure

Synopsis

```
DROP PROCEDURE [ IF EXISTS ] name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
 [, ...]
    [ CASCADE | RESTRICT ]
```

Description

`DROP PROCEDURE` removes the definition of one or more existing procedures. To execute this command the user must be the owner of the procedure(s). The argument types to the procedure(s) usually must be specified, since several different procedures can exist with the same name and different argument lists.

Parameters

`IF EXISTS`

Do not throw an error if the procedure does not exist. A notice is issued in this case.

`name`

The name (optionally schema-qualified) of an existing procedure.

`argmode`

The mode of an argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN` (but see below).

`argname`

The name of an argument. Note that `DROP PROCEDURE` does not actually pay any attention to argument names, since only the argument data types are used to determine the procedure's identity.

`argtype`

The data type(s) of the procedure's arguments (optionally schema-qualified), if any. See below for details.

`CASCADE`

Automatically drop objects that depend on the procedure, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the procedure if any objects depend on it. This is the default.

Notes

If there is only one procedure of the given name, the argument list can be omitted. Omit the parentheses too in this case.

In PostgreSQL, it's sufficient to list the input (including `INOUT`) arguments, because no two routines of the same name are allowed to share the same input-argument list. Moreover, the `DROP` command will not actually check that you wrote the types of `OUT` arguments correctly; so any arguments that are explicitly marked `OUT` are just noise. But writing them is recommendable for consistency with the corresponding `CREATE` command.

For compatibility with the SQL standard, it is also allowed to write all the argument data types (including those of `OUT` arguments) without any *`argmode`* markers. When this is done, the types of the procedure's

`OUT` argument(s) *will* be verified against the command. This provision creates an ambiguity, in that when the argument list contains no *`argmode`* markers, it's unclear which rule is intended. The `DROP` command will attempt the lookup both ways, and will throw an error if two different procedures are found. To avoid the risk of such ambiguity, it's recommendable to write `IN` markers explicitly rather than letting them be defaulted, thus forcing the traditional PostgreSQL interpretation to be used.

The lookup rules just explained are also used by other commands that act on existing procedures, such as `ALTER PROCEDURE` and `COMMENT ON PROCEDURE`.

Examples

If there is only one procedure `do_db_maintenance`, this command is sufficient to drop it:

```
DROP PROCEDURE do_db_maintenance;
```

Given this procedure definition:

```
CREATE PROCEDURE do_db_maintenance(IN target_schema text, OUT results text) ...
```

any one of these commands would work to drop it:

```
DROP PROCEDURE do_db_maintenance(IN target_schema text, OUT results text);
DROP PROCEDURE do_db_maintenance(IN text, OUT text);
DROP PROCEDURE do_db_maintenance(IN text);
DROP PROCEDURE do_db_maintenance(text);
DROP PROCEDURE do_db_maintenance(text, text);  -- potentially ambiguous
```

However, the last example would be ambiguous if there is also, say,

```
CREATE PROCEDURE do_db_maintenance(IN target_schema text, IN options text) ...
```

Compatibility

This command conforms to the SQL standard, with these Postgres Pro extensions:

- The standard only allows one procedure to be dropped per command.
- The `IF EXISTS` option is an extension.
- The ability to specify argument modes and names is an extension, and the lookup rules differ when modes are given.

See Also

CREATE PROCEDURE, ALTER PROCEDURE, DROP FUNCTION, DROP ROUTINE

DROP PROFILE

DROP PROFILE — remove an authentication profile

Synopsis

```
DROP PROFILE [ IF EXISTS ] name
```

Description

The `DROP PROFILE` command removes the specified profile. You must be a database superuser to use this command.

A profile cannot be removed if it is still referenced in any database of the cluster; if this is the case, an error is raised. Before dropping the profile, you must drop all the roles to which it is assigned, or assign another profile to them. Use the ALTER ROLE command if you need to reassign the profile.

Parameters

`IF EXISTS`

Do not throw an error if the profile does not exist. A notice is issued in this case.

name

The name of the profile to remove.

Examples

Drop the specified profile:

```
DROP PROFILE admin_profile;
```

See Also

CREATE PROFILE, ALTER PROFILE, ALTER ROLE

DROP PUBLICATION

DROP PUBLICATION — remove a publication

Synopsis

```
DROP PUBLICATION [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP PUBLICATION` removes an existing publication from the database.

A publication can only be dropped by its owner or a superuser.

Parameters

`IF EXISTS`

Do not throw an error if the publication does not exist. A notice is issued in this case.

name

The name of an existing publication.

`CASCADE`
`RESTRICT`

These key words do not have any effect, since there are no dependencies on publications.

Examples

Drop a publication:

```
DROP PUBLICATION mypublication;
```

Compatibility

`DROP PUBLICATION` is a Postgres Pro extension.

See Also

CREATE PUBLICATION, ALTER PUBLICATION

DROP ROLE

DROP ROLE — remove a database role

Synopsis

```
DROP ROLE [ IF EXISTS ] name [, ...]
```

Description

`DROP ROLE` removes the specified role(s). To drop a superuser role, you must be a superuser yourself; to drop non-superuser roles, you must have `CREATEROLE` privilege and have been granted `ADMIN OPTION` on the role.

A role cannot be removed if it is still referenced in any database of the cluster; an error will be raised if so. Before dropping the role, you must drop all the objects it owns (or reassign their ownership) and revoke any privileges the role has been granted on other objects. The `REASSIGN OWNED` and `DROP OWNED` commands can be useful for this purpose; see Section 21.4 for more discussion.

However, it is not necessary to remove role memberships involving the role; `DROP ROLE` automatically revokes any memberships of the target role in other roles, and of other roles in the target role. The other roles are not dropped nor otherwise affected.

Parameters

`IF EXISTS`

Do not throw an error if the role does not exist. A notice is issued in this case.

name

The name of the role to remove.

Notes

Postgres Pro includes a program dropuser that has the same functionality as this command (in fact, it calls this command) but can be run from the command shell.

Examples

To drop a role:

```
DROP ROLE jonathan;
```

Compatibility

The SQL standard defines `DROP ROLE`, but it allows only one role to be dropped at a time, and it specifies different privilege requirements than Postgres Pro uses.

See Also

CREATE ROLE, ALTER ROLE, SET ROLE

DROP ROUTINE

DROP ROUTINE — remove a routine

Synopsis

```
DROP ROUTINE [ IF EXISTS ] name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ]
 [, ...]
    [ CASCADE | RESTRICT ]
```

Description

`DROP ROUTINE` removes the definition of one or more existing routines. The term “routine” includes aggregate functions, normal functions, and procedures. See under DROP AGGREGATE, DROP FUNCTION, and DROP PROCEDURE for the description of the parameters, more examples, and further details.

Notes

The lookup rules used by `DROP ROUTINE` are fundamentally the same as for `DROP PROCEDURE`; in particular, `DROP ROUTINE` shares that command's behavior of considering an argument list that has no *argmode* markers to be possibly using the SQL standard's definition that `OUT` arguments are included in the list. (`DROP AGGREGATE` and `DROP FUNCTION` do not do that.)

In some cases where the same name is shared by routines of different kinds, it is possible for `DROP ROUTINE` to fail with an ambiguity error when a more specific command (`DROP FUNCTION`, etc.) would work. Specifying the argument type list more carefully will also resolve such problems.

These lookup rules are also used by other commands that act on existing routines, such as `ALTER ROUTINE` and `COMMENT ON ROUTINE`.

Examples

To drop the routine `foo` for type `integer`:

```
DROP ROUTINE foo(integer);
```

This command will work independent of whether `foo` is an aggregate, function, or procedure.

Compatibility

This command conforms to the SQL standard, with these Postgres Pro extensions:

- The standard only allows one routine to be dropped per command.
- The `IF EXISTS` option is an extension.
- The ability to specify argument modes and names is an extension, and the lookup rules differ when modes are given.
- User-definable aggregate functions are an extension.

See Also

DROP AGGREGATE, DROP FUNCTION, DROP PROCEDURE, ALTER ROUTINE

Note that there is no `CREATE ROUTINE` command.

DROP RULE

DROP RULE — remove a rewrite rule

Synopsis

```
DROP RULE [ IF EXISTS ] name ON table_name [ CASCADE | RESTRICT ]
```

Description

`DROP RULE` drops a rewrite rule.

Parameters

`IF EXISTS`

Do not throw an error if the rule does not exist. A notice is issued in this case.

`name`

The name of the rule to drop.

`table_name`

The name (optionally schema-qualified) of the table or view that the rule applies to.

`CASCADE`

Automatically drop objects that depend on the rule, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the rule if any objects depend on it. This is the default.

Examples

To drop the rewrite rule `newrule`:

```
DROP RULE newrule ON mytable;
```

Compatibility

`DROP RULE` is a Postgres Pro language extension, as is the entire query rewrite system.

See Also

CREATE RULE, ALTER RULE

DROP SCHEMA

DROP SCHEMA — remove a schema

Synopsis

```
DROP SCHEMA [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP SCHEMA` removes schemas from the database.

A schema can only be dropped by its owner or a superuser. Note that the owner can drop the schema (and thereby all contained objects) even if they do not own some of the objects within the schema.

Parameters

`IF EXISTS`

Do not throw an error if the schema does not exist. A notice is issued in this case.

name

The name of a schema.

`CASCADE`

Automatically drop objects (tables, functions, etc.) that are contained in the schema, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the schema if it contains any objects. This is the default.

Notes

Using the `CASCADE` option might make the command remove objects in other schemas besides the one(s) named.

Examples

To remove schema `mystuff` from the database, along with everything it contains:

```
DROP SCHEMA mystuff CASCADE;
```

Compatibility

`DROP SCHEMA` is fully conforming with the SQL standard, except that the standard only allows one schema to be dropped per command, and apart from the `IF EXISTS` option, which is a Postgres Pro extension.

See Also

ALTER SCHEMA, CREATE SCHEMA

DROP SEQUENCE

DROP SEQUENCE — remove a sequence

Synopsis

```
DROP SEQUENCE [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP SEQUENCE` removes sequence number generators. A sequence can only be dropped by its owner or a superuser.

Parameters

`IF EXISTS`

Do not throw an error if the sequence does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of a sequence.

`CASCADE`

Automatically drop objects that depend on the sequence, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the sequence if any objects depend on it. This is the default.

Examples

To remove the sequence `serial`:

```
DROP SEQUENCE serial;
```

Compatibility

`DROP SEQUENCE` conforms to the SQL standard, except that the standard only allows one sequence to be dropped per command, and apart from the `IF EXISTS` option, which is a Postgres Pro extension.

See Also

CREATE SEQUENCE, ALTER SEQUENCE

DROP SERVER

DROP SERVER — remove a foreign server descriptor

Synopsis

```
DROP SERVER [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP SERVER` removes an existing foreign server descriptor. To execute this command, the current user must be the owner of the server.

Parameters

`IF EXISTS`

Do not throw an error if the server does not exist. A notice is issued in this case.

name

The name of an existing server.

`CASCADE`

Automatically drop objects that depend on the server (such as user mappings), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the server if any objects depend on it. This is the default.

Examples

Drop a server `foo` if it exists:

```
DROP SERVER IF EXISTS foo;
```

Compatibility

`DROP SERVER` conforms to ISO/IEC 9075-9 (SQL/MED). The `IF EXISTS` clause is a Postgres Pro extension.

See Also

CREATE SERVER, ALTER SERVER

DROP STATISTICS

DROP STATISTICS — remove extended statistics

Synopsis

```
DROP STATISTICS [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP STATISTICS` removes statistics object(s) from the database. Only the statistics object's owner, the schema owner, or a superuser can drop a statistics object.

Parameters

`IF EXISTS`

Do not throw an error if the statistics object does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of the statistics object to drop.

`CASCADE`
`RESTRICT`

These key words do not have any effect, since there are no dependencies on statistics.

Examples

To destroy two statistics objects in different schemas, without failing if they don't exist:

```
DROP STATISTICS IF EXISTS
    accounting.users_uid_creation,
    public.grants_user_role;
```

Compatibility

There is no `DROP STATISTICS` command in the SQL standard.

See Also

ALTER STATISTICS, CREATE STATISTICS

DROP SUBSCRIPTION

DROP SUBSCRIPTION — remove a subscription

Synopsis

```
DROP SUBSCRIPTION [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP SUBSCRIPTION` removes a subscription from the database cluster.

A subscription can only be dropped by a superuser.

`DROP SUBSCRIPTION` cannot be executed inside a transaction block if the subscription is associated with a replication slot. (You can use `ALTER SUBSCRIPTION` to unset the slot.)

Parameters

name

The name of a subscription to be dropped.

`CASCADE`
`RESTRICT`

These key words do not have any effect, since there are no dependencies on subscriptions.

Notes

When dropping a subscription that is associated with a replication slot on the remote host (the normal state), `DROP SUBSCRIPTION` will connect to the remote host and try to drop the replication slot (and any remaining table synchronization slots) as part of its operation. This is necessary so that the resources allocated for the subscription on the remote host are released. If this fails, either because the remote host is not reachable or because the remote replication slot cannot be dropped or does not exist or never existed, the `DROP SUBSCRIPTION` command will fail. To proceed in this situation, first disable the subscription by executing `ALTER SUBSCRIPTION ... DISABLE`, and then disassociate it from the replication slot by executing `ALTER SUBSCRIPTION ... SET (slot_name = NONE)`. After that, `DROP SUBSCRIPTION` will no longer attempt any actions on a remote host. Note that if the remote replication slot still exists, it (and any related table synchronization slots) should then be dropped manually; otherwise it/they will continue to reserve WAL and might eventually cause the disk to fill up. See also Section 30.2.1.

If a subscription is associated with a replication slot, then `DROP SUBSCRIPTION` cannot be executed inside a transaction block.

Examples

Drop a subscription:

```
DROP SUBSCRIPTION mysub;
```

Compatibility

`DROP SUBSCRIPTION` is a Postgres Pro extension.

See Also

CREATE SUBSCRIPTION, ALTER SUBSCRIPTION

DROP TABLE

DROP TABLE — remove a table

Synopsis

```
DROP TABLE [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP TABLE` removes tables from the database. Only the table owner, the schema owner, and superuser can drop a table. To empty a table of rows without destroying the table, use `DELETE` or `TRUNCATE`.

`DROP TABLE` always removes any indexes, rules, triggers, and constraints that exist for the target table. However, to drop a table that is referenced by a view or a foreign-key constraint of another table, `CASCADE` must be specified. (`CASCADE` will remove a dependent view entirely, but in the foreign-key case it will only remove the foreign-key constraint, not the other table entirely.)

Parameters

`IF EXISTS`

Do not throw an error if the table does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of the table to drop.

`CASCADE`

Automatically drop objects that depend on the table (such as views), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the table if any objects depend on it. This is the default.

Examples

To destroy two tables, `films` and `distributors`:

```
DROP TABLE films, distributors;
```

Compatibility

This command conforms to the SQL standard, except that the standard only allows one table to be dropped per command, and apart from the `IF EXISTS` option, which is a Postgres Pro extension.

See Also

ALTER TABLE, CREATE TABLE

DROP TABLESPACE

DROP TABLESPACE — remove a tablespace

Synopsis

```
DROP TABLESPACE [ IF EXISTS ] name
```

Description

`DROP TABLESPACE` removes a tablespace from the system.

A tablespace can only be dropped by its owner or a superuser. The tablespace must be empty of all database objects before it can be dropped. It is possible that objects in other databases might still reside in the tablespace even if no objects in the current database are using the tablespace. Also, if the tablespace is listed in the temp_tablespaces setting of any active session, the `DROP` might fail due to temporary files residing in the tablespace.

Parameters

`IF EXISTS`

Do not throw an error if the tablespace does not exist. A notice is issued in this case.

name

The name of a tablespace.

Notes

`DROP TABLESPACE` cannot be executed inside a transaction block.

Examples

To remove tablespace `mystuff` from the system:

```
DROP TABLESPACE mystuff;
```

Compatibility

`DROP TABLESPACE` is a Postgres Pro extension.

See Also

CREATE TABLESPACE, ALTER TABLESPACE

DROP TEXT SEARCH CONFIGURATION

DROP TEXT SEARCH CONFIGURATION — remove a text search configuration

Synopsis

```
DROP TEXT SEARCH CONFIGURATION [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP TEXT SEARCH CONFIGURATION` drops an existing text search configuration. To execute this command you must be the owner of the configuration.

Parameters

`IF EXISTS`

Do not throw an error if the text search configuration does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an existing text search configuration.

`CASCADE`

Automatically drop objects that depend on the text search configuration, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the text search configuration if any objects depend on it. This is the default.

Examples

Remove the text search configuration `my_english`:

```
DROP TEXT SEARCH CONFIGURATION my_english;
```

This command will not succeed if there are any existing indexes that reference the configuration in `to_tsvector` calls. Add `CASCADE` to drop such indexes along with the text search configuration.

Compatibility

There is no `DROP TEXT SEARCH CONFIGURATION` statement in the SQL standard.

See Also

ALTER TEXT SEARCH CONFIGURATION, CREATE TEXT SEARCH CONFIGURATION

DROP TEXT SEARCH DICTIONARY

DROP TEXT SEARCH DICTIONARY — remove a text search dictionary

Synopsis

```
DROP TEXT SEARCH DICTIONARY [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP TEXT SEARCH DICTIONARY` drops an existing text search dictionary. To execute this command you must be the owner of the dictionary.

Parameters

`IF EXISTS`

Do not throw an error if the text search dictionary does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an existing text search dictionary.

`CASCADE`

Automatically drop objects that depend on the text search dictionary, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the text search dictionary if any objects depend on it. This is the default.

Examples

Remove the text search dictionary `english`:

```
DROP TEXT SEARCH DICTIONARY english;
```

This command will not succeed if there are any existing text search configurations that use the dictionary. Add `CASCADE` to drop such configurations along with the dictionary.

Compatibility

There is no `DROP TEXT SEARCH DICTIONARY` statement in the SQL standard.

See Also

ALTER TEXT SEARCH DICTIONARY, CREATE TEXT SEARCH DICTIONARY

DROP TEXT SEARCH PARSER

DROP TEXT SEARCH PARSER — remove a text search parser

Synopsis

```
DROP TEXT SEARCH PARSER [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP TEXT SEARCH PARSER` drops an existing text search parser. You must be a superuser to use this command.

Parameters

`IF EXISTS`

Do not throw an error if the text search parser does not exist. A notice is issued in this case.

`name`

The name (optionally schema-qualified) of an existing text search parser.

`CASCADE`

Automatically drop objects that depend on the text search parser, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the text search parser if any objects depend on it. This is the default.

Examples

Remove the text search parser `my_parser`:

```
DROP TEXT SEARCH PARSER my_parser;
```

This command will not succeed if there are any existing text search configurations that use the parser. Add `CASCADE` to drop such configurations along with the parser.

Compatibility

There is no `DROP TEXT SEARCH PARSER` statement in the SQL standard.

See Also

ALTER TEXT SEARCH PARSER, CREATE TEXT SEARCH PARSER

DROP TEXT SEARCH TEMPLATE

DROP TEXT SEARCH TEMPLATE — remove a text search template

Synopsis

```
DROP TEXT SEARCH TEMPLATE [ IF EXISTS ] name [ CASCADE | RESTRICT ]
```

Description

`DROP TEXT SEARCH TEMPLATE` drops an existing text search template. You must be a superuser to use this command.

Parameters

`IF EXISTS`

Do not throw an error if the text search template does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of an existing text search template.

`CASCADE`

Automatically drop objects that depend on the text search template, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the text search template if any objects depend on it. This is the default.

Examples

Remove the text search template `thesaurus`:

```
DROP TEXT SEARCH TEMPLATE thesaurus;
```

This command will not succeed if there are any existing text search dictionaries that use the template. Add `CASCADE` to drop such dictionaries along with the template.

Compatibility

There is no `DROP TEXT SEARCH TEMPLATE` statement in the SQL standard.

See Also

ALTER TEXT SEARCH TEMPLATE, CREATE TEXT SEARCH TEMPLATE

DROP TRANSFORM

DROP TRANSFORM — remove a transform

Synopsis

```
DROP TRANSFORM [ IF EXISTS ] FOR type_name LANGUAGE lang_name [ CASCADE | RESTRICT ]
```

Description

`DROP TRANSFORM` removes a previously defined transform.

To be able to drop a transform, you must own the type and the language. These are the same privileges that are required to create a transform.

Parameters

`IF EXISTS`

Do not throw an error if the transform does not exist. A notice is issued in this case.

`type_name`

The name of the data type of the transform.

`lang_name`

The name of the language of the transform.

`CASCADE`

Automatically drop objects that depend on the transform, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the transform if any objects depend on it. This is the default.

Examples

To drop the transform for type `hstore` and language `plpythonu`:

```
DROP TRANSFORM FOR hstore LANGUAGE plpythonu;
```

Compatibility

This form of `DROP TRANSFORM` is a Postgres Pro extension. See CREATE TRANSFORM for details.

See Also

CREATE TRANSFORM

DROP TRIGGER

DROP TRIGGER — remove a trigger

Synopsis

```
DROP TRIGGER [ IF EXISTS ] name ON table_name [ CASCADE | RESTRICT ]
```

Description

`DROP TRIGGER` removes an existing trigger definition. To execute this command, the current user must be the owner of the table for which the trigger is defined.

Parameters

`IF EXISTS`

Do not throw an error if the trigger does not exist. A notice is issued in this case.

`name`

The name of the trigger to remove.

`table_name`

The name (optionally schema-qualified) of the table for which the trigger is defined.

`CASCADE`

Automatically drop objects that depend on the trigger, and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the trigger if any objects depend on it. This is the default.

Examples

Destroy the trigger `if_dist_exists` on the table `films`:

```
DROP TRIGGER if_dist_exists ON films;
```

Compatibility

The `DROP TRIGGER` statement in Postgres Pro is incompatible with the SQL standard. In the SQL standard, trigger names are not local to tables, so the command is simply `DROP TRIGGER` *`name`*.

See Also

CREATE TRIGGER

DROP TYPE

DROP TYPE — remove a data type

Synopsis

```
DROP TYPE [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP TYPE` removes a user-defined data type. Only the owner of a type can remove it.

Parameters

`IF EXISTS`

Do not throw an error if the type does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of the data type to remove.

`CASCADE`

Automatically drop objects that depend on the type (such as table columns, functions, and operators), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the type if any objects depend on it. This is the default.

Examples

To remove the data type `box`:

```
DROP TYPE box;
```

Compatibility

This command is similar to the corresponding command in the SQL standard, apart from the `IF EXISTS` option, which is a Postgres Pro extension. But note that much of the `CREATE TYPE` command and the data type extension mechanisms in Postgres Pro differ from the SQL standard.

See Also

ALTER TYPE, CREATE TYPE

DROP USER

DROP USER — remove a database role

Synopsis

```
DROP USER [ IF EXISTS ] name [, ...]
```

Description

`DROP USER` is simply an alternate spelling of `DROP ROLE`.

Compatibility

The `DROP USER` statement is a Postgres Pro extension. The SQL standard leaves the definition of users to the implementation.

See Also

DROP ROLE

DROP USER MAPPING

DROP USER MAPPING — remove a user mapping for a foreign server

Synopsis

```
DROP USER MAPPING [ IF EXISTS ] FOR { user_name | USER | CURRENT_ROLE | CURRENT_USER |
 PUBLIC } SERVER server_name
```

Description

`DROP USER MAPPING` removes an existing user mapping from foreign server.

The owner of a foreign server can drop user mappings for that server for any user. Also, a user can drop a user mapping for their own user name if `USAGE` privilege on the server has been granted to the user.

Parameters

`IF EXISTS`

Do not throw an error if the user mapping does not exist. A notice is issued in this case.

`user_name`

User name of the mapping. `CURRENT_ROLE`, `CURRENT_USER`, and `USER` match the name of the current user. `PUBLIC` is used to match all present and future user names in the system.

`server_name`

Server name of the user mapping.

Examples

Drop a user mapping `bob`, server `foo` if it exists:

```
DROP USER MAPPING IF EXISTS FOR bob SERVER foo;
```

Compatibility

`DROP USER MAPPING` conforms to ISO/IEC 9075-9 (SQL/MED). The `IF EXISTS` clause is a Postgres Pro extension.

See Also

CREATE USER MAPPING, ALTER USER MAPPING

DROP VIEW

DROP VIEW — remove a view

Synopsis

```
DROP VIEW [ IF EXISTS ] name [, ...] [ CASCADE | RESTRICT ]
```

Description

`DROP VIEW` drops an existing view. To execute this command you must be the owner of the view.

Parameters

`IF EXISTS`

Do not throw an error if the view does not exist. A notice is issued in this case.

name

The name (optionally schema-qualified) of the view to remove.

`CASCADE`

Automatically drop objects that depend on the view (such as other views), and in turn all objects that depend on those objects (see Section 5.14).

`RESTRICT`

Refuse to drop the view if any objects depend on it. This is the default.

Examples

This command will remove the view called `kinds`:

```
DROP VIEW kinds;
```

Compatibility

This command conforms to the SQL standard, except that the standard only allows one view to be dropped per command, and apart from the `IF EXISTS` option, which is a Postgres Pro extension.

See Also

ALTER VIEW, CREATE VIEW

END

END — commit the current transaction

Synopsis

```
END [ AUTONOMOUS ] [ WORK | TRANSACTION ] [ AND [ NO ] CHAIN ]
```

Description

`END` commits the current transaction. All changes made by the transaction become visible to others and are guaranteed to be durable if a crash occurs. This command is a Postgres Pro extension that is equivalent to `COMMIT`.

Parameters

`AUTONOMOUS`

Optional key word that can be used when committing an autonomous transaction. For details on autonomous transactions, see Chapter 16.

`WORK`
`TRANSACTION`
`AUTONOMOUS`

Optional key words. They have no effect.

`AND CHAIN`

If `AND CHAIN` is specified, a new transaction is immediately started with the same transaction characteristics (see SET TRANSACTION) as the just finished one. Otherwise, no new transaction is started.

Notes

Use `ROLLBACK` to abort a transaction.

Issuing `END` when not inside a transaction does no harm, but it will provoke a warning message.

Examples

To commit the current transaction and make all changes permanent:

```
END;
```

Compatibility

`END` is a Postgres Pro extension that provides functionality equivalent to `COMMIT`, which is specified in the SQL standard.

See Also

BEGIN, COMMIT, ROLLBACK

EXECUTE

EXECUTE — execute a prepared statement

Synopsis

```
EXECUTE name [ ( parameter [, ...] ) ]
```

Description

`EXECUTE` is used to execute a previously prepared statement. Since prepared statements only exist for the duration of a session, the prepared statement must have been created by a `PREPARE` statement executed earlier in the current session.

If the `PREPARE` statement that created the statement specified some parameters, a compatible set of parameters must be passed to the `EXECUTE` statement, or else an error is raised. Note that (unlike functions) prepared statements are not overloaded based on the type or number of their parameters; the name of a prepared statement must be unique within a database session.

For more information on the creation and usage of prepared statements, see PREPARE.

Parameters

name

The name of the prepared statement to execute.

parameter

The actual value of a parameter to the prepared statement. This must be an expression yielding a value that is compatible with the data type of this parameter, as was determined when the prepared statement was created.

Outputs

The command tag returned by `EXECUTE` is that of the prepared statement, and not `EXECUTE`.

Examples

Examples are given in Examples in the PREPARE documentation.

Compatibility

The SQL standard includes an `EXECUTE` statement, but it is only for use in embedded SQL. This version of the `EXECUTE` statement also uses a somewhat different syntax.

See Also

DEALLOCATE, PREPARE

EXPLAIN

EXPLAIN — show the execution plan of a statement

Synopsis

```
EXPLAIN [ ( option [, ...] ) ] statement
EXPLAIN [ ANALYZE ] [ VERBOSE ] statement

where option can be one of:

    ANALYZE [ boolean ]
    VERBOSE [ boolean ]
    COSTS [ boolean ]
    SETTINGS [ boolean ]
    BUFFERS [ boolean ]
    WAL [ boolean ]
    TIMING [ boolean ]
    SUMMARY [ boolean ]
    FORMAT { TEXT | XML | JSON | YAML }
```

Description

This command displays the execution plan that the Postgres Pro planner generates for the supplied statement. The execution plan shows how the table(s) referenced by the statement will be scanned — by plain sequential scan, index scan, etc. — and if multiple tables are referenced, what join algorithms will be used to bring together the required rows from each input table.

The most critical part of the display is the estimated statement execution cost, which is the planner's guess at how long it will take to run the statement (measured in cost units that are arbitrary, but conventionally mean disk page fetches). Actually two numbers are shown: the start-up cost before the first row can be returned, and the total cost to return all the rows. For most queries the total cost is what matters, but in contexts such as a subquery in `EXISTS`, the planner will choose the smallest start-up cost instead of the smallest total cost (since the executor will stop after getting one row, anyway). Also, if you limit the number of rows to return with a `LIMIT` clause, the planner makes an appropriate interpolation between the endpoint costs to estimate which plan is really the cheapest.

The `ANALYZE` option causes the statement to be actually executed, not only planned. Then actual run time statistics are added to the display, including the total elapsed time expended within each plan node (in milliseconds) and the total number of rows it actually returned. This is useful for seeing whether the planner's estimates are close to reality.

> **Important**
>
> Keep in mind that the statement is actually executed when the `ANALYZE` option is used. Although `EXPLAIN` will discard any output that a `SELECT` would return, other side effects of the statement will happen as usual. If you wish to use `EXPLAIN ANALYZE` on an `INSERT`, `UPDATE`, `DELETE`, `CREATE TABLE AS`, or `EXECUTE` statement without letting the command affect your data, use this approach:
>
> ```
> BEGIN;
> EXPLAIN ANALYZE ...;
> ROLLBACK;
> ```

Only the `ANALYZE` and `VERBOSE` options can be specified, and only in that order, without surrounding the option list in parentheses. Prior to PostgreSQL 9.0, the unparenthesized syntax was the only one supported. It is expected that all new options will be supported only in the parenthesized syntax.

Parameters

ANALYZE

Carry out the command and show actual run times and other statistics. This parameter defaults to FALSE.

VERBOSE

Display additional information regarding the plan. Specifically, include the output column list for each node in the plan tree, schema-qualify table and function names, always label variables in expressions with their range table alias, and always print the name of each trigger for which statistics are displayed. The query identifier will also be displayed if one has been computed, see compute_query_id for more details. This parameter defaults to FALSE.

COSTS

Include information on the estimated startup and total cost of each plan node, as well as the estimated number of rows and the estimated width of each row. This parameter defaults to TRUE.

SETTINGS

Include information on configuration parameters. Specifically, include options affecting query planning with value different from the built-in default value. This parameter defaults to FALSE.

BUFFERS

Include information on buffer usage. Specifically, include the number of shared blocks hit, read, dirtied, and written, the number of local blocks hit, read, dirtied, and written, the number of temp blocks read and written, and the time spent reading and writing data file blocks (in milliseconds) if track_io_timing is enabled. A *hit* means that a read was avoided because the block was found already in cache when needed. Shared blocks contain data from regular tables and indexes; local blocks contain data from temporary tables and indexes; while temp blocks contain short-term working data used in sorts, hashes, Materialize plan nodes, and similar cases. The number of blocks *dirtied* indicates the number of previously unmodified blocks that were changed by this query; while the number of blocks *written* indicates the number of previously-dirtied blocks evicted from cache by this backend during query processing. The number of blocks shown for an upper-level node includes those used by all its child nodes. In text format, only non-zero values are printed. It defaults to FALSE.

WAL

Include information on WAL record generation. Specifically, include the number of records, number of full page images (fpi) and the amount of WAL generated in bytes. In text format, only non-zero values are printed. This parameter may only be used when ANALYZE is also enabled. It defaults to FALSE.

TIMING

Include actual startup time and time spent in each node in the output. The overhead of repeatedly reading the system clock can slow down the query significantly on some systems, so it may be useful to set this parameter to FALSE when only actual row counts, and not exact times, are needed. Run time of the entire statement is always measured, even when node-level timing is turned off with this option. This parameter may only be used when ANALYZE is also enabled. It defaults to TRUE.

SUMMARY

Include summary information (e.g., totaled timing information) after the query plan. Summary information is included by default when ANALYZE is used but otherwise is not included by default, but can be enabled using this option. Planning time in EXPLAIN EXECUTE includes the time required to fetch the plan from the cache and the time required for re-planning, if necessary.

FORMAT

Specify the output format, which can be TEXT, XML, JSON, or YAML. Non-text output contains the same information as the text output format, but is easier for programs to parse. This parameter defaults to TEXT.

boolean

Specifies whether the selected option should be turned on or off. You can write `TRUE`, `ON`, or `1` to enable the option, and `FALSE`, `OFF`, or `0` to disable it. The *boolean* value can also be omitted, in which case `TRUE` is assumed.

statement

Any `SELECT`, `INSERT`, `UPDATE`, `DELETE`, `VALUES`, `EXECUTE`, `DECLARE`, `CREATE TABLE AS`, or `CREATE MATERIALIZED VIEW AS` statement, whose execution plan you wish to see.

Outputs

The command's result is a textual description of the plan selected for the *statement*, optionally annotated with execution statistics. Section 14.1 describes the information provided.

Notes

In order to allow the Postgres Pro query planner to make reasonably informed decisions when optimizing queries, the `pg_statistic` data should be up-to-date for all tables used in the query. Normally the auto-vacuum daemon will take care of that automatically. But if a table has recently had substantial changes in its contents, you might need to do a manual `ANALYZE` rather than wait for autovacuum to catch up with the changes.

In order to measure the run-time cost of each node in the execution plan, the current implementation of `EXPLAIN ANALYZE` adds profiling overhead to query execution. As a result, running `EXPLAIN ANALYZE` on a query can sometimes take significantly longer than executing the query normally. The amount of overhead depends on the nature of the query, as well as the platform being used. The worst case occurs for plan nodes that in themselves require very little time per execution, and on machines that have relatively slow operating system calls for obtaining the time of day.

Examples

To show the plan for a simple query on a table with a single `integer` column and 10000 rows:

```
EXPLAIN SELECT * FROM foo;

                       QUERY PLAN
-----------------------------------------------------------
 Seq Scan on foo  (cost=0.00..155.00 rows=10000 width=4)
(1 row)
```

Here is the same query, with JSON output formatting:

```
EXPLAIN (FORMAT JSON) SELECT * FROM foo;
           QUERY PLAN
--------------------------------
 [                             +
   {                           +
     "Plan": {                 +
       "Node Type": "Seq Scan",+
       "Relation Name": "foo", +
       "Alias": "foo",         +
       "Startup Cost": 0.00,   +
       "Total Cost": 155.00,   +
       "Plan Rows": 10000,     +
       "Plan Width": 4         +
     }                         +
   }                           +
 ]
(1 row)
```

If there is an index and we use a query with an indexable `WHERE` condition, `EXPLAIN` might show a different plan:

```
EXPLAIN SELECT * FROM foo WHERE i = 4;

                           QUERY PLAN
-----------------------------------------------------------------
 Index Scan using fi on foo  (cost=0.00..5.98 rows=1 width=4)
   Index Cond: (i = 4)
(2 rows)
```

Here is the same query, but in YAML format:

```
EXPLAIN (FORMAT YAML) SELECT * FROM foo WHERE i='4';
          QUERY PLAN
------------------------------
 - Plan:                      +
     Node Type: "Index Scan"  +
     Scan Direction: "Forward"+
     Index Name: "fi"         +
     Relation Name: "foo"     +
     Alias: "foo"             +
     Startup Cost: 0.00       +
     Total Cost: 5.98         +
     Plan Rows: 1             +
     Plan Width: 4            +
     Index Cond: "(i = 4)"
(1 row)
```

XML format is left as an exercise for the reader.

Here is the same plan with cost estimates suppressed:

```
EXPLAIN (COSTS FALSE) SELECT * FROM foo WHERE i = 4;

        QUERY PLAN
---------------------------
 Index Scan using fi on foo
   Index Cond: (i = 4)
(2 rows)
```

Here is an example of a query plan for a query using an aggregate function:

```
EXPLAIN SELECT sum(i) FROM foo WHERE i < 10;

                              QUERY PLAN
-----------------------------------------------------------------------
 Aggregate  (cost=23.93..23.93 rows=1 width=4)
   ->  Index Scan using fi on foo  (cost=0.00..23.92 rows=6 width=4)
         Index Cond: (i < 10)
(3 rows)
```

Here is an example of using `EXPLAIN EXECUTE` to display the execution plan for a prepared query:

```
PREPARE query(int, int) AS SELECT sum(bar) FROM test
    WHERE id > $1 AND id < $2
    GROUP BY foo;

EXPLAIN ANALYZE EXECUTE query(100, 200);

                                                        QUERY PLAN
```

```
------------------------------------------------------------------------
------------------------------------------------------
 HashAggregate  (cost=9.54..9.54 rows=1 width=8) (actual time=0.156..0.161 rows=11
 loops=1)
   Group Key: foo
   ->  Index Scan using test_pkey on test  (cost=0.29..9.29 rows=50 width=8) (actual
 time=0.039..0.091 rows=99 loops=1)
         Index Cond: ((id > $1) AND (id < $2))
 Planning time: 0.197 ms
 Execution time: 0.225 ms
(6 rows)
```

Of course, the specific numbers shown here depend on the actual contents of the tables involved. Also note that the numbers, and even the selected query strategy, might vary between Postgres Pro releases due to planner improvements. In addition, the `ANALYZE` command uses random sampling to estimate data statistics; therefore, it is possible for cost estimates to change after a fresh run of `ANALYZE`, even if the actual distribution of data in the table has not changed.

Compatibility

There is no `EXPLAIN` statement defined in the SQL standard.

See Also

ANALYZE

FETCH

FETCH — retrieve rows from a query using a cursor

Synopsis

```
FETCH [ direction ] [ FROM | IN ] cursor_name

where direction can be one of:

    NEXT
    PRIOR
    FIRST
    LAST
    ABSOLUTE count
    RELATIVE count
    count
    ALL
    FORWARD
    FORWARD count
    FORWARD ALL
    BACKWARD
    BACKWARD count
    BACKWARD ALL
```

Description

`FETCH` retrieves rows using a previously-created cursor.

A cursor has an associated position, which is used by `FETCH`. The cursor position can be before the first row of the query result, on any particular row of the result, or after the last row of the result. When created, a cursor is positioned before the first row. After fetching some rows, the cursor is positioned on the row most recently retrieved. If `FETCH` runs off the end of the available rows then the cursor is left positioned after the last row, or before the first row if fetching backward. `FETCH ALL` or `FETCH BACKWARD ALL` will always leave the cursor positioned after the last row or before the first row.

The forms `NEXT`, `PRIOR`, `FIRST`, `LAST`, `ABSOLUTE`, `RELATIVE` fetch a single row after moving the cursor appropriately. If there is no such row, an empty result is returned, and the cursor is left positioned before the first row or after the last row as appropriate.

The forms using `FORWARD` and `BACKWARD` retrieve the indicated number of rows moving in the forward or backward direction, leaving the cursor positioned on the last-returned row (or after/before all rows, if the *count* exceeds the number of rows available).

`RELATIVE 0`, `FORWARD 0`, and `BACKWARD 0` all request fetching the current row without moving the cursor, that is, re-fetching the most recently fetched row. This will succeed unless the cursor is positioned before the first row or after the last row; in which case, no row is returned.

> **Note**
>
> This page describes usage of cursors at the SQL command level. If you are trying to use cursors inside a PL/pgSQL function, the rules are different — see Section 45.7.3.

Parameters

direction

direction defines the fetch direction and number of rows to fetch. It can be one of the following:

`NEXT`

Fetch the next row. This is the default if *direction* is omitted.

`PRIOR`

Fetch the prior row.

`FIRST`

Fetch the first row of the query (same as `ABSOLUTE 1`).

`LAST`

Fetch the last row of the query (same as `ABSOLUTE -1`).

`ABSOLUTE` *count*

Fetch the *count*'th row of the query, or the `abs(`*count*`)`'th row from the end if *count* is negative. Position before first row or after last row if *count* is out of range; in particular, `ABSOLUTE 0` positions before the first row.

`RELATIVE` *count*

Fetch the *count*'th succeeding row, or the `abs(`*count*`)`'th prior row if *count* is negative. `RELATIVE 0` re-fetches the current row, if any.

count

Fetch the next *count* rows (same as `FORWARD` *count*).

`ALL`

Fetch all remaining rows (same as `FORWARD ALL`).

`FORWARD`

Fetch the next row (same as `NEXT`).

`FORWARD` *count*

Fetch the next *count* rows. `FORWARD 0` re-fetches the current row.

`FORWARD ALL`

Fetch all remaining rows.

`BACKWARD`

Fetch the prior row (same as `PRIOR`).

`BACKWARD` *count*

Fetch the prior *count* rows (scanning backwards). `BACKWARD 0` re-fetches the current row.

`BACKWARD ALL`

Fetch all prior rows (scanning backwards).

count

count is a possibly-signed integer constant, determining the location or number of rows to fetch. For `FORWARD` and `BACKWARD` cases, specifying a negative *count* is equivalent to changing the sense of `FORWARD` and `BACKWARD`.

cursor_name

An open cursor's name.

Outputs

On successful completion, a FETCH command returns a command tag of the form

FETCH *count*

The *count* is the number of rows fetched (possibly zero). Note that in psql, the command tag will not actually be displayed, since psql displays the fetched rows instead.

Notes

The cursor should be declared with the SCROLL option if one intends to use any variants of FETCH other than FETCH NEXT or FETCH FORWARD with a positive count. For simple queries Postgres Pro will allow backwards fetch from cursors not declared with SCROLL, but this behavior is best not relied on. If the cursor is declared with NO SCROLL, no backward fetches are allowed.

ABSOLUTE fetches are not any faster than navigating to the desired row with a relative move: the underlying implementation must traverse all the intermediate rows anyway. Negative absolute fetches are even worse: the query must be read to the end to find the last row, and then traversed backward from there. However, rewinding to the start of the query (as with FETCH ABSOLUTE 0) is fast.

DECLARE is used to define a cursor. Use MOVE to change cursor position without retrieving data.

Examples

The following example traverses a table using a cursor:

```
BEGIN WORK;

-- Set up a cursor:
DECLARE liahona SCROLL CURSOR FOR SELECT * FROM films;

-- Fetch the first 5 rows in the cursor liahona:
FETCH FORWARD 5 FROM liahona;

 code  |          title           | did | date_prod  |   kind   |  len
-------+--------------------------+-----+------------+----------+-------
 BL101 | The Third Man            | 101 | 1949-12-23 | Drama    | 01:44
 BL102 | The African Queen        | 101 | 1951-08-11 | Romantic | 01:43
 JL201 | Une Femme est une Femme  | 102 | 1961-03-12 | Romantic | 01:25
 P_301 | Vertigo                  | 103 | 1958-11-14 | Action   | 02:08
 P_302 | Becket                   | 103 | 1964-02-03 | Drama    | 02:28

-- Fetch the previous row:
FETCH PRIOR FROM liahona;

 code  |  title  | did | date_prod  |  kind  |  len
-------+---------+-----+------------+--------+-------
 P_301 | Vertigo | 103 | 1958-11-14 | Action | 02:08

-- Close the cursor and end the transaction:
CLOSE liahona;
COMMIT WORK;
```

Compatibility

The SQL standard defines FETCH for use in embedded SQL only. The variant of FETCH described here returns the data as if it were a SELECT result rather than placing it in host variables. Other than this point, FETCH is fully upward-compatible with the SQL standard.

The FETCH forms involving FORWARD and BACKWARD, as well as the forms FETCH *count* and FETCH ALL, in which FORWARD is implicit, are Postgres Pro extensions.

The SQL standard allows only `FROM` preceding the cursor name; the option to use `IN`, or to leave them out altogether, is an extension.

See Also

CLOSE, DECLARE, MOVE

GRANT

GRANT — define access privileges

Synopsis

```
GRANT { { SELECT | INSERT | UPDATE | DELETE | TRUNCATE | REFERENCES | TRIGGER }
    [, ...] | ALL [ PRIVILEGES ] }
    ON { [ TABLE ] table_name [, ...]
         | ALL TABLES IN SCHEMA schema_name [, ...] }
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { { SELECT | INSERT | UPDATE | REFERENCES } ( column_name [, ...] )
    [, ...] | ALL [ PRIVILEGES ] ( column_name [, ...] ) }
    ON [ TABLE ] table_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { { USAGE | SELECT | UPDATE }
    [, ...] | ALL [ PRIVILEGES ] }
    ON { SEQUENCE sequence_name [, ...]
         | ALL SEQUENCES IN SCHEMA schema_name [, ...] }
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { { CREATE | CONNECT | TEMPORARY | TEMP } [, ...] | ALL [ PRIVILEGES ] }
    ON DATABASE database_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { USAGE | ALL [ PRIVILEGES ] }
    ON DOMAIN domain_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { USAGE | ALL [ PRIVILEGES ] }
    ON FOREIGN DATA WRAPPER fdw_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { USAGE | ALL [ PRIVILEGES ] }
    ON FOREIGN SERVER server_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { EXECUTE | ALL [ PRIVILEGES ] }
    ON { { FUNCTION | PROCEDURE | ROUTINE } routine_name [ ( [ [ argmode ] [ arg_name
 ] arg_type [, ...] ] ) ] [, ...]
         | ALL { FUNCTIONS | PROCEDURES | ROUTINES } IN SCHEMA schema_name [, ...] }
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { USAGE | ALL [ PRIVILEGES ] }
    ON LANGUAGE lang_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]
```

```
GRANT { { SELECT | UPDATE } [, ...] | ALL [ PRIVILEGES ] }
    ON LARGE OBJECT loid [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { { CREATE | USAGE } [, ...] | ALL [ PRIVILEGES ] }
    ON SCHEMA schema_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { CREATE | ALL [ PRIVILEGES ] }
    ON TABLESPACE tablespace_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT { USAGE | ALL [ PRIVILEGES ] }
    ON TYPE type_name [, ...]
    TO role_specification [, ...] [ WITH GRANT OPTION ]
    [ GRANTED BY role_specification ]

GRANT role_name [, ...] TO role_specification [, ...]
    [ WITH ADMIN OPTION ]
    [ GRANTED BY role_specification ]

where role_specification can be:

    [ GROUP ] role_name
  | PUBLIC
  | CURRENT_ROLE
  | CURRENT_USER
  | SESSION_USER
```

Description

The GRANT command has two basic variants: one that grants privileges on a database object (table, column, view, foreign table, sequence, database, foreign-data wrapper, foreign server, function, procedure, procedural language, schema, or tablespace), and one that grants membership in a role. These variants are similar in many ways, but they are different enough to be described separately.

GRANT on Database Objects

This variant of the GRANT command gives specific privileges on a database object to one or more roles. These privileges are added to those already granted, if any.

The key word PUBLIC indicates that the privileges are to be granted to all roles, including those that might be created later. PUBLIC can be thought of as an implicitly defined group that always includes all roles. Any particular role will have the sum of privileges granted directly to it, privileges granted to any role it is presently a member of, and privileges granted to PUBLIC.

If WITH GRANT OPTION is specified, the recipient of the privilege can in turn grant it to others. Without a grant option, the recipient cannot do that. Grant options cannot be granted to PUBLIC.

If GRANTED BY is specified, the specified grantor must be the current user. This clause is currently present in this form only for SQL compatibility.

There is no need to grant privileges to the owner of an object (usually the user that created it), as the owner has all privileges by default. (The owner could, however, choose to revoke some of their own privileges for safety.)

The right to drop an object, or to alter its definition in any way, is not treated as a grantable privilege; it is inherent in the owner, and cannot be granted or revoked. (However, a similar effect can be obtained by granting or revoking membership in the role that owns the object; see below.) The owner implicitly has all grant options for the object, too.

The possible privileges are:

`SELECT`
`INSERT`
`UPDATE`
`DELETE`
`TRUNCATE`
`REFERENCES`
`TRIGGER`
`CREATE`
`CONNECT`
`TEMPORARY`
`EXECUTE`
`USAGE`

Specific types of privileges, as defined in Section 5.7.

`TEMP`

Alternative spelling for `TEMPORARY`.

`ALL PRIVILEGES`

Grant all of the privileges available for the object's type. The `PRIVILEGES` key word is optional in Postgres Pro, though it is required by strict SQL.

The `FUNCTION` syntax works for plain functions, aggregate functions, and window functions, but not for procedures; use `PROCEDURE` for those. Alternatively, use `ROUTINE` to refer to a function, aggregate function, window function, or procedure regardless of its precise type.

There is also an option to grant privileges on all objects of the same type within one or more schemas. This functionality is currently supported only for tables, sequences, functions, and procedures. `ALL TABLES` also affects views and foreign tables, just like the specific-object `GRANT` command. `ALL FUNCTIONS` also affects aggregate and window functions, but not procedures, again just like the specific-object `GRANT` command. Use `ALL ROUTINES` to include procedures.

GRANT on Roles

This variant of the `GRANT` command grants membership in a role to one or more other roles. Membership in a role is significant because it conveys the privileges granted to a role to each of its members.

If `WITH ADMIN OPTION` is specified, the member can in turn grant membership in the role to others, and revoke membership in the role as well. Without the admin option, ordinary users cannot do that. A role is not considered to hold `WITH ADMIN OPTION` on itself, but it may grant or revoke membership in itself from a database session where the session user matches the role. Database superusers can grant or revoke membership in any role to anyone.

If `GRANTED BY` is specified, the grant is recorded as having been done by the specified role. Only database superusers may use this option, except when it names the same role executing the command.

Unlike the case with privileges, membership in a role cannot be granted to `PUBLIC`. Note also that this form of the command does not allow the noise word `GROUP` in *`role_specification`*.

Notes

The `REVOKE` command is used to revoke access privileges.

Since PostgreSQL 8.1, the concepts of users and groups have been unified into a single kind of entity called a role. It is therefore no longer necessary to use the keyword GROUP to identify whether a grantee is a user or a group. GROUP is still allowed in the command, but it is a noise word.

A user may perform SELECT, INSERT, etc. on a column if they hold that privilege for either the specific column or its whole table. Granting the privilege at the table level and then revoking it for one column will not do what one might wish: the table-level grant is unaffected by a column-level operation.

When a non-owner of an object attempts to GRANT privileges on the object, the command will fail outright if the user has no privileges whatsoever on the object. As long as some privilege is available, the command will proceed, but it will grant only those privileges for which the user has grant options. The GRANT ALL PRIVILEGES forms will issue a warning message if no grant options are held, while the other forms will issue a warning if grant options for any of the privileges specifically named in the command are not held. (In principle these statements apply to the object owner as well, but since the owner is always treated as holding all grant options, the cases can never occur.)

It should be noted that database superusers can access all objects regardless of object privilege settings. This is comparable to the rights of root in a Unix system. As with root, it's unwise to operate as a superuser except when absolutely necessary.

If a superuser chooses to issue a GRANT or REVOKE command, the command is performed as though it were issued by the owner of the affected object. In particular, privileges granted via such a command will appear to have been granted by the object owner. (For role membership, the membership appears to have been granted by the containing role itself.)

GRANT and REVOKE can also be done by a role that is not the owner of the affected object, but is a member of the role that owns the object, or is a member of a role that holds privileges WITH GRANT OPTION on the object. In this case the privileges will be recorded as having been granted by the role that actually owns the object or holds the privileges WITH GRANT OPTION. For example, if table t1 is owned by role g1, of which role u1 is a member, then u1 can grant privileges on t1 to u2, but those privileges will appear to have been granted directly by g1. Any other member of role g1 could revoke them later.

If the role executing GRANT holds the required privileges indirectly via more than one role membership path, it is unspecified which containing role will be recorded as having done the grant. In such cases it is best practice to use SET ROLE to become the specific role you want to do the GRANT as.

Granting permission on a table does not automatically extend permissions to any sequences used by the table, including sequences tied to SERIAL columns. Permissions on sequences must be set separately.

See Section 5.7 for more information about specific privilege types, as well as how to inspect objects' privileges.

Examples

Grant insert privilege to all users on table films:

```
GRANT INSERT ON films TO PUBLIC;
```

Grant all available privileges to user manuel on view kinds:

```
GRANT ALL PRIVILEGES ON kinds TO manuel;
```

Note that while the above will indeed grant all privileges if executed by a superuser or the owner of kinds, when executed by someone else it will only grant those permissions for which the someone else has grant options.

Grant membership in role admins to user joe:

```
GRANT admins TO joe;
```

Compatibility

According to the SQL standard, the PRIVILEGES key word in ALL PRIVILEGES is required. The SQL standard does not support setting the privileges on more than one object per command.

Postgres Pro allows an object owner to revoke their own ordinary privileges: for example, a table owner can make the table read-only to themselves by revoking their own `INSERT`, `UPDATE`, `DELETE`, and `TRUNCATE` privileges. This is not possible according to the SQL standard. The reason is that Postgres Pro treats the owner's privileges as having been granted by the owner to themselves; therefore they can revoke them too. In the SQL standard, the owner's privileges are granted by an assumed entity “_SYSTEM”. Not being “_SYSTEM”, the owner cannot revoke these rights.

According to the SQL standard, grant options can be granted to `PUBLIC`; Postgres Pro only supports granting grant options to roles.

The SQL standard allows the `GRANTED BY` option to specify only `CURRENT_USER` or `CURRENT_ROLE`. The other variants are PostgreSQL extensions.

The SQL standard provides for a `USAGE` privilege on other kinds of objects: character sets, collations, translations.

In the SQL standard, sequences only have a `USAGE` privilege, which controls the use of the `NEXT VALUE FOR` expression, which is equivalent to the function `nextval` in Postgres Pro. The sequence privileges `SELECT` and `UPDATE` are Postgres Pro extensions. The application of the sequence `USAGE` privilege to the `currval` function is also a Postgres Pro extension (as is the function itself).

Privileges on databases, tablespaces, schemas, and languages are Postgres Pro extensions.

See Also

REVOKE, ALTER DEFAULT PRIVILEGES

IMPORT FOREIGN SCHEMA

IMPORT FOREIGN SCHEMA — import table definitions from a foreign server

Synopsis

```
IMPORT FOREIGN SCHEMA remote_schema
    [ { LIMIT TO | EXCEPT } ( table_name [, ...] ) ]
    FROM SERVER server_name
    INTO local_schema
    [ OPTIONS ( option 'value' [, ... ] ) ]
```

Description

`IMPORT FOREIGN SCHEMA` creates foreign tables that represent tables existing on a foreign server. The new foreign tables will be owned by the user issuing the command and are created with the correct column definitions and options to match the remote tables.

By default, all tables and views existing in a particular schema on the foreign server are imported. Optionally, the list of tables can be limited to a specified subset, or specific tables can be excluded. The new foreign tables are all created in the target schema, which must already exist.

To use `IMPORT FOREIGN SCHEMA`, the user must have `USAGE` privilege on the foreign server, as well as `CREATE` privilege on the target schema.

Parameters

remote_schema

The remote schema to import from. The specific meaning of a remote schema depends on the foreign data wrapper in use.

`LIMIT TO ( table_name [, ...] )`

Import only foreign tables matching one of the given table names. Other tables existing in the foreign schema will be ignored.

`EXCEPT ( table_name [, ...] )`

Exclude specified foreign tables from the import. All tables existing in the foreign schema will be imported except the ones listed here.

server_name

The foreign server to import from.

local_schema

The schema in which the imported foreign tables will be created.

`OPTIONS ( option 'value' [, ...] )`

Options to be used during the import. The allowed option names and values are specific to each foreign data wrapper.

Examples

Import table definitions from a remote schema `foreign_films` on server `film_server`, creating the foreign tables in local schema `films`:

```
IMPORT FOREIGN SCHEMA foreign_films
    FROM SERVER film_server INTO films;
```

As above, but import only the two tables `actors` and `directors` (if they exist):

```
IMPORT FOREIGN SCHEMA foreign_films LIMIT TO (actors, directors)
    FROM SERVER film_server INTO films;
```

Compatibility

The `IMPORT FOREIGN SCHEMA` command conforms to the SQL standard, except that the `OPTIONS` clause is a Postgres Pro extension.

See Also

CREATE FOREIGN TABLE, CREATE SERVER

INSERT

INSERT — create new rows in a table

Synopsis

```
[ WITH [ RECURSIVE ] with_query [, ...] ]
INSERT INTO table_name [ AS alias ] [ ( column_name [, ...] ) ]
    [ OVERRIDING { SYSTEM | USER } VALUE ]
    { DEFAULT VALUES | VALUES ( { expression | DEFAULT } [, ...] ) [, ...] | query }
    [ ON CONFLICT [ conflict_target ] conflict_action ]
    [ RETURNING { * | output_expression [ [ AS ] output_name ] } [, ...] ]

where conflict_target can be one of:

    ( { index_column_name | ( index_expression ) } [ COLLATE collation ] [ opclass ]
 [, ...] ) [ WHERE index_predicate ]
    ON CONSTRAINT constraint_name

and conflict_action is one of:

    DO NOTHING
    DO UPDATE SET { column_name = { expression | DEFAULT } |
                    ( column_name [, ...] ) = [ ROW ] ( { expression | DEFAULT }
 [, ...] ) |
                    ( column_name [, ...] ) = ( sub-SELECT )
                  } [, ...]
              [ WHERE condition ]
```

Description

`INSERT` inserts new rows into a table. One can insert one or more rows specified by value expressions, or zero or more rows resulting from a query.

The target column names can be listed in any order. If no list of column names is given at all, the default is all the columns of the table in their declared order; or the first *N* column names, if there are only *N* columns supplied by the `VALUES` clause or *query*. The values supplied by the `VALUES` clause or *query* are associated with the explicit or implicit column list left-to-right.

Each column not present in the explicit or implicit column list will be filled with a default value, either its declared default value or null if there is none.

If the expression for any column is not of the correct data type, automatic type conversion will be attempted.

`INSERT` into tables that lack unique indexes will not be blocked by concurrent activity. Tables with unique indexes might block if concurrent sessions perform actions that lock or modify rows matching the unique index values being inserted; the details are covered in Section 62.5. `ON CONFLICT` can be used to specify an alternative action to raising a unique constraint or exclusion constraint violation error. (See ON CONFLICT Clause below.)

The optional `RETURNING` clause causes `INSERT` to compute and return value(s) based on each row actually inserted (or updated, if an `ON CONFLICT DO UPDATE` clause was used). This is primarily useful for obtaining values that were supplied by defaults, such as a serial sequence number. However, any expression using the table's columns is allowed. The syntax of the `RETURNING` list is identical to that of the output list of `SELECT`. Only rows that were successfully inserted or updated will be returned. For example, if a row was locked but not updated because an `ON CONFLICT DO UPDATE ... WHERE` clause *condition* was not satisfied, the row will not be returned.

You must have INSERT privilege on a table in order to insert into it. If ON CONFLICT DO UPDATE is present, UPDATE privilege on the table is also required.

If a column list is specified, you only need INSERT privilege on the listed columns. Similarly, when ON CONFLICT DO UPDATE is specified, you only need UPDATE privilege on the column(s) that are listed to be updated. However, ON CONFLICT DO UPDATE also requires SELECT privilege on any column whose values are read in the ON CONFLICT DO UPDATE expressions or *condition*.

Use of the RETURNING clause requires SELECT privilege on all columns mentioned in RETURNING. If you use the *query* clause to insert rows from a query, you of course need to have SELECT privilege on any table or column used in the query.

Parameters

Inserting

This section covers parameters that may be used when only inserting new rows. Parameters *exclusively* used with the ON CONFLICT clause are described separately.

with_query

The WITH clause allows you to specify one or more subqueries that can be referenced by name in the INSERT query. See Section 7.8 and SELECT for details.

It is possible for the *query* (SELECT statement) to also contain a WITH clause. In such a case both sets of *with_query* can be referenced within the *query*, but the second one takes precedence since it is more closely nested.

table_name

The name (optionally schema-qualified) of an existing table.

alias

A substitute name for *table_name*. When an alias is provided, it completely hides the actual name of the table. This is particularly useful when ON CONFLICT DO UPDATE targets a table named excluded, since that will otherwise be taken as the name of the special table representing the row proposed for insertion.

column_name

The name of a column in the table named by *table_name*. The column name can be qualified with a subfield name or array subscript, if needed. (Inserting into only some fields of a composite column leaves the other fields null.) When referencing a column with ON CONFLICT DO UPDATE, do not include the table's name in the specification of a target column. For example, INSERT INTO table_name ... ON CONFLICT DO UPDATE SET table_name.col = 1 is invalid (this follows the general behavior for UPDATE).

OVERRIDING SYSTEM VALUE

If this clause is specified, then any values supplied for identity columns will override the default sequence-generated values.

For an identity column defined as GENERATED ALWAYS, it is an error to insert an explicit value (other than DEFAULT) without specifying either OVERRIDING SYSTEM VALUE or OVERRIDING USER VALUE. (For an identity column defined as GENERATED BY DEFAULT, OVERRIDING SYSTEM VALUE is the normal behavior and specifying it does nothing, but PostgreSQL allows it as an extension.)

OVERRIDING USER VALUE

If this clause is specified, then any values supplied for identity columns are ignored and the default sequence-generated values are applied.

This clause is useful for example when copying values between tables. Writing `INSERT INTO tbl2 OVERRIDING USER VALUE SELECT * FROM tbl1` will copy from `tbl1` all columns that are not identity columns in `tbl2` while values for the identity columns in `tbl2` will be generated by the sequences associated with `tbl2`.

`DEFAULT VALUES`

All columns will be filled with their default values, as if `DEFAULT` were explicitly specified for each column. (An `OVERRIDING` clause is not permitted in this form.)

`expression`

An expression or value to assign to the corresponding column.

`DEFAULT`

The corresponding column will be filled with its default value. An identity column will be filled with a new value generated by the associated sequence. For a generated column, specifying this is permitted but merely specifies the normal behavior of computing the column from its generation expression.

`query`

A query (`SELECT` statement) that supplies the rows to be inserted. Refer to the SELECT statement for a description of the syntax.

`output_expression`

An expression to be computed and returned by the `INSERT` command after each row is inserted or updated. The expression can use any column names of the table named by *`table_name`*. Write `*` to return all columns of the inserted or updated row(s).

`output_name`

A name to use for a returned column.

`ON CONFLICT` Clause

The optional `ON CONFLICT` clause specifies an alternative action to raising a unique violation or exclusion constraint violation error. For each individual row proposed for insertion, either the insertion proceeds, or, if an *arbiter* constraint or index specified by *`conflict_target`* is violated, the alternative *`conflict_action`* is taken. `ON CONFLICT DO NOTHING` simply avoids inserting a row as its alternative action. `ON CONFLICT DO UPDATE` updates the existing row that conflicts with the row proposed for insertion as its alternative action.

`conflict_target` can perform *unique index inference*. When performing inference, it consists of one or more *`index_column_name`* columns and/or *`index_expression`* expressions, and an optional *`index_predicate`*. All *`table_name`* unique indexes that, without regard to order, contain exactly the *`conflict_target`*-specified columns/expressions are inferred (chosen) as arbiter indexes. If an *`index_predicate`* is specified, it must, as a further requirement for inference, satisfy arbiter indexes. Note that this means a non-partial unique index (a unique index without a predicate) will be inferred (and thus used by `ON CONFLICT`) if such an index satisfying every other criteria is available. If an attempt at inference is unsuccessful, an error is raised.

`ON CONFLICT DO UPDATE` guarantees an atomic `INSERT` or `UPDATE` outcome; provided there is no independent error, one of those two outcomes is guaranteed, even under high concurrency. This is also known as *UPSERT* — "UPDATE or INSERT".

`conflict_target`

Specifies which conflicts `ON CONFLICT` takes the alternative action on by choosing *arbiter indexes*. Either performs *unique index inference*, or names a constraint explicitly. For `ON CONFLICT DO NOTHING`, it is optional to specify a *`conflict_target`*; when omitted, conflicts with all usable constraints (and unique indexes) are handled. For `ON CONFLICT DO UPDATE`, a *`conflict_target`* *must* be provided.

conflict_action

conflict_action specifies an alternative ON CONFLICT action. It can be either DO NOTHING, or a DO UPDATE clause specifying the exact details of the UPDATE action to be performed in case of a conflict. The SET and WHERE clauses in ON CONFLICT DO UPDATE have access to the existing row using the table's name (or an alias), and to the row proposed for insertion using the special excluded table. SELECT privilege is required on any column in the target table where corresponding excluded columns are read.

Note that the effects of all per-row BEFORE INSERT triggers are reflected in excluded values, since those effects may have contributed to the row being excluded from insertion.

index_column_name

The name of a *table_name* column. Used to infer arbiter indexes. Follows CREATE INDEX format. SELECT privilege on *index_column_name* is required.

index_expression

Similar to *index_column_name*, but used to infer expressions on *table_name* columns appearing within index definitions (not simple columns). Follows CREATE INDEX format. SELECT privilege on any column appearing within *index_expression* is required.

collation

When specified, mandates that corresponding *index_column_name* or *index_expression* use a particular collation in order to be matched during inference. Typically this is omitted, as collations usually do not affect whether or not a constraint violation occurs. Follows CREATE INDEX format.

opclass

When specified, mandates that corresponding *index_column_name* or *index_expression* use particular operator class in order to be matched during inference. Typically this is omitted, as the *equality* semantics are often equivalent across a type's operator classes anyway, or because it's sufficient to trust that the defined unique indexes have the pertinent definition of equality. Follows CREATE INDEX format.

index_predicate

Used to allow inference of partial unique indexes. Any indexes that satisfy the predicate (which need not actually be partial indexes) can be inferred. Follows CREATE INDEX format. SELECT privilege on any column appearing within *index_predicate* is required.

constraint_name

Explicitly specifies an arbiter *constraint* by name, rather than inferring a constraint or index.

condition

An expression that returns a value of type boolean. Only rows for which this expression returns true will be updated, although all rows will be locked when the ON CONFLICT DO UPDATE action is taken. Note that *condition* is evaluated last, after a conflict has been identified as a candidate to update.

Note that exclusion constraints are not supported as arbiters with ON CONFLICT DO UPDATE. In all cases, only NOT DEFERRABLE constraints and unique indexes are supported as arbiters.

INSERT with an ON CONFLICT DO UPDATE clause is a “deterministic” statement. This means that the command will not be allowed to affect any single existing row more than once; a cardinality violation error will be raised when this situation arises. Rows proposed for insertion should not duplicate each other in terms of attributes constrained by an arbiter index or constraint.

Note that it is currently not supported for the ON CONFLICT DO UPDATE clause of an INSERT applied to a partitioned table to update the partition key of a conflicting row such that it requires the row be moved to a new partition.

> **Tip**
>
> It is often preferable to use unique index inference rather than naming a constraint directly using `ON CONFLICT ON CONSTRAINT` *`constraint_name`*. Inference will continue to work correctly when the underlying index is replaced by another more or less equivalent index in an overlapping way, for example when using `CREATE UNIQUE INDEX ... CONCURRENTLY` before dropping the index being replaced.

Outputs

On successful completion, an `INSERT` command returns a command tag of the form

```
INSERT oid count
```

The *`count`* is the number of rows inserted or updated. *`oid`* is always 0 (it used to be the OID assigned to the inserted row if *`count`* was exactly one and the target table was declared `WITH OIDS` and 0 otherwise, but creating a table `WITH OIDS` is not supported anymore).

If the `INSERT` command contains a `RETURNING` clause, the result will be similar to that of a `SELECT` statement containing the columns and values defined in the `RETURNING` list, computed over the row(s) inserted or updated by the command.

Notes

If the specified table is a partitioned table, each row is routed to the appropriate partition and inserted into it. If the specified table is a partition, an error will occur if one of the input rows violates the partition constraint.

Examples

Insert a single row into table `films`:

```
INSERT INTO films VALUES
    ('UA502', 'Bananas', 105, '1971-07-13', 'Comedy', '82 minutes');
```

In this example, the `len` column is omitted and therefore it will have the default value:

```
INSERT INTO films (code, title, did, date_prod, kind)
    VALUES ('T_601', 'Yojimbo', 106, '1961-06-16', 'Drama');
```

This example uses the `DEFAULT` clause for the date columns rather than specifying a value:

```
INSERT INTO films VALUES
    ('UA502', 'Bananas', 105, DEFAULT, 'Comedy', '82 minutes');
INSERT INTO films (code, title, did, date_prod, kind)
    VALUES ('T_601', 'Yojimbo', 106, DEFAULT, 'Drama');
```

To insert a row consisting entirely of default values:

```
INSERT INTO films DEFAULT VALUES;
```

To insert multiple rows using the multirow `VALUES` syntax:

```
INSERT INTO films (code, title, did, date_prod, kind) VALUES
    ('B6717', 'Tampopo', 110, '1985-02-10', 'Comedy'),
    ('HG120', 'The Dinner Game', 140, DEFAULT, 'Comedy');
```

This example inserts some rows into table `films` from a table `tmp_films` with the same column layout as `films`:

```
INSERT INTO films SELECT * FROM tmp_films WHERE date_prod < '2004-05-07';
```

This example inserts into array columns:

```
-- Create an empty 3x3 gameboard for noughts-and-crosses
INSERT INTO tictactoe (game, board[1:3][1:3])
    VALUES (1, '{{" "," "," "},{" "," "," "},{" "," "," "}}');
-- The subscripts in the above example aren't really needed
INSERT INTO tictactoe (game, board)
    VALUES (2, '{{X," "," "},{" ",O," "},{" ",X," "}}');
```

Insert a single row into table `distributors`, returning the sequence number generated by the `DEFAULT` clause:

```
INSERT INTO distributors (did, dname) VALUES (DEFAULT, 'XYZ Widgets')
   RETURNING did;
```

Increment the sales count of the salesperson who manages the account for Acme Corporation, and record the whole updated row along with current time in a log table:

```
WITH upd AS (
  UPDATE employees SET sales_count = sales_count + 1 WHERE id =
    (SELECT sales_person FROM accounts WHERE name = 'Acme Corporation')
    RETURNING *
)
INSERT INTO employees_log SELECT *, current_timestamp FROM upd;
```

Insert or update new distributors as appropriate. Assumes a unique index has been defined that constrains values appearing in the `did` column. Note that the special `excluded` table is used to reference values originally proposed for insertion:

```
INSERT INTO distributors (did, dname)
    VALUES (5, 'Gizmo Transglobal'), (6, 'Associated Computing, Inc')
    ON CONFLICT (did) DO UPDATE SET dname = EXCLUDED.dname;
```

Insert a distributor, or do nothing for rows proposed for insertion when an existing, excluded row (a row with a matching constrained column or columns after before row insert triggers fire) exists. Example assumes a unique index has been defined that constrains values appearing in the `did` column:

```
INSERT INTO distributors (did, dname) VALUES (7, 'Redline GmbH')
    ON CONFLICT (did) DO NOTHING;
```

Insert or update new distributors as appropriate. Example assumes a unique index has been defined that constrains values appearing in the `did` column. `WHERE` clause is used to limit the rows actually updated (any existing row not updated will still be locked, though):

```
-- Don't update existing distributors based in a certain ZIP code
INSERT INTO distributors AS d (did, dname) VALUES (8, 'Anvil Distribution')
    ON CONFLICT (did) DO UPDATE
    SET dname = EXCLUDED.dname || ' (formerly ' || d.dname || ')'
    WHERE d.zipcode <> '21201';

-- Name a constraint directly in the statement (uses associated
-- index to arbitrate taking the DO NOTHING action)
INSERT INTO distributors (did, dname) VALUES (9, 'Antwerp Design')
    ON CONFLICT ON CONSTRAINT distributors_pkey DO NOTHING;
```

Insert new distributor if possible; otherwise `DO NOTHING`. Example assumes a unique index has been defined that constrains values appearing in the `did` column on a subset of rows where the `is_active` Boolean column evaluates to `true`:

```
-- This statement could infer a partial unique index on "did"
-- with a predicate of "WHERE is_active", but it could also
-- just use a regular unique constraint on "did"
```

```
INSERT INTO distributors (did, dname) VALUES (10, 'Conrad International')
    ON CONFLICT (did) WHERE is_active DO NOTHING;
```

Compatibility

`INSERT` conforms to the SQL standard, except that the `RETURNING` clause is a Postgres Pro extension, as is the ability to use `WITH` with `INSERT`, and the ability to specify an alternative action with `ON CONFLICT`. Also, the case in which a column name list is omitted, but not all the columns are filled from the `VALUES` clause or *`query`*, is disallowed by the standard.

The SQL standard specifies that `OVERRIDING SYSTEM VALUE` can only be specified if an identity column that is generated always exists. Postgres Pro allows the clause in any case and ignores it if it is not applicable.

Possible limitations of the *`query`* clause are documented under SELECT.

LISTEN

LISTEN — listen for a notification

Synopsis

```
LISTEN channel
```

Description

`LISTEN` registers the current session as a listener on the notification channel named *channel*. If the current session is already registered as a listener for this notification channel, nothing is done.

Whenever the command `NOTIFY` *channel* is invoked, either by this session or another one connected to the same database, all the sessions currently listening on that notification channel are notified, and each will in turn notify its connected client application.

A session can be unregistered for a given notification channel with the `UNLISTEN` command. A session's listen registrations are automatically cleared when the session ends.

The method a client application must use to detect notification events depends on which Postgres Pro application programming interface it uses. With the libpq library, the application issues `LISTEN` as an ordinary SQL command, and then must periodically call the function `PQnotifies` to find out whether any notification events have been received. Other interfaces such as libpgtcl provide higher-level methods for handling notify events; indeed, with libpgtcl the application programmer should not even issue `LISTEN` or `UNLISTEN` directly. See the documentation for the interface you are using for more details.

Parameters

channel

Name of a notification channel (any identifier).

Notes

`LISTEN` takes effect at transaction commit. If `LISTEN` or `UNLISTEN` is executed within a transaction that later rolls back, the set of notification channels being listened to is unchanged.

A transaction that has executed `LISTEN` cannot be prepared for two-phase commit.

There is a race condition when first setting up a listening session: if concurrently-committing transactions are sending notify events, exactly which of those will the newly listening session receive? The answer is that the session will receive all events committed after an instant during the transaction's commit step. But that is slightly later than any database state that the transaction could have observed in queries. This leads to the following rule for using `LISTEN`: first execute (and commit!) that command, then in a new transaction inspect the database state as needed by the application logic, then rely on notifications to find out about subsequent changes to the database state. The first few received notifications might refer to updates already observed in the initial database inspection, but this is usually harmless.

NOTIFY contains a more extensive discussion of the use of `LISTEN` and `NOTIFY`.

Examples

Configure and execute a listen/notify sequence from psql:

```
LISTEN virtual;
NOTIFY virtual;
Asynchronous notification "virtual" received from server process with PID 8448.
```

Compatibility

There is no `LISTEN` statement in the SQL standard.

See Also

NOTIFY, UNLISTEN

LOAD

LOAD — load a shared library file

Synopsis

```
LOAD 'filename'
```

Description

This command loads a shared library file into the Postgres Pro server's address space. If the file has been loaded already, the command does nothing. Shared library files that contain C functions are automatically loaded whenever one of their functions is called. Therefore, an explicit `LOAD` is usually only needed to load a library that modifies the server's behavior through “hooks” rather than providing a set of functions.

The library file name is typically given as just a bare file name, which is sought in the server's library search path (set by dynamic_library_path). Alternatively it can be given as a full path name. In either case the platform's standard shared library file name extension may be omitted. See Section 40.10.1 for more information on this topic.

Non-superusers can only apply `LOAD` to library files located in `$libdir/plugins/` — the specified *filename* must begin with exactly that string. (It is the database administrator's responsibility to ensure that only “safe” libraries are installed there.)

Compatibility

`LOAD` is a Postgres Pro extension.

See Also

CREATE FUNCTION

LOCK

LOCK — lock a table

Synopsis

```
LOCK [ TABLE ] [ ONLY ] name [ * ] [, ...] [ IN lockmode MODE ] [ NOWAIT ]

where lockmode is one of:

    ACCESS SHARE | ROW SHARE | ROW EXCLUSIVE | SHARE UPDATE EXCLUSIVE
    | SHARE | SHARE ROW EXCLUSIVE | EXCLUSIVE | ACCESS EXCLUSIVE
```

Description

`LOCK TABLE` obtains a table-level lock, waiting if necessary for any conflicting locks to be released. If `NOWAIT` is specified, `LOCK TABLE` does not wait to acquire the desired lock: if it cannot be acquired immediately, the command is aborted and an error is emitted. Once obtained, the lock is held for the remainder of the current transaction. (There is no `UNLOCK TABLE` command; locks are always released at transaction end.)

When a view is locked, all relations appearing in the view definition query are also locked recursively with the same lock mode.

When acquiring locks automatically for commands that reference tables, Postgres Pro always uses the least restrictive lock mode possible. `LOCK TABLE` provides for cases when you might need more restrictive locking. For example, suppose an application runs a transaction at the `READ COMMITTED` isolation level and needs to ensure that data in a table remains stable for the duration of the transaction. To achieve this you could obtain `SHARE` lock mode over the table before querying. This will prevent concurrent data changes and ensure subsequent reads of the table see a stable view of committed data, because `SHARE` lock mode conflicts with the `ROW EXCLUSIVE` lock acquired by writers, and your `LOCK TABLE name IN SHARE MODE` statement will wait until any concurrent holders of `ROW EXCLUSIVE` mode locks commit or roll back. Thus, once you obtain the lock, there are no uncommitted writes outstanding; furthermore none can begin until you release the lock.

To achieve a similar effect when running a transaction at the `REPEATABLE READ` or `SERIALIZABLE` isolation level, you have to execute the `LOCK TABLE` statement before executing any `SELECT` or data modification statement. A `REPEATABLE READ` or `SERIALIZABLE` transaction's view of data will be frozen when its first `SELECT` or data modification statement begins. A `LOCK TABLE` later in the transaction will still prevent concurrent writes — but it won't ensure that what the transaction reads corresponds to the latest committed values.

If a transaction of this sort is going to change the data in the table, then it should use `SHARE ROW EXCLUSIVE` lock mode instead of `SHARE` mode. This ensures that only one transaction of this type runs at a time. Without this, a deadlock is possible: two transactions might both acquire `SHARE` mode, and then be unable to also acquire `ROW EXCLUSIVE` mode to actually perform their updates. (Note that a transaction's own locks never conflict, so a transaction can acquire `ROW EXCLUSIVE` mode when it holds `SHARE` mode — but not if anyone else holds `SHARE` mode.) To avoid deadlocks, make sure all transactions acquire locks on the same objects in the same order, and if multiple lock modes are involved for a single object, then transactions should always acquire the most restrictive mode first.

More information about the lock modes and locking strategies can be found in Section 13.3.

Parameters

name

The name (optionally schema-qualified) of an existing table to lock. If `ONLY` is specified before the table name, only that table is locked. If `ONLY` is not specified, the table and all its descendant tables

(if any) are locked. Optionally, * can be specified after the table name to explicitly indicate that descendant tables are included.

The command LOCK TABLE a, b; is equivalent to LOCK TABLE a; LOCK TABLE b;. The tables are locked one-by-one in the order specified in the LOCK TABLE command.

lockmode

The lock mode specifies which locks this lock conflicts with. Lock modes are described in Section 13.3.

If no lock mode is specified, then ACCESS EXCLUSIVE, the most restrictive mode, is used.

NOWAIT

Specifies that LOCK TABLE should not wait for any conflicting locks to be released: if the specified lock(s) cannot be acquired immediately without waiting, the transaction is aborted.

Notes

LOCK TABLE ... IN ACCESS SHARE MODE requires SELECT privileges on the target table. LOCK TABLE ... IN ROW EXCLUSIVE MODE requires INSERT, UPDATE, DELETE, or TRUNCATE privileges on the target table. All other forms of LOCK require table-level UPDATE, DELETE, or TRUNCATE privileges.

The user performing the lock on the view must have the corresponding privilege on the view. In addition the view's owner must have the relevant privileges on the underlying base relations, but the user performing the lock does not need any permissions on the underlying base relations.

LOCK TABLE is useless outside a transaction block: the lock would remain held only to the completion of the statement. Therefore Postgres Pro reports an error if LOCK is used outside a transaction block. Use BEGIN and COMMIT (or ROLLBACK) to define a transaction block.

LOCK TABLE only deals with table-level locks, and so the mode names involving ROW are all misnomers. These mode names should generally be read as indicating the intention of the user to acquire row-level locks within the locked table. Also, ROW EXCLUSIVE mode is a shareable table lock. Keep in mind that all the lock modes have identical semantics so far as LOCK TABLE is concerned, differing only in the rules about which modes conflict with which. For information on how to acquire an actual row-level lock, see Section 13.3.2 and The Locking Clause in the SELECT documentation.

Examples

Obtain a SHARE lock on a primary key table when going to perform inserts into a foreign key table:

```
BEGIN WORK;
LOCK TABLE films IN SHARE MODE;
SELECT id FROM films
    WHERE name = 'Star Wars: Episode I - The Phantom Menace';
-- Do ROLLBACK if record was not returned
INSERT INTO films_user_comments VALUES
    (_id_, 'GREAT! I was waiting for it for so long!');
COMMIT WORK;
```

Take a SHARE ROW EXCLUSIVE lock on a primary key table when going to perform a delete operation:

```
BEGIN WORK;
LOCK TABLE films IN SHARE ROW EXCLUSIVE MODE;
DELETE FROM films_user_comments WHERE id IN
    (SELECT id FROM films WHERE rating < 5);
DELETE FROM films WHERE rating < 5;
COMMIT WORK;
```

Compatibility

There is no `LOCK TABLE` in the SQL standard, which instead uses `SET TRANSACTION` to specify concurrency levels on transactions. Postgres Pro supports that too; see SET TRANSACTION for details.

Except for `ACCESS SHARE`, `ACCESS EXCLUSIVE`, and `SHARE UPDATE EXCLUSIVE` lock modes, the Postgres Pro lock modes and the `LOCK TABLE` syntax are compatible with those present in Oracle.

MOVE

MOVE — position a cursor

Synopsis

```
MOVE [ direction ] [ FROM | IN ] cursor_name

where direction can be one of:

    NEXT
    PRIOR
    FIRST
    LAST
    ABSOLUTE count
    RELATIVE count
    count
    ALL
    FORWARD
    FORWARD count
    FORWARD ALL
    BACKWARD
    BACKWARD count
    BACKWARD ALL
```

Description

`MOVE` repositions a cursor without retrieving any data. `MOVE` works exactly like the `FETCH` command, except it only positions the cursor and does not return rows.

The parameters for the `MOVE` command are identical to those of the `FETCH` command; refer to FETCH for details on syntax and usage.

Outputs

On successful completion, a `MOVE` command returns a command tag of the form

```
MOVE count
```

The *count* is the number of rows that a `FETCH` command with the same parameters would have returned (possibly zero).

Examples

```
BEGIN WORK;
DECLARE liahona CURSOR FOR SELECT * FROM films;

-- Skip the first 5 rows:
MOVE FORWARD 5 IN liahona;
MOVE 5

-- Fetch the 6th row from the cursor liahona:
FETCH 1 FROM liahona;
 code  | title  | did | date_prod  |  kind  |  len
-------+--------+-----+------------+--------+-------
 P_303 | 48 Hrs | 103 | 1982-10-22 | Action | 01:37
(1 row)
```

```
-- Close the cursor liahona and end the transaction:
CLOSE liahona;
COMMIT WORK;
```

Compatibility

There is no `MOVE` statement in the SQL standard.

See Also

CLOSE, DECLARE, FETCH

NOTIFY

NOTIFY — generate a notification

Synopsis

```
NOTIFY channel [ , payload ]
```

Description

The NOTIFY command sends a notification event together with an optional “payload” string to each client application that has previously executed LISTEN *channel* for the specified channel name in the current database. Notifications are visible to all users.

NOTIFY provides a simple interprocess communication mechanism for a collection of processes accessing the same Postgres Pro database. A payload string can be sent along with the notification, and higher-level mechanisms for passing structured data can be built by using tables in the database to pass additional data from notifier to listener(s).

The information passed to the client for a notification event includes the notification channel name, the notifying session's server process PID, and the payload string, which is an empty string if it has not been specified.

It is up to the database designer to define the channel names that will be used in a given database and what each one means. Commonly, the channel name is the same as the name of some table in the database, and the notify event essentially means, “I changed this table, take a look at it to see what's new”. But no such association is enforced by the NOTIFY and LISTEN commands. For example, a database designer could use several different channel names to signal different sorts of changes to a single table. Alternatively, the payload string could be used to differentiate various cases.

When NOTIFY is used to signal the occurrence of changes to a particular table, a useful programming technique is to put the NOTIFY in a statement trigger that is triggered by table updates. In this way, notification happens automatically when the table is changed, and the application programmer cannot accidentally forget to do it.

NOTIFY interacts with SQL transactions in some important ways. Firstly, if a NOTIFY is executed inside a transaction, the notify events are not delivered until and unless the transaction is committed. This is appropriate, since if the transaction is aborted, all the commands within it have had no effect, including NOTIFY. But it can be disconcerting if one is expecting the notification events to be delivered immediately. Secondly, if a listening session receives a notification signal while it is within a transaction, the notification event will not be delivered to its connected client until just after the transaction is completed (either committed or aborted). Again, the reasoning is that if a notification were delivered within a transaction that was later aborted, one would want the notification to be undone somehow — but the server cannot “take back” a notification once it has sent it to the client. So notification events are only delivered between transactions. The upshot of this is that applications using NOTIFY for real-time signaling should try to keep their transactions short.

If the same channel name is signaled multiple times with identical payload strings within the same transaction, only one instance of the notification event is delivered to listeners. On the other hand, notifications with distinct payload strings will always be delivered as distinct notifications. Similarly, notifications from different transactions will never get folded into one notification. Except for dropping later instances of duplicate notifications, NOTIFY guarantees that notifications from the same transaction get delivered in the order they were sent. It is also guaranteed that messages from different transactions are delivered in the order in which the transactions committed.

It is common for a client that executes NOTIFY to be listening on the same notification channel itself. In that case it will get back a notification event, just like all the other listening sessions. Depending on the application logic, this could result in useless work, for example, reading a database table to find the

same updates that that session just wrote out. It is possible to avoid such extra work by noticing whether the notifying session's server process PID (supplied in the notification event message) is the same as one's own session's PID (available from libpq). When they are the same, the notification event is one's own work bouncing back, and can be ignored.

Parameters

channel

Name of the notification channel to be signaled (any identifier).

payload

The “payload” string to be communicated along with the notification. This must be specified as a simple string literal. In the default configuration it must be shorter than 8000 bytes. (If binary data or large amounts of information need to be communicated, it's best to put it in a database table and send the key of the record.)

Notes

There is a queue that holds notifications that have been sent but not yet processed by all listening sessions. If this queue becomes full, transactions calling `NOTIFY` will fail at commit. The queue is quite large (8GB in a standard installation) and should be sufficiently sized for almost every use case. However, no cleanup can take place if a session executes `LISTEN` and then enters a transaction for a very long time. Once the queue is half full you will see warnings in the log file pointing you to the session that is preventing cleanup. In this case you should make sure that this session ends its current transaction so that cleanup can proceed.

The function `pg_notification_queue_usage` returns the fraction of the queue that is currently occupied by pending notifications. See Section 9.26 for more information.

A transaction that has executed `NOTIFY` cannot be prepared for two-phase commit.

pg_notify

To send a notification you can also use the function `pg_notify(text, text)`. The function takes the channel name as the first argument and the payload as the second. The function is much easier to use than the `NOTIFY` command if you need to work with non-constant channel names and payloads.

Examples

Configure and execute a listen/notify sequence from psql:

```
LISTEN virtual;
NOTIFY virtual;
Asynchronous notification "virtual" received from server process with PID 8448.
NOTIFY virtual, 'This is the payload';
Asynchronous notification "virtual" with payload "This is the payload" received from
 server process with PID 8448.

LISTEN foo;
SELECT pg_notify('fo' || 'o', 'pay' || 'load');
Asynchronous notification "foo" with payload "payload" received from server process
 with PID 14728.
```

Compatibility

There is no `NOTIFY` statement in the SQL standard.

See Also

LISTEN, UNLISTEN

PREPARE

PREPARE — prepare a statement for execution

Synopsis

```
PREPARE name [ ( data_type [, ...] ) ] AS statement
```

Description

`PREPARE` creates a prepared statement. A prepared statement is a server-side object that can be used to optimize performance. When the `PREPARE` statement is executed, the specified statement is parsed, analyzed, and rewritten. When an `EXECUTE` command is subsequently issued, the prepared statement is planned and executed. This division of labor avoids repetitive parse analysis work, while allowing the execution plan to depend on the specific parameter values supplied.

Prepared statements can take parameters: values that are substituted into the statement when it is executed. When creating the prepared statement, refer to parameters by position, using `$1`, `$2`, etc. A corresponding list of parameter data types can optionally be specified. When a parameter's data type is not specified or is declared as `unknown`, the type is inferred from the context in which the parameter is first referenced (if possible). When executing the statement, specify the actual values for these parameters in the `EXECUTE` statement. Refer to EXECUTE for more information about that.

Prepared statements only last for the duration of the current database session. When the session ends, the prepared statement is forgotten, so it must be recreated before being used again. This also means that a single prepared statement cannot be used by multiple simultaneous database clients; however, each client can create their own prepared statement to use. Prepared statements can be manually cleaned up using the `DEALLOCATE` command.

Prepared statements potentially have the largest performance advantage when a single session is being used to execute a large number of similar statements. The performance difference will be particularly significant if the statements are complex to plan or rewrite, e.g., if the query involves a join of many tables or requires the application of several rules. If the statement is relatively simple to plan and rewrite but relatively expensive to execute, the performance advantage of prepared statements will be less noticeable.

Parameters

name

An arbitrary name given to this particular prepared statement. It must be unique within a single session and is subsequently used to execute or deallocate a previously prepared statement.

data_type

The data type of a parameter to the prepared statement. If the data type of a particular parameter is unspecified or is specified as `unknown`, it will be inferred from the context in which the parameter is first referenced. To refer to the parameters in the prepared statement itself, use `$1`, `$2`, etc.

statement

Any `SELECT`, `INSERT`, `UPDATE`, `DELETE`, or `VALUES` statement.

Notes

A prepared statement can be executed with either a *generic plan* or a *custom plan*. A generic plan is the same across all executions, while a custom plan is generated for a specific execution using the parameter values given in that call. Use of a generic plan avoids planning overhead, but in some situations a custom plan will be much more efficient to execute because the planner can make use of knowledge of the

parameter values. (Of course, if the prepared statement has no parameters, then this is moot and a generic plan is always used.)

By default (that is, when plan_cache_mode is set to `auto`), the server will automatically choose whether to use a generic or custom plan for a prepared statement that has parameters. The current rule for this is that the first five executions are done with custom plans and the average estimated cost of those plans is calculated. Then a generic plan is created and its estimated cost is compared to the average custom-plan cost. Subsequent executions use the generic plan if its cost is not so much higher than the average custom-plan cost as to make repeated replanning seem preferable.

This heuristic can be overridden, forcing the server to use either generic or custom plans, by setting `plan_cache_mode` to `force_generic_plan` or `force_custom_plan` respectively. This setting is primarily useful if the generic plan's cost estimate is badly off for some reason, allowing it to be chosen even though its actual cost is much more than that of a custom plan.

By default, generic plans for only 64 most recent prepared statements are kept in memory; older statements have to be parsed and analyzed again if they are called later. This limit is enforced by the plan_cache_lru_size configuration parameter, which enables you to control the amount of memory used by prepared statements. If you would like to keep plans in memory for all prepared statements as long as possible, set this parameter to `0`.

To examine the query plan Postgres Pro is using for a prepared statement, use `EXPLAIN`, for example

```
EXPLAIN EXECUTE name(parameter_values);
```

If a generic plan is in use, it will contain parameter symbols `$n`, while a custom plan will have the supplied parameter values substituted into it.

For more information on query planning and the statistics collected by Postgres Pro for that purpose, see the ANALYZE documentation.

Although the main point of a prepared statement is to avoid repeated parse analysis and planning of the statement, Postgres Pro will force re-analysis and re-planning of the statement before using it whenever database objects used in the statement have undergone definitional (DDL) changes or their planner statistics have been updated since the previous use of the prepared statement. Also, if the value of search_path changes from one use to the next, the statement will be re-parsed using the new `search_path`. (This latter behavior is new as of PostgreSQL 9.3.) These rules make use of a prepared statement semantically almost equivalent to re-submitting the same query text over and over, but with a performance benefit if no object definitions are changed, especially if the best plan remains the same across uses. An example of a case where the semantic equivalence is not perfect is that if the statement refers to a table by an unqualified name, and then a new table of the same name is created in a schema appearing earlier in the `search_path`, no automatic re-parse will occur since no object used in the statement changed. However, if some other change forces a re-parse, the new table will be referenced in subsequent uses.

You can see all prepared statements available in the session by querying the `pg_prepared_statements` system view.

Examples

Create a prepared statement for an `INSERT` statement, and then execute it:

```
PREPARE fooplan (int, text, bool, numeric) AS
    INSERT INTO foo VALUES($1, $2, $3, $4);
EXECUTE fooplan(1, 'Hunter Valley', 't', 200.00);
```

Create a prepared statement for a `SELECT` statement, and then execute it:

```
PREPARE usrrptplan (int) AS
    SELECT * FROM users u, logs l WHERE u.usrid=$1 AND u.usrid=l.usrid
    AND l.date = $2;
```

```
EXECUTE usrrptplan(1, current_date);
```

In this example, the data type of the second parameter is not specified, so it is inferred from the context in which `$2` is used.

Compatibility

The SQL standard includes a `PREPARE` statement, but it is only for use in embedded SQL. This version of the `PREPARE` statement also uses a somewhat different syntax.

See Also

DEALLOCATE, EXECUTE

PREPARE TRANSACTION

PREPARE TRANSACTION — prepare the current transaction for two-phase commit

Synopsis

```
PREPARE TRANSACTION transaction_id
```

Description

`PREPARE TRANSACTION` prepares the current transaction for two-phase commit. After this command, the transaction is no longer associated with the current session; instead, its state is fully stored on disk, and there is a very high probability that it can be committed successfully, even if a database crash occurs before the commit is requested.

Once prepared, a transaction can later be committed or rolled back with `COMMIT PREPARED` or `ROLLBACK PREPARED`, respectively. Those commands can be issued from any session, not only the one that executed the original transaction.

From the point of view of the issuing session, `PREPARE TRANSACTION` is not unlike a `ROLLBACK` command: after executing it, there is no active current transaction, and the effects of the prepared transaction are no longer visible. (The effects will become visible again if the transaction is committed.)

If the `PREPARE TRANSACTION` command fails for any reason, it becomes a `ROLLBACK`: the current transaction is canceled.

Parameters

transaction_id

An arbitrary identifier that later identifies this transaction for `COMMIT PREPARED` or `ROLLBACK PREPARED`. The identifier must be written as a string literal, and must be less than 200 bytes long. It must not be the same as the identifier used for any currently prepared transaction.

Notes

`PREPARE TRANSACTION` is not intended for use in applications or interactive sessions. Its purpose is to allow an external transaction manager to perform atomic global transactions across multiple databases or other transactional resources. Unless you're writing a transaction manager, you probably shouldn't be using `PREPARE TRANSACTION`.

This command must be used inside a transaction block. Use `BEGIN` to start one.

It is not currently allowed to `PREPARE` a transaction that has executed any operations involving temporary tables or the session's temporary namespace, created any cursors `WITH HOLD`, or executed `LISTEN`, `UNLISTEN`, or `NOTIFY`. Those features are too tightly tied to the current session to be useful in a transaction to be prepared.

If the transaction modified any run-time parameters with `SET` (without the `LOCAL` option), those effects persist after `PREPARE TRANSACTION`, and will not be affected by any later `COMMIT PREPARED` or `ROLLBACK PREPARED`. Thus, in this one respect `PREPARE TRANSACTION` acts more like `COMMIT` than `ROLLBACK`.

All currently available prepared transactions are listed in the `pg_prepared_xacts` system view.

Caution

It is unwise to leave transactions in the prepared state for a long time. This will interfere with the ability of `VACUUM` to reclaim storage. Keep in mind also that the transaction continues to hold

whatever locks it held. The intended usage of the feature is that a prepared transaction will normally be committed or rolled back as soon as an external transaction manager has verified that other databases are also prepared to commit.

If you have not set up an external transaction manager to track prepared transactions and ensure they get closed out promptly, it is best to keep the prepared-transaction feature disabled by setting max_prepared_transactions to zero. This will prevent accidental creation of prepared transactions that might then be forgotten and eventually cause problems.

Examples

Prepare the current transaction for two-phase commit, using `foobar` as the transaction identifier:

```
PREPARE TRANSACTION 'foobar';
```

Compatibility

`PREPARE TRANSACTION` is a Postgres Pro extension. It is intended for use by external transaction management systems, some of which are covered by standards (such as X/Open XA), but the SQL side of those systems is not standardized.

See Also

COMMIT PREPARED, ROLLBACK PREPARED

REASSIGN OWNED

REASSIGN OWNED — change the ownership of database objects owned by a database role

Synopsis

```
REASSIGN OWNED BY { old_role | CURRENT_ROLE | CURRENT_USER | SESSION_USER } [, ...]
               TO { new_role | CURRENT_ROLE | CURRENT_USER | SESSION_USER }
```

Description

`REASSIGN OWNED` instructs the system to change the ownership of database objects owned by any of the *`old_roles`* to *`new_role`*.

Parameters

`old_role`

The name of a role. The ownership of all the objects within the current database, and of all shared objects (databases, tablespaces), owned by this role will be reassigned to *`new_role`*.

`new_role`

The name of the role that will be made the new owner of the affected objects.

Notes

`REASSIGN OWNED` is often used to prepare for the removal of one or more roles. Because `REASSIGN OWNED` does not affect objects within other databases, it is usually necessary to execute this command in each database that contains objects owned by a role that is to be removed.

`REASSIGN OWNED` requires membership on both the source role(s) and the target role.

The `DROP OWNED` command is an alternative that simply drops all the database objects owned by one or more roles.

The `REASSIGN OWNED` command does not affect any privileges granted to the *`old_roles`* on objects that are not owned by them. Likewise, it does not affect default privileges created with `ALTER DEFAULT PRIVILEGES`. Use `DROP OWNED` to revoke such privileges.

See Section 21.4 for more discussion.

Compatibility

The `REASSIGN OWNED` command is a Postgres Pro extension.

See Also

DROP OWNED, DROP ROLE, ALTER DATABASE

REFRESH MATERIALIZED VIEW

REFRESH MATERIALIZED VIEW — replace the contents of a materialized view

Synopsis

```
REFRESH MATERIALIZED VIEW [ CONCURRENTLY ] name
    [ WITH [ NO ] DATA ]
```

Description

`REFRESH MATERIALIZED VIEW` completely replaces the contents of a materialized view. To execute this command you must be the owner of the materialized view. The old contents are discarded. If `WITH DATA` is specified (or defaults) the backing query is executed to provide the new data, and the materialized view is left in a scannable state. If `WITH NO DATA` is specified no new data is generated and the materialized view is left in an unscannable state.

`CONCURRENTLY` and `WITH NO DATA` may not be specified together.

Parameters

`CONCURRENTLY`

Refresh the materialized view without locking out concurrent selects on the materialized view. Without this option a refresh which affects a lot of rows will tend to use fewer resources and complete more quickly, but could block other connections which are trying to read from the materialized view. This option may be faster in cases where a small number of rows are affected.

This option is only allowed if there is at least one `UNIQUE` index on the materialized view which uses only column names and includes all rows; that is, it must not be an expression index or include a `WHERE` clause.

This option may not be used when the materialized view is not already populated.

Even with this option only one `REFRESH` at a time may run against any one materialized view.

name

The name (optionally schema-qualified) of the materialized view to refresh.

Notes

If there is an `ORDER BY` clause in the materialized view's defining query, the original contents of the materialized view will be ordered that way; but `REFRESH MATERIALIZED VIEW` does not guarantee to preserve that ordering.

Examples

This command will replace the contents of the materialized view called `order_summary` using the query from the materialized view's definition, and leave it in a scannable state:

```
REFRESH MATERIALIZED VIEW order_summary;
```

This command will free storage associated with the materialized view `annual_statistics_basis` and leave it in an unscannable state:

```
REFRESH MATERIALIZED VIEW annual_statistics_basis WITH NO DATA;
```

Compatibility

`REFRESH MATERIALIZED VIEW` is a Postgres Pro extension.

See Also

CREATE MATERIALIZED VIEW, ALTER MATERIALIZED VIEW, DROP MATERIALIZED VIEW

REINDEX

REINDEX — rebuild indexes

Synopsis

```
REINDEX [ ( option [, ...] ) ] { INDEX | TABLE | SCHEMA | DATABASE | SYSTEM }
 [ CONCURRENTLY ] name

where option can be one of:

    CONCURRENTLY [ boolean ]
    TABLESPACE new_tablespace
    VERBOSE [ boolean ]
```

Description

`REINDEX` rebuilds an index using the data stored in the index's table, replacing the old copy of the index. There are several scenarios in which to use `REINDEX`:

- An index has become corrupted, and no longer contains valid data. Although in theory this should never happen, in practice indexes can become corrupted due to software bugs or hardware failures. `REINDEX` provides a recovery method.
- An index has become “bloated”, that is it contains many empty or nearly-empty pages. This can occur with B-tree indexes in Postgres Pro under certain uncommon access patterns. `REINDEX` provides a way to reduce the space consumption of the index by writing a new version of the index without the dead pages. See Section 24.2 for more information.
- You have altered a storage parameter (such as fillfactor) for an index, and wish to ensure that the change has taken full effect.
- If an index build fails with the `CONCURRENTLY` option, this index is left as “invalid”. Such indexes are useless but it can be convenient to use `REINDEX` to rebuild them. Note that only `REINDEX INDEX` is able to perform a concurrent build on an invalid index.

Parameters

`INDEX`

Recreate the specified index. This form of `REINDEX` cannot be executed inside a transaction block when used with a partitioned index.

`TABLE`

Recreate all indexes of the specified table. If the table has a secondary “TOAST” table, that is reindexed as well. This form of `REINDEX` cannot be executed inside a transaction block when used with a partitioned table.

`SCHEMA`

Recreate all indexes of the specified schema. If a table of this schema has a secondary “TOAST” table, that is reindexed as well. Indexes on shared system catalogs are also processed. This form of `REINDEX` cannot be executed inside a transaction block.

`DATABASE`

Recreate all indexes within the current database. Indexes on shared system catalogs are also processed. This form of `REINDEX` cannot be executed inside a transaction block.

SYSTEM

Recreate all indexes on system catalogs within the current database. Indexes on shared system catalogs are included. Indexes on user tables are not processed. This form of REINDEX cannot be executed inside a transaction block.

name

The name of the specific index, table, or database to be reindexed. Index and table names can be schema-qualified. Presently, REINDEX DATABASE and REINDEX SYSTEM can only reindex the current database, so their parameter must match the current database's name.

CONCURRENTLY

When this option is used, Postgres Pro will rebuild the index without taking any locks that prevent concurrent inserts, updates, or deletes on the table; whereas a standard index rebuild locks out writes (but not reads) on the table until it's done. There are several caveats to be aware of when using this option — see Rebuilding Indexes Concurrently below.

For temporary tables, REINDEX is always non-concurrent, as no other session can access them, and non-concurrent reindex is cheaper.

TABLESPACE

Specifies that indexes will be rebuilt on a new tablespace.

VERBOSE

Prints a progress report as each index is reindexed.

boolean

Specifies whether the selected option should be turned on or off. You can write TRUE, ON, or 1 to enable the option, and FALSE, OFF, or 0 to disable it. The *boolean* value can also be omitted, in which case TRUE is assumed.

new_tablespace

The tablespace where indexes will be rebuilt.

Notes

If you suspect corruption of an index on a user table, you can simply rebuild that index, or all indexes on the table, using REINDEX INDEX or REINDEX TABLE.

Things are more difficult if you need to recover from corruption of an index on a system table. In this case it's important for the system to not have used any of the suspect indexes itself. (Indeed, in this sort of scenario you might find that server processes are crashing immediately at start-up, due to reliance on the corrupted indexes.) To recover safely, the server must be started with the -P option, which prevents it from using indexes for system catalog lookups.

One way to do this is to shut down the server and start a single-user Postgres Pro server with the -P option included on its command line. Then, REINDEX DATABASE, REINDEX SYSTEM, REINDEX TABLE, or REINDEX INDEX can be issued, depending on how much you want to reconstruct. If in doubt, use REINDEX SYSTEM to select reconstruction of all system indexes in the database. Then quit the single-user server session and restart the regular server. See the postgres reference page for more information about how to interact with the single-user server interface.

Alternatively, a regular server session can be started with -P included in its command line options. The method for doing this varies across clients, but in all libpq-based clients, it is possible to set the PGOPTIONS environment variable to -P before starting the client. Note that while this method does not

require locking out other clients, it might still be wise to prevent other users from connecting to the damaged database until repairs have been completed.

REINDEX is similar to a drop and recreate of the index in that the index contents are rebuilt from scratch. However, the locking considerations are rather different. REINDEX locks out writes but not reads of the index's parent table. It also takes an ACCESS EXCLUSIVE lock on the specific index being processed, which will block reads that attempt to use that index. In contrast, DROP INDEX momentarily takes an ACCESS EXCLUSIVE lock on the parent table, blocking both writes and reads. The subsequent CREATE INDEX locks out writes but not reads; since the index is not there, no read will attempt to use it, meaning that there will be no blocking but reads might be forced into expensive sequential scans.

Reindexing a single index or table requires being the owner of that index or table. Reindexing a schema or database requires being the owner of that schema or database. Note specifically that it's thus possible for non-superusers to rebuild indexes of tables owned by other users. However, as a special exception, when REINDEX DATABASE, REINDEX SCHEMA or REINDEX SYSTEM is issued by a non-superuser, indexes on shared catalogs will be skipped unless the user owns the catalog (which typically won't be the case). Of course, superusers can always reindex anything.

Reindexing partitioned indexes or partitioned tables is supported with REINDEX INDEX or REINDEX TABLE, respectively. Each partition of the specified partitioned relation is reindexed in a separate transaction. Those commands cannot be used inside a transaction block when working on a partitioned table or index.

When using the TABLESPACE clause with REINDEX on a partitioned index or table, only the tablespace references of the leaf partitions are updated. As partitioned indexes are not updated, it is recommended to separately use ALTER TABLE ONLY on them so as any new partitions attached inherit the new tablespace. On failure, it may not have moved all the indexes to the new tablespace. Re-running the command will rebuild all the leaf partitions and move previously-unprocessed indexes to the new tablespace.

If SCHEMA, DATABASE or SYSTEM is used with TABLESPACE, system relations are skipped and a single WARNING will be generated. Indexes on TOAST tables are rebuilt, but not moved to the new tablespace.

Rebuilding Indexes Concurrently

Rebuilding an index can interfere with regular operation of a database. Normally Postgres Pro locks the table whose index is rebuilt against writes and performs the entire index build with a single scan of the table. Other transactions can still read the table, but if they try to insert, update, or delete rows in the table they will block until the index rebuild is finished. This could have a severe effect if the system is a live production database. Very large tables can take many hours to be indexed, and even for smaller tables, an index rebuild can lock out writers for periods that are unacceptably long for a production system.

Postgres Pro supports rebuilding indexes with minimum locking of writes. This method is invoked by specifying the CONCURRENTLY option of REINDEX. When this option is used, Postgres Pro must perform two scans of the table for each index that needs to be rebuilt and wait for termination of all existing transactions that could potentially use the index. This method requires more total work than a standard index rebuild and takes significantly longer to complete as it needs to wait for unfinished transactions that might modify the index. However, since it allows normal operations to continue while the index is being rebuilt, this method is useful for rebuilding indexes in a production environment. Of course, the extra CPU, memory and I/O load imposed by the index rebuild may slow down other operations.

The following steps occur in a concurrent reindex. Each step is run in a separate transaction. If there are multiple indexes to be rebuilt, then each step loops through all the indexes before moving to the next step.

1. A new transient index definition is added to the catalog pg_index. This definition will be used to replace the old index. A SHARE UPDATE EXCLUSIVE lock at session level is taken on the indexes being reindexed as well as their associated tables to prevent any schema modification while processing.
2. A first pass to build the index is done for each new index. Once the index is built, its flag pg_index.indisready is switched to “true” to make it ready for inserts, making it visible to other sessions

once the transaction that performed the build is finished. This step is done in a separate transaction for each index.

3. Then a second pass is performed to add tuples that were added while the first pass was running. This step is also done in a separate transaction for each index.
4. All the constraints that refer to the index are changed to refer to the new index definition, and the names of the indexes are changed. At this point, `pg_index.indisvalid` is switched to "true" for the new index and to "false" for the old, and a cache invalidation is done causing all sessions that referenced the old index to be invalidated.
5. The old indexes have `pg_index.indisready` switched to "false" to prevent any new tuple insertions, after waiting for running queries that might reference the old index to complete.
6. The old indexes are dropped. The `SHARE UPDATE EXCLUSIVE` session locks for the indexes and the table are released.

If a problem arises while rebuilding the indexes, such as a uniqueness violation in a unique index, the `REINDEX` command will fail but leave behind an "invalid" new index in addition to the pre-existing one. This index will be ignored for querying purposes because it might be incomplete; however it will still consume update overhead. The psql `\d` command will report such an index as `INVALID`:

```
postgres=# \d tab
       Table "public.tab"
 Column |  Type   | Modifiers
--------+---------+-----------
 col    | integer |
Indexes:
    "idx" btree (col)
    "idx_ccnew" btree (col) INVALID
```

If the index marked `INVALID` is suffixed `ccnew`, then it corresponds to the transient index created during the concurrent operation, and the recommended recovery method is to drop it using `DROP INDEX`, then attempt `REINDEX CONCURRENTLY` again. If the invalid index is instead suffixed `ccold`, it corresponds to the original index which could not be dropped; the recommended recovery method is to just drop said index, since the rebuild proper has been successful.

Regular index builds permit other regular index builds on the same table to occur simultaneously, but only one concurrent index build can occur on a table at a time. In both cases, no other types of schema modification on the table are allowed meanwhile. Another difference is that a regular `REINDEX TABLE` or `REINDEX INDEX` command can be performed within a transaction block, but `REINDEX CONCURRENTLY` cannot.

Like any long-running transaction, `REINDEX` on a table can affect which tuples can be removed by concurrent `VACUUM` on any other table.

`REINDEX SYSTEM` does not support `CONCURRENTLY` since system catalogs cannot be reindexed concurrently.

Furthermore, indexes for exclusion constraints cannot be reindexed concurrently. If such an index is named directly in this command, an error is raised. If a table or database with exclusion constraint indexes is reindexed concurrently, those indexes will be skipped. (It is possible to reindex such indexes without the `CONCURRENTLY` option.)

Each backend running `REINDEX` will report its progress in the `pg_stat_progress_create_index` view. See Section 27.4.2 for details.

Examples

Rebuild a single index:

```
REINDEX INDEX my_index;
```

Rebuild all the indexes on the table `my_table`:

```
REINDEX TABLE my_table;
```

Rebuild all indexes in a particular database, without trusting the system indexes to be valid already:

```
$ export PGOPTIONS="-P"
$ psql broken_db
...
broken_db=> REINDEX DATABASE broken_db;
broken_db=> \q
```

Rebuild indexes for a table, without blocking read and write operations on involved relations while reindexing is in progress:

```
REINDEX TABLE CONCURRENTLY my_broken_table;
```

Compatibility

There is no `REINDEX` command in the SQL standard.

See Also

CREATE INDEX, DROP INDEX, reindexdb, Section 27.4.2

RELEASE SAVEPOINT

RELEASE SAVEPOINT — destroy a previously defined savepoint

Synopsis

```
RELEASE [ SAVEPOINT ] savepoint_name
```

Description

`RELEASE SAVEPOINT` destroys a savepoint previously defined in the current transaction.

Destroying a savepoint makes it unavailable as a rollback point, but it has no other user visible behavior. It does not undo the effects of commands executed after the savepoint was established. (To do that, see ROLLBACK TO SAVEPOINT.) Destroying a savepoint when it is no longer needed allows the system to reclaim some resources earlier than transaction end.

`RELEASE SAVEPOINT` also destroys all savepoints that were established after the named savepoint was established.

Parameters

savepoint_name

The name of the savepoint to destroy.

Notes

Specifying a savepoint name that was not previously defined is an error.

It is not possible to release a savepoint when the transaction is in an aborted state.

If multiple savepoints have the same name, only the most recently defined unreleased one is released. Repeated commands will release progressively older savepoints.

Examples

To establish and later destroy a savepoint:

```
BEGIN;
    INSERT INTO table1 VALUES (3);
    SAVEPOINT my_savepoint;
    INSERT INTO table1 VALUES (4);
    RELEASE SAVEPOINT my_savepoint;
COMMIT;
```

The above transaction will insert both 3 and 4.

Compatibility

This command conforms to the SQL standard. The standard specifies that the key word `SAVEPOINT` is mandatory, but Postgres Pro allows it to be omitted.

See Also

BEGIN, COMMIT, ROLLBACK, ROLLBACK TO SAVEPOINT, SAVEPOINT

RESET

RESET — restore the value of a run-time parameter to the default value

Synopsis

```
RESET configuration_parameter
RESET ALL
```

Description

`RESET` restores run-time parameters to their default values. `RESET` is an alternative spelling for

```
SET configuration_parameter TO DEFAULT
```

Refer to SET for details.

The default value is defined as the value that the parameter would have had, if no `SET` had ever been issued for it in the current session. The actual source of this value might be a compiled-in default, the configuration file, command-line options, or per-database or per-user default settings. This is subtly different from defining it as “the value that the parameter had at session start”, because if the value came from the configuration file, it will be reset to whatever is specified by the configuration file now. See Chapter 19 for details.

The transactional behavior of `RESET` is the same as `SET`: its effects will be undone by transaction rollback.

Parameters

configuration_parameter

Name of a settable run-time parameter. Available parameters are documented in Chapter 19 and on the SET reference page.

`ALL`

Resets all settable run-time parameters to default values.

Examples

Set the `timezone` configuration variable to its default value:

```
RESET timezone;
```

Compatibility

`RESET` is a Postgres Pro extension.

See Also

SET, SHOW

REVOKE

REVOKE — remove access privileges

Synopsis

```
REVOKE [ GRANT OPTION FOR ]
    { { SELECT | INSERT | UPDATE | DELETE | TRUNCATE | REFERENCES | TRIGGER }
    [, ...] | ALL [ PRIVILEGES ] }
    ON { [ TABLE ] table_name [, ...]
         | ALL TABLES IN SCHEMA schema_name [, ...] }
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { { SELECT | INSERT | UPDATE | REFERENCES } ( column_name [, ...] )
    [, ...] | ALL [ PRIVILEGES ] ( column_name [, ...] ) }
    ON [ TABLE ] table_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { { USAGE | SELECT | UPDATE }
    [, ...] | ALL [ PRIVILEGES ] }
    ON { SEQUENCE sequence_name [, ...]
         | ALL SEQUENCES IN SCHEMA schema_name [, ...] }
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { { CREATE | CONNECT | TEMPORARY | TEMP } [, ...] | ALL [ PRIVILEGES ] }
    ON DATABASE database_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { USAGE | ALL [ PRIVILEGES ] }
    ON DOMAIN domain_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { USAGE | ALL [ PRIVILEGES ] }
    ON FOREIGN DATA WRAPPER fdw_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { USAGE | ALL [ PRIVILEGES ] }
    ON FOREIGN SERVER server_name [, ...]
    FROM role_specification [, ...]
```

```
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { EXECUTE | ALL [ PRIVILEGES ] }
    ON { { FUNCTION | PROCEDURE | ROUTINE } function_name [ ( [ [ argmode ] [ arg_name
 ] arg_type [, ...] ] ) ] [, ...]
         | ALL { FUNCTIONS | PROCEDURES | ROUTINES } IN SCHEMA schema_name [, ...] }
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { USAGE | ALL [ PRIVILEGES ] }
    ON LANGUAGE lang_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { { SELECT | UPDATE } [, ...] | ALL [ PRIVILEGES ] }
    ON LARGE OBJECT loid [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { { CREATE | USAGE } [, ...] | ALL [ PRIVILEGES ] }
    ON SCHEMA schema_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { CREATE | ALL [ PRIVILEGES ] }
    ON TABLESPACE tablespace_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ GRANT OPTION FOR ]
    { USAGE | ALL [ PRIVILEGES ] }
    ON TYPE type_name [, ...]
    FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

REVOKE [ ADMIN OPTION FOR ]
    role_name [, ...] FROM role_specification [, ...]
    [ GRANTED BY role_specification ]
    [ CASCADE | RESTRICT ]

where role_specification can be:

    [ GROUP ] role_name
  | PUBLIC
  | CURRENT_ROLE
  | CURRENT_USER
```

```
    | SESSION_USER
```

Description

The REVOKE command revokes previously granted privileges from one or more roles. The key word PUBLIC refers to the implicitly defined group of all roles.

See the description of the GRANT command for the meaning of the privilege types.

Note that any particular role will have the sum of privileges granted directly to it, privileges granted to any role it is presently a member of, and privileges granted to PUBLIC. Thus, for example, revoking SELECT privilege from PUBLIC does not necessarily mean that all roles have lost SELECT privilege on the object: those who have it granted directly or via another role will still have it. Similarly, revoking SELECT from a user might not prevent that user from using SELECT if PUBLIC or another membership role still has SELECT rights.

If GRANT OPTION FOR is specified, only the grant option for the privilege is revoked, not the privilege itself. Otherwise, both the privilege and the grant option are revoked.

If a user holds a privilege with grant option and has granted it to other users then the privileges held by those other users are called dependent privileges. If the privilege or the grant option held by the first user is being revoked and dependent privileges exist, those dependent privileges are also revoked if CASCADE is specified; if it is not, the revoke action will fail. This recursive revocation only affects privileges that were granted through a chain of users that is traceable to the user that is the subject of this REVOKE command. Thus, the affected users might effectively keep the privilege if it was also granted through other users.

When revoking privileges on a table, the corresponding column privileges (if any) are automatically revoked on each column of the table, as well. On the other hand, if a role has been granted privileges on a table, then revoking the same privileges from individual columns will have no effect.

When revoking membership in a role, GRANT OPTION is instead called ADMIN OPTION, but the behavior is similar. This form of the command also allows a GRANTED BY option, but that option is currently ignored (except for checking the existence of the named role). Note also that this form of the command does not allow the noise word GROUP in *role_specification*.

Notes

A user can only revoke privileges that were granted directly by that user. If, for example, user A has granted a privilege with grant option to user B, and user B has in turn granted it to user C, then user A cannot revoke the privilege directly from C. Instead, user A could revoke the grant option from user B and use the CASCADE option so that the privilege is in turn revoked from user C. For another example, if both A and B have granted the same privilege to C, A can revoke their own grant but not B's grant, so C will still effectively have the privilege.

When a non-owner of an object attempts to REVOKE privileges on the object, the command will fail outright if the user has no privileges whatsoever on the object. As long as some privilege is available, the command will proceed, but it will revoke only those privileges for which the user has grant options. The REVOKE ALL PRIVILEGES forms will issue a warning message if no grant options are held, while the other forms will issue a warning if grant options for any of the privileges specifically named in the command are not held. (In principle these statements apply to the object owner as well, but since the owner is always treated as holding all grant options, the cases can never occur.)

If a superuser chooses to issue a GRANT or REVOKE command, the command is performed as though it were issued by the owner of the affected object. Since all privileges ultimately come from the object owner (possibly indirectly via chains of grant options), it is possible for a superuser to revoke all privileges, but this might require use of CASCADE as stated above.

REVOKE can also be done by a role that is not the owner of the affected object, but is a member of the role that owns the object, or is a member of a role that holds privileges WITH GRANT OPTION on the object. In

this case the command is performed as though it were issued by the containing role that actually owns the object or holds the privileges `WITH GRANT OPTION`. For example, if table `t1` is owned by role `g1`, of which role `u1` is a member, then `u1` can revoke privileges on `t1` that are recorded as being granted by `g1`. This would include grants made by `u1` as well as by other members of role `g1`.

If the role executing `REVOKE` holds privileges indirectly via more than one role membership path, it is unspecified which containing role will be used to perform the command. In such cases it is best practice to use `SET ROLE` to become the specific role you want to do the `REVOKE` as. Failure to do so might lead to revoking privileges other than the ones you intended, or not revoking anything at all.

See Section 5.7 for more information about specific privilege types, as well as how to inspect objects' privileges.

Examples

Revoke insert privilege for the public on table `films`:

```
REVOKE INSERT ON films FROM PUBLIC;
```

Revoke all privileges from user `manuel` on view `kinds`:

```
REVOKE ALL PRIVILEGES ON kinds FROM manuel;
```

Note that this actually means “revoke all privileges that I granted”.

Revoke membership in role `admins` from user `joe`:

```
REVOKE admins FROM joe;
```

Compatibility

The compatibility notes of the `GRANT` command apply analogously to `REVOKE`. The keyword `RESTRICT` or `CASCADE` is required according to the standard, but Postgres Pro assumes `RESTRICT` by default.

See Also

GRANT, ALTER DEFAULT PRIVILEGES

ROLLBACK

ROLLBACK — abort the current transaction

Synopsis

```
ROLLBACK [ AUTONOMOUS ] [ WORK | TRANSACTION ] [ AND [ NO ] CHAIN ]
```

Description

`ROLLBACK` rolls back the current transaction and causes all the updates made by the transaction to be discarded.

Parameters

`AUTONOMOUS`

Optional key word that can be used when aborting an autonomous transaction. For details on autonomous transactions, see Chapter 16.

`WORK`
`TRANSACTION`

Optional key words. They have no effect.

`AND CHAIN`

If `AND CHAIN` is specified, a new transaction is immediately started with the same transaction characteristics (see SET TRANSACTION) as the just finished one. Otherwise, no new transaction is started.

Notes

Use `COMMIT` to successfully terminate a transaction.

Issuing `ROLLBACK` outside of a transaction block emits a warning and otherwise has no effect. `ROLLBACK AND CHAIN` outside of a transaction block is an error.

Examples

To abort all changes:

```
ROLLBACK;
```

Compatibility

The command `ROLLBACK` conforms to the SQL standard. The form `ROLLBACK TRANSACTION` is a Postgres Pro extension.

See Also

BEGIN, COMMIT, ROLLBACK TO SAVEPOINT

ROLLBACK PREPARED

ROLLBACK PREPARED — cancel a transaction that was earlier prepared for two-phase commit

Synopsis

```
ROLLBACK PREPARED transaction_id
```

Description

`ROLLBACK PREPARED` rolls back a transaction that is in prepared state.

Parameters

transaction_id

The transaction identifier of the transaction that is to be rolled back.

Notes

To roll back a prepared transaction, you must be either the same user that executed the transaction originally, or a superuser. But you do not have to be in the same session that executed the transaction.

This command cannot be executed inside a transaction block. The prepared transaction is rolled back immediately.

All currently available prepared transactions are listed in the `pg_prepared_xacts` system view.

Examples

Roll back the transaction identified by the transaction identifier `foobar`:

```
ROLLBACK PREPARED 'foobar';
```

Compatibility

`ROLLBACK PREPARED` is a Postgres Pro extension. It is intended for use by external transaction management systems, some of which are covered by standards (such as X/Open XA), but the SQL side of those systems is not standardized.

See Also

PREPARE TRANSACTION, COMMIT PREPARED

ROLLBACK TO SAVEPOINT

ROLLBACK TO SAVEPOINT — roll back to a savepoint

Synopsis

```
ROLLBACK [ WORK | TRANSACTION ] TO [ SAVEPOINT ] savepoint_name
```

Description

Roll back all commands that were executed after the savepoint was established. The savepoint remains valid and can be rolled back to again later, if needed.

`ROLLBACK TO SAVEPOINT` implicitly destroys all savepoints that were established after the named savepoint.

Parameters

savepoint_name

The savepoint to roll back to.

Notes

Use `RELEASE SAVEPOINT` to destroy a savepoint without discarding the effects of commands executed after it was established.

Specifying a savepoint name that has not been established is an error.

Cursors have somewhat non-transactional behavior with respect to savepoints. Any cursor that is opened inside a savepoint will be closed when the savepoint is rolled back. If a previously opened cursor is affected by a `FETCH` or `MOVE` command inside a savepoint that is later rolled back, the cursor remains at the position that `FETCH` left it pointing to (that is, the cursor motion caused by `FETCH` is not rolled back). Closing a cursor is not undone by rolling back, either. However, other side-effects caused by the cursor's query (such as side-effects of volatile functions called by the query) *are* rolled back if they occur during a savepoint that is later rolled back. A cursor whose execution causes a transaction to abort is put in a cannot-execute state, so while the transaction can be restored using `ROLLBACK TO SAVEPOINT`, the cursor can no longer be used.

Examples

To undo the effects of the commands executed after `my_savepoint` was established:

```
ROLLBACK TO SAVEPOINT my_savepoint;
```

Cursor positions are not affected by savepoint rollback:

```
BEGIN;

DECLARE foo CURSOR FOR SELECT 1 UNION SELECT 2;

SAVEPOINT foo;

FETCH 1 FROM foo;
 ?column?
----------
        1

ROLLBACK TO SAVEPOINT foo;
```

```
FETCH 1 FROM foo;
 ?column?
----------
        2

COMMIT;
```

Compatibility

The SQL standard specifies that the key word `SAVEPOINT` is mandatory, but Postgres Pro and Oracle allow it to be omitted. SQL allows only `WORK`, not `TRANSACTION`, as a noise word after `ROLLBACK`. Also, SQL has an optional clause `AND [ NO ] CHAIN` which is not currently supported by Postgres Pro. Otherwise, this command conforms to the SQL standard.

See Also

BEGIN, COMMIT, RELEASE SAVEPOINT, ROLLBACK, SAVEPOINT

SAVEPOINT

SAVEPOINT — define a new savepoint within the current transaction

Synopsis

```
SAVEPOINT savepoint_name
```

Description

`SAVEPOINT` establishes a new savepoint within the current transaction.

A savepoint is a special mark inside a transaction that allows all commands that are executed after it was established to be rolled back, restoring the transaction state to what it was at the time of the savepoint.

Parameters

savepoint_name

The name to give to the new savepoint. If savepoints with the same name already exist, they will be inaccessible until newer identically-named savepoints are released.

Notes

Use `ROLLBACK TO` to rollback to a savepoint. Use `RELEASE SAVEPOINT` to destroy a savepoint, keeping the effects of commands executed after it was established.

Savepoints can only be established when inside a transaction block. There can be multiple savepoints defined within a transaction.

Examples

To establish a savepoint and later undo the effects of all commands executed after it was established:

```
BEGIN;
    INSERT INTO table1 VALUES (1);
    SAVEPOINT my_savepoint;
    INSERT INTO table1 VALUES (2);
    ROLLBACK TO SAVEPOINT my_savepoint;
    INSERT INTO table1 VALUES (3);
COMMIT;
```

The above transaction will insert the values 1 and 3, but not 2.

To establish and later destroy a savepoint:

```
BEGIN;
    INSERT INTO table1 VALUES (3);
    SAVEPOINT my_savepoint;
    INSERT INTO table1 VALUES (4);
    RELEASE SAVEPOINT my_savepoint;
COMMIT;
```

The above transaction will insert both 3 and 4.

To use a single savepoint name:

```
BEGIN;
    INSERT INTO table1 VALUES (1);
    SAVEPOINT my_savepoint;
    INSERT INTO table1 VALUES (2);
```

```
    SAVEPOINT my_savepoint;
    INSERT INTO table1 VALUES (3);

    -- rollback to the second savepoint
    ROLLBACK TO SAVEPOINT my_savepoint;
    SELECT * FROM table1;               -- shows rows 1 and 2

    -- release the second savepoint
    RELEASE SAVEPOINT my_savepoint;

    -- rollback to the first savepoint
    ROLLBACK TO SAVEPOINT my_savepoint;
    SELECT * FROM table1;               -- shows only row 1
COMMIT;
```

The above transaction shows row 3 being rolled back first, then row 2.

Compatibility

SQL requires a savepoint to be destroyed automatically when another savepoint with the same name is established. In Postgres Pro, the old savepoint is kept, though only the more recent one will be used when rolling back or releasing. (Releasing the newer savepoint with `RELEASE SAVEPOINT` will cause the older one to again become accessible to `ROLLBACK TO SAVEPOINT` and `RELEASE SAVEPOINT`.) Otherwise, `SAVEPOINT` is fully SQL conforming.

See Also

BEGIN, COMMIT, RELEASE SAVEPOINT, ROLLBACK, ROLLBACK TO SAVEPOINT

SECURITY LABEL

SECURITY LABEL — define or change a security label applied to an object

Synopsis

```
SECURITY LABEL [ FOR provider ] ON
{
  TABLE object_name |
  COLUMN table_name.column_name |
  AGGREGATE aggregate_name ( aggregate_signature ) |
  DATABASE object_name |
  DOMAIN object_name |
  EVENT TRIGGER object_name |
  FOREIGN TABLE object_name |
  FUNCTION function_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  LARGE OBJECT large_object_oid |
  MATERIALIZED VIEW object_name |
  [ PROCEDURAL ] LANGUAGE object_name |
  PROCEDURE procedure_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  PUBLICATION object_name |
  PROFILE object_name |
  ROLE object_name |
  ROUTINE routine_name [ ( [ [ argmode ] [ argname ] argtype [, ...] ] ) ] |
  SCHEMA object_name |
  SEQUENCE object_name |
  SUBSCRIPTION object_name |
  TABLESPACE object_name |
  TYPE object_name |
  VIEW object_name
} IS { string_literal | NULL }

where aggregate_signature is:

* |
[ argmode ] [ argname ] argtype [ , ... ] |
[ [ argmode ] [ argname ] argtype [ , ... ] ] ORDER BY [ argmode ] [ argname ] argtype
 [ , ... ]
```

Description

`SECURITY LABEL` applies a security label to a database object. An arbitrary number of security labels, one per label provider, can be associated with a given database object. Label providers are loadable modules which register themselves by using the function `register_label_provider`.

> **Note**
>
> `register_label_provider` is not an SQL function; it can only be called from C code loaded into the backend.

The label provider determines whether a given label is valid and whether it is permissible to assign that label to a given object. The meaning of a given label is likewise at the discretion of the label provider. Postgres Pro places no restrictions on whether or how a label provider must interpret security labels; it merely provides a mechanism for storing them. In practice, this facility is intended to allow integration with label-based mandatory access control (MAC) systems such as SELinux. Such systems make all

access control decisions based on object labels, rather than traditional discretionary access control (DAC) concepts such as users and groups.

Parameters

object_name
table_name.column_name
aggregate_name
function_name
procedure_name
routine_name

The name of the object to be labeled. Names of objects that reside in schemas (tables, functions, etc.) can be schema-qualified.

provider

The name of the provider with which this label is to be associated. The named provider must be loaded and must consent to the proposed labeling operation. If exactly one provider is loaded, the provider name may be omitted for brevity.

argmode

The mode of a function, procedure, or aggregate argument: `IN`, `OUT`, `INOUT`, or `VARIADIC`. If omitted, the default is `IN`. Note that `SECURITY LABEL` does not actually pay any attention to `OUT` arguments, since only the input arguments are needed to determine the function's identity. So it is sufficient to list the `IN`, `INOUT`, and `VARIADIC` arguments.

argname

The name of a function, procedure, or aggregate argument. Note that `SECURITY LABEL` does not actually pay any attention to argument names, since only the argument data types are needed to determine the function's identity.

argtype

The data type of a function, procedure, or aggregate argument.

large_object_oid

The OID of the large object.

`PROCEDURAL`

This is a noise word.

string_literal

The new setting of the security label, written as a string literal.

`NULL`

Write `NULL` to drop the security label.

Examples

The following example shows how the security label of a table could be set or changed:

```
SECURITY LABEL FOR selinux ON TABLE mytable IS 'system_u:object_r:sepgsql_table_t:s0';
```

To remove the label:

```
SECURITY LABEL FOR selinux ON TABLE mytable IS NULL;
```

Compatibility

There is no `SECURITY LABEL` command in the SQL standard.

SELECT

SELECT, TABLE, WITH — retrieve rows from a table or view

Synopsis

```
[ WITH [ RECURSIVE ] with_query [, ...] ]
SELECT [ ALL | DISTINCT [ ON ( expression [, ...] ) ] ]
    [ { * | expression [ [ AS ] output_name ] } [, ...] ]
    [ FROM from_item [, ...] ]
    [ WHERE condition ]
    [ GROUP BY [ ALL | DISTINCT ] grouping_element [, ...] ]
    [ HAVING condition ]
    [ WINDOW window_name AS ( window_definition ) [, ...] ]
    [ { UNION | INTERSECT | EXCEPT } [ ALL | DISTINCT ] select ]
    [ ORDER BY expression [ ASC | DESC | USING operator ] [ NULLS { FIRST | LAST } ]
 [, ...] ]
    [ LIMIT { count | ALL } ]
    [ OFFSET start [ ROW | ROWS ] ]
    [ FETCH { FIRST | NEXT } [ count ] { ROW | ROWS } { ONLY | WITH TIES } ]
    [ FOR { UPDATE | NO KEY UPDATE | SHARE | KEY SHARE } [ OF table_name [, ...] ]
 [ NOWAIT | SKIP LOCKED ] [...] ]

where from_item can be one of:

    [ ONLY ] table_name [ * ] [ [ AS ] alias [ ( column_alias [, ...] ) ] ]
                [ TABLESAMPLE sampling_method ( argument [, ...] ) [ REPEATABLE ( seed
 ) ] ]
    [ LATERAL ] ( select ) [ AS ] alias [ ( column_alias [, ...] ) ]
    with_query_name [ [ AS ] alias [ ( column_alias [, ...] ) ] ]
    [ LATERAL ] function_name ( [ argument [, ...] ] )
                [ WITH ORDINALITY ] [ [ AS ] alias [ ( column_alias [, ...] ) ] ]
    [ LATERAL ] function_name ( [ argument [, ...] ] ) [ AS ] alias ( column_definition
 [, ...] )
    [ LATERAL ] function_name ( [ argument [, ...] ] ) AS ( column_definition [, ...] )
    [ LATERAL ] ROWS FROM( function_name ( [ argument [, ...] ] ) [ AS
 ( column_definition [, ...] ) ] [, ...] )
                [ WITH ORDINALITY ] [ [ AS ] alias [ ( column_alias [, ...] ) ] ]
    from_item join_type from_item { ON join_condition | USING ( join_column [, ...] )
 [ AS join_using_alias ] }
    from_item NATURAL join_type from_item
    from_item CROSS JOIN from_item

and grouping_element can be one of:

    ( )
    expression
    ( expression [, ...] )
    ROLLUP ( { expression | ( expression [, ...] ) } [, ...] )
    CUBE ( { expression | ( expression [, ...] ) } [, ...] )
    GROUPING SETS ( grouping_element [, ...] )

and with_query is:

    with_query_name [ ( column_name [, ...] ) ] AS [ [ NOT ] MATERIALIZED ] ( select
 | values | insert | update | delete )
```

```
        [ SEARCH { BREADTH | DEPTH } FIRST BY column_name [, ...]
  SET search_seq_col_name ]
        [ CYCLE column_name [, ...] SET cycle_mark_col_name [ TO cycle_mark_value
  DEFAULT cycle_mark_default ] USING cycle_path_col_name ]

TABLE [ ONLY ] table_name [ * ]
```

Description

SELECT retrieves rows from zero or more tables. The general processing of SELECT is as follows:

1. All queries in the WITH list are computed. These effectively serve as temporary tables that can be referenced in the FROM list. A WITH query that is referenced more than once in FROM is computed only once, unless specified otherwise with NOT MATERIALIZED. (See WITH Clause below.)
2. All elements in the FROM list are computed. (Each element in the FROM list is a real or virtual table.) If more than one element is specified in the FROM list, they are cross-joined together. (See FROM Clause below.)
3. If the WHERE clause is specified, all rows that do not satisfy the condition are eliminated from the output. (See WHERE Clause below.)
4. If the GROUP BY clause is specified, or if there are aggregate function calls, the output is combined into groups of rows that match on one or more values, and the results of aggregate functions are computed. If the HAVING clause is present, it eliminates groups that do not satisfy the given condition. (See GROUP BY Clause and HAVING Clause below.) Although query output columns are nominally computed in the next step, they can also be referenced (by name or ordinal number) in the GROUP BY clause.
5. The actual output rows are computed using the SELECT output expressions for each selected row or row group. (See SELECT List below.)
6. SELECT DISTINCT eliminates duplicate rows from the result. SELECT DISTINCT ON eliminates rows that match on all the specified expressions. SELECT ALL (the default) will return all candidate rows, including duplicates. (See DISTINCT Clause below.)
7. Using the operators UNION, INTERSECT, and EXCEPT, the output of more than one SELECT statement can be combined to form a single result set. The UNION operator returns all rows that are in one or both of the result sets. The INTERSECT operator returns all rows that are strictly in both result sets. The EXCEPT operator returns the rows that are in the first result set but not in the second. In all three cases, duplicate rows are eliminated unless ALL is specified. The noise word DISTINCT can be added to explicitly specify eliminating duplicate rows. Notice that DISTINCT is the default behavior here, even though ALL is the default for SELECT itself. (See UNION Clause, INTERSECT Clause, and EXCEPT Clause below.)
8. If the ORDER BY clause is specified, the returned rows are sorted in the specified order. If ORDER BY is not given, the rows are returned in whatever order the system finds fastest to produce. (See ORDER BY Clause below.)
9. If the LIMIT (or FETCH FIRST) or OFFSET clause is specified, the SELECT statement only returns a subset of the result rows. (See LIMIT Clause below.)
10. If FOR UPDATE, FOR NO KEY UPDATE, FOR SHARE or FOR KEY SHARE is specified, the SELECT statement locks the selected rows against concurrent updates. (See The Locking Clause below.)

You must have SELECT privilege on each column used in a SELECT command. The use of FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE or FOR KEY SHARE requires UPDATE privilege as well (for at least one column of each table so selected).

Parameters

WITH Clause

The WITH clause allows you to specify one or more subqueries that can be referenced by name in the primary query. The subqueries effectively act as temporary tables or views for the duration of the pri-

mary query. Each subquery can be a SELECT, TABLE, VALUES, INSERT, UPDATE or DELETE statement. When writing a data-modifying statement (INSERT, UPDATE or DELETE) in WITH, it is usual to include a RETURNING clause. It is the output of RETURNING, *not* the underlying table that the statement modifies, that forms the temporary table that is read by the primary query. If RETURNING is omitted, the statement is still executed, but it produces no output so it cannot be referenced as a table by the primary query.

A name (without schema qualification) must be specified for each WITH query. Optionally, a list of column names can be specified; if this is omitted, the column names are inferred from the subquery.

If RECURSIVE is specified, it allows a SELECT subquery to reference itself by name. Such a subquery must have the form

non_recursive_term UNION [ALL | DISTINCT] *recursive_term*

where the recursive self-reference must appear on the right-hand side of the UNION. Only one recursive self-reference is permitted per query. Recursive data-modifying statements are not supported, but you can use the results of a recursive SELECT query in a data-modifying statement. See Section 7.8 for an example.

Another effect of RECURSIVE is that WITH queries need not be ordered: a query can reference another one that is later in the list. (However, circular references, or mutual recursion, are not implemented.) Without RECURSIVE, WITH queries can only reference sibling WITH queries that are earlier in the WITH list.

When there are multiple queries in the WITH clause, RECURSIVE should be written only once, immediately after WITH. It applies to all queries in the WITH clause, though it has no effect on queries that do not use recursion or forward references.

The optional SEARCH clause computes a *search sequence column* that can be used for ordering the results of a recursive query in either breadth-first or depth-first order. The supplied column name list specifies the row key that is to be used for keeping track of visited rows. A column named *search_seq_col_name* will be added to the result column list of the WITH query. This column can be ordered by in the outer query to achieve the respective ordering. See Section 7.8.2.1 for examples.

The optional CYCLE clause is used to detect cycles in recursive queries. The supplied column name list specifies the row key that is to be used for keeping track of visited rows. A column named *cycle_mark_col_name* will be added to the result column list of the WITH query. This column will be set to *cycle_mark_value* when a cycle has been detected, else to *cycle_mark_default*. Furthermore, processing of the recursive union will stop when a cycle has been detected. *cycle_mark_value* and *cycle_mark_default* must be constants and they must be coercible to a common data type, and the data type must have an inequality operator. (The SQL standard requires that they be Boolean constants or character strings, but PostgreSQL does not require that.) By default, TRUE and FALSE (of type boolean) are used. Furthermore, a column named *cycle_path_col_name* will be added to the result column list of the WITH query. This column is used internally for tracking visited rows. See Section 7.8.2.2 for examples.

Both the SEARCH and the CYCLE clause are only valid for recursive WITH queries. The *with_query* must be a UNION (or UNION ALL) of two SELECT (or equivalent) commands (no nested UNIONs). If both clauses are used, the column added by the SEARCH clause appears before the columns added by the CYCLE clause.

The primary query and the WITH queries are all (notionally) executed at the same time. This implies that the effects of a data-modifying statement in WITH cannot be seen from other parts of the query, other than by reading its RETURNING output. If two such data-modifying statements attempt to modify the same row, the results are unspecified.

A key property of WITH queries is that they are normally evaluated only once per execution of the primary query, even if the primary query refers to them more than once. In particular, data-modifying statements are guaranteed to be executed once and only once, regardless of whether the primary query reads all or any of their output.

However, a WITH query can be marked NOT MATERIALIZED to remove this guarantee. In that case, the WITH query can be folded into the primary query much as though it were a simple sub-SELECT in the

primary query's FROM clause. This results in duplicate computations if the primary query refers to that WITH query more than once; but if each such use requires only a few rows of the WITH query's total output, NOT MATERIALIZED can provide a net savings by allowing the queries to be optimized jointly. NOT MATERIALIZED is ignored if it is attached to a WITH query that is recursive or is not side-effect-free (i.e., is not a plain SELECT containing no volatile functions).

By default, a side-effect-free WITH query is folded into the primary query if it is used exactly once in the primary query's FROM clause. This allows joint optimization of the two query levels in situations where that should be semantically invisible. However, such folding can be prevented by marking the WITH query as MATERIALIZED. That might be useful, for example, if the WITH query is being used as an optimization fence to prevent the planner from choosing a bad plan. Postgres Pro versions before v12 never did such folding, so queries written for older versions might rely on WITH to act as an optimization fence.

See Section 7.8 for additional information.

FROM Clause

The FROM clause specifies one or more source tables for the SELECT. If multiple sources are specified, the result is the Cartesian product (cross join) of all the sources. But usually qualification conditions are added (via WHERE) to restrict the returned rows to a small subset of the Cartesian product.

The FROM clause can contain the following elements:

table_name

The name (optionally schema-qualified) of an existing table or view. If ONLY is specified before the table name, only that table is scanned. If ONLY is not specified, the table and all its descendant tables (if any) are scanned. Optionally, * can be specified after the table name to explicitly indicate that descendant tables are included.

alias

A substitute name for the FROM item containing the alias. An alias is used for brevity or to eliminate ambiguity for self-joins (where the same table is scanned multiple times). When an alias is provided, it completely hides the actual name of the table or function; for example given FROM foo AS f, the remainder of the SELECT must refer to this FROM item as f not foo. If an alias is written, a column alias list can also be written to provide substitute names for one or more columns of the table.

TABLESAMPLE *sampling_method* (*argument* [, ...]) [REPEATABLE (*seed*)]

A TABLESAMPLE clause after a *table_name* indicates that the specified *sampling_method* should be used to retrieve a subset of the rows in that table. This sampling precedes the application of any other filters such as WHERE clauses. The standard Postgres Pro distribution includes two sampling methods, BERNOULLI and SYSTEM, and other sampling methods can be installed in the database via extensions.

The BERNOULLI and SYSTEM sampling methods each accept a single *argument* which is the fraction of the table to sample, expressed as a percentage between 0 and 100. This argument can be any real-valued expression. (Other sampling methods might accept more or different arguments.) These two methods each return a randomly-chosen sample of the table that will contain approximately the specified percentage of the table's rows. The BERNOULLI method scans the whole table and selects or ignores individual rows independently with the specified probability. The SYSTEM method does block-level sampling with each block having the specified chance of being selected; all rows in each selected block are returned. The SYSTEM method is significantly faster than the BERNOULLI method when small sampling percentages are specified, but it may return a less-random sample of the table as a result of clustering effects.

The optional REPEATABLE clause specifies a *seed* number or expression to use for generating random numbers within the sampling method. The seed value can be any non-null floating-point value. Two queries that specify the same seed and *argument* values will select the same sample of the table, if the table has not been changed meanwhile. But different seed values will usually produce different samples. If REPEATABLE is not given then a new random sample is selected for each query, based

upon a system-generated seed. Note that some add-on sampling methods do not accept REPEATABLE, and will always produce new samples on each use.

select

A sub-SELECT can appear in the FROM clause. This acts as though its output were created as a temporary table for the duration of this single SELECT command. Note that the sub-SELECT must be surrounded by parentheses, and an alias *must* be provided for it. A VALUES command can also be used here.

with_query_name

A WITH query is referenced by writing its name, just as though the query's name were a table name. (In fact, the WITH query hides any real table of the same name for the purposes of the primary query. If necessary, you can refer to a real table of the same name by schema-qualifying the table's name.) An alias can be provided in the same way as for a table.

function_name

Function calls can appear in the FROM clause. (This is especially useful for functions that return result sets, but any function can be used.) This acts as though the function's output were created as a temporary table for the duration of this single SELECT command. If the function's result type is composite (including the case of a function with multiple OUT parameters), each attribute becomes a separate column in the implicit table.

When the optional WITH ORDINALITY clause is added to the function call, an additional column of type bigint will be appended to the function's result column(s). This column numbers the rows of the function's result set, starting from 1. By default, this column is named ordinality.

An alias can be provided in the same way as for a table. If an alias is written, a column alias list can also be written to provide substitute names for one or more attributes of the function's composite return type, including the ordinality column if present.

Multiple function calls can be combined into a single FROM-clause item by surrounding them with ROWS FROM(...). The output of such an item is the concatenation of the first row from each function, then the second row from each function, etc. If some of the functions produce fewer rows than others, null values are substituted for the missing data, so that the total number of rows returned is always the same as for the function that produced the most rows.

If the function has been defined as returning the record data type, then an alias or the key word AS must be present, followed by a column definition list in the form (*column_name data_type* [, ...]). The column definition list must match the actual number and types of columns returned by the function.

When using the ROWS FROM(...) syntax, if one of the functions requires a column definition list, it's preferred to put the column definition list after the function call inside ROWS FROM(...). A column definition list can be placed after the ROWS FROM(...) construct only if there's just a single function and no WITH ORDINALITY clause.

To use ORDINALITY together with a column definition list, you must use the ROWS FROM(...) syntax and put the column definition list inside ROWS FROM(...).

join_type

One of

- [INNER] JOIN
- LEFT [OUTER] JOIN
- RIGHT [OUTER] JOIN
- FULL [OUTER] JOIN

For the INNER and OUTER join types, a join condition must be specified, namely exactly one of ON *join_condition*, USING (*join_column* [, ...]), or NATURAL. See below for the meaning.

A JOIN clause combines two FROM items, which for convenience we will refer to as “tables”, though in reality they can be any type of FROM item. Use parentheses if necessary to determine the order of nesting. In the absence of parentheses, JOINs nest left-to-right. In any case JOIN binds more tightly than the commas separating FROM-list items. All the JOIN options are just a notational convenience, since they do nothing you couldn't do with plain FROM and WHERE.

LEFT OUTER JOIN returns all rows in the qualified Cartesian product (i.e., all combined rows that pass its join condition), plus one copy of each row in the left-hand table for which there was no right-hand row that passed the join condition. This left-hand row is extended to the full width of the joined table by inserting null values for the right-hand columns. Note that only the JOIN clause's own condition is considered while deciding which rows have matches. Outer conditions are applied afterwards.

Conversely, RIGHT OUTER JOIN returns all the joined rows, plus one row for each unmatched right-hand row (extended with nulls on the left). This is just a notational convenience, since you could convert it to a LEFT OUTER JOIN by switching the left and right tables.

FULL OUTER JOIN returns all the joined rows, plus one row for each unmatched left-hand row (extended with nulls on the right), plus one row for each unmatched right-hand row (extended with nulls on the left).

ON *join_condition*

join_condition is an expression resulting in a value of type boolean (similar to a WHERE clause) that specifies which rows in a join are considered to match.

USING (*join_column* [, ...]) [AS *join_using_alias*]

A clause of the form USING (a, b, ...) is shorthand for ON left_table.a = right_table.a AND left_table.b = right_table.b .... Also, USING implies that only one of each pair of equivalent columns will be included in the join output, not both.

If a *join_using_alias* name is specified, it provides a table alias for the join columns. Only the join columns listed in the USING clause are addressable by this name. Unlike a regular *alias*, this does not hide the names of the joined tables from the rest of the query. Also unlike a regular *alias*, you cannot write a column alias list — the output names of the join columns are the same as they appear in the USING list.

NATURAL

NATURAL is shorthand for a USING list that mentions all columns in the two tables that have matching names. If there are no common column names, NATURAL is equivalent to ON TRUE.

CROSS JOIN

CROSS JOIN is equivalent to INNER JOIN ON (TRUE), that is, no rows are removed by qualification. They produce a simple Cartesian product, the same result as you get from listing the two tables at the top level of FROM, but restricted by the join condition (if any).

LATERAL

The LATERAL key word can precede a sub-SELECT FROM item. This allows the sub-SELECT to refer to columns of FROM items that appear before it in the FROM list. (Without LATERAL, each sub-SELECT is evaluated independently and so cannot cross-reference any other FROM item.)

LATERAL can also precede a function-call FROM item, but in this case it is a noise word, because the function expression can refer to earlier FROM items in any case.

A LATERAL item can appear at top level in the FROM list, or within a JOIN tree. In the latter case it can also refer to any items that are on the left-hand side of a JOIN that it is on the right-hand side of.

When a FROM item contains LATERAL cross-references, evaluation proceeds as follows: for each row of the FROM item providing the cross-referenced column(s), or set of rows of multiple FROM items providing the columns, the LATERAL item is evaluated using that row or row set's values of the columns. The resulting row(s) are joined as usual with the rows they were computed from. This is repeated for each row or set of rows from the column source table(s).

The column source table(s) must be INNER or LEFT joined to the LATERAL item, else there would not be a well-defined set of rows from which to compute each set of rows for the LATERAL item. Thus, although a construct such as *X* RIGHT JOIN LATERAL *Y* is syntactically valid, it is not actually allowed for *Y* to reference *X*.

WHERE Clause

The optional WHERE clause has the general form

```
WHERE condition
```

where *condition* is any expression that evaluates to a result of type boolean. Any row that does not satisfy this condition will be eliminated from the output. A row satisfies the condition if it returns true when the actual row values are substituted for any variable references.

GROUP BY Clause

The optional GROUP BY clause has the general form

```
GROUP BY [ ALL | DISTINCT ] grouping_element [, ...]
```

GROUP BY will condense into a single row all selected rows that share the same values for the grouped expressions. An *expression* used inside a *grouping_element* can be an input column name, or the name or ordinal number of an output column (SELECT list item), or an arbitrary expression formed from input-column values. In case of ambiguity, a GROUP BY name will be interpreted as an input-column name rather than an output column name.

If any of GROUPING SETS, ROLLUP or CUBE are present as grouping elements, then the GROUP BY clause as a whole defines some number of independent *grouping sets*. The effect of this is equivalent to constructing a UNION ALL between subqueries with the individual grouping sets as their GROUP BY clauses. The optional DISTINCT clause removes duplicate sets before processing; it does *not* transform the UNION ALL into a UNION DISTINCT. For further details on the handling of grouping sets see Section 7.2.4.

Aggregate functions, if any are used, are computed across all rows making up each group, producing a separate value for each group. (If there are aggregate functions but no GROUP BY clause, the query is treated as having a single group comprising all the selected rows.) The set of rows fed to each aggregate function can be further filtered by attaching a FILTER clause to the aggregate function call; see Section 4.2.7 for more information. When a FILTER clause is present, only those rows matching it are included in the input to that aggregate function.

When GROUP BY is present, or any aggregate functions are present, it is not valid for the SELECT list expressions to refer to ungrouped columns except within aggregate functions or when the ungrouped column is functionally dependent on the grouped columns, since there would otherwise be more than one possible value to return for an ungrouped column. A functional dependency exists if the grouped columns (or a subset thereof) are the primary key of the table containing the ungrouped column.

Keep in mind that all aggregate functions are evaluated before evaluating any “scalar” expressions in the HAVING clause or SELECT list. This means that, for example, a CASE expression cannot be used to skip evaluation of an aggregate function; see Section 4.2.14.

Currently, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE and FOR KEY SHARE cannot be specified with GROUP BY.

HAVING Clause

The optional HAVING clause has the general form

```
HAVING condition
```

where *condition* is the same as specified for the WHERE clause.

HAVING eliminates group rows that do not satisfy the condition. HAVING is different from WHERE: WHERE filters individual rows before the application of GROUP BY, while HAVING filters group rows created by GROUP BY. Each column referenced in *condition* must unambiguously reference a grouping column, unless the reference appears within an aggregate function or the ungrouped column is functionally dependent on the grouping columns.

The presence of HAVING turns a query into a grouped query even if there is no GROUP BY clause. This is the same as what happens when the query contains aggregate functions but no GROUP BY clause. All the selected rows are considered to form a single group, and the SELECT list and HAVING clause can only reference table columns from within aggregate functions. Such a query will emit a single row if the HAVING condition is true, zero rows if it is not true.

Currently, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE and FOR KEY SHARE cannot be specified with HAVING.

WINDOW Clause

The optional WINDOW clause has the general form

```
WINDOW window_name AS ( window_definition ) [, ...]
```

where *window_name* is a name that can be referenced from OVER clauses or subsequent window definitions, and *window_definition* is

```
[ existing_window_name ]
[ PARTITION BY expression [, ...] ]
[ ORDER BY expression [ ASC | DESC | USING operator ] [ NULLS { FIRST | LAST } ]
 [, ...] ]
[ frame_clause ]
```

If an *existing_window_name* is specified it must refer to an earlier entry in the WINDOW list; the new window copies its partitioning clause from that entry, as well as its ordering clause if any. In this case the new window cannot specify its own PARTITION BY clause, and it can specify ORDER BY only if the copied window does not have one. The new window always uses its own frame clause; the copied window must not specify a frame clause.

The elements of the PARTITION BY list are interpreted in much the same fashion as elements of a GROUP BY clause, except that they are always simple expressions and never the name or number of an output column. Another difference is that these expressions can contain aggregate function calls, which are not allowed in a regular GROUP BY clause. They are allowed here because windowing occurs after grouping and aggregation.

Similarly, the elements of the ORDER BY list are interpreted in much the same fashion as elements of a statement-level ORDER BY clause, except that the expressions are always taken as simple expressions and never the name or number of an output column.

The optional *frame_clause* defines the *window frame* for window functions that depend on the frame (not all do). The window frame is a set of related rows for each row of the query (called the *current row*). The *frame_clause* can be one of

```
{ RANGE | ROWS | GROUPS } frame_start [ frame_exclusion ]
{ RANGE | ROWS | GROUPS } BETWEEN frame_start AND frame_end [ frame_exclusion ]
```

where *frame_start* and *frame_end* can be one of

```
UNBOUNDED PRECEDING
offset PRECEDING
CURRENT ROW
offset FOLLOWING
```

```
UNBOUNDED FOLLOWING
```

and *frame_exclusion* can be one of

```
EXCLUDE CURRENT ROW
EXCLUDE GROUP
EXCLUDE TIES
EXCLUDE NO OTHERS
```

If *frame_end* is omitted it defaults to CURRENT ROW. Restrictions are that *frame_start* cannot be UNBOUNDED FOLLOWING, *frame_end* cannot be UNBOUNDED PRECEDING, and the *frame_end* choice cannot appear earlier in the above list of *frame_start* and *frame_end* options than the *frame_start* choice does — for example RANGE BETWEEN CURRENT ROW AND *offset* PRECEDING is not allowed.

The default framing option is RANGE UNBOUNDED PRECEDING, which is the same as RANGE BETWEEN UNBOUNDED PRECEDING AND CURRENT ROW; it sets the frame to be all rows from the partition start up through the current row's last *peer* (a row that the window's ORDER BY clause considers equivalent to the current row; all rows are peers if there is no ORDER BY). In general, UNBOUNDED PRECEDING means that the frame starts with the first row of the partition, and similarly UNBOUNDED FOLLOWING means that the frame ends with the last row of the partition, regardless of RANGE, ROWS or GROUPS mode. In ROWS mode, CURRENT ROW means that the frame starts or ends with the current row; but in RANGE or GROUPS mode it means that the frame starts or ends with the current row's first or last peer in the ORDER BY ordering. The *offset* PRECEDING and *offset* FOLLOWING options vary in meaning depending on the frame mode. In ROWS mode, the *offset* is an integer indicating that the frame starts or ends that many rows before or after the current row. In GROUPS mode, the *offset* is an integer indicating that the frame starts or ends that many peer groups before or after the current row's peer group, where a *peer group* is a group of rows that are equivalent according to the window's ORDER BY clause. In RANGE mode, use of an *offset* option requires that there be exactly one ORDER BY column in the window definition. Then the frame contains those rows whose ordering column value is no more than *offset* less than (for PRECEDING) or more than (for FOLLOWING) the current row's ordering column value. In these cases the data type of the *offset* expression depends on the data type of the ordering column. For numeric ordering columns it is typically of the same type as the ordering column, but for datetime ordering columns it is an interval. In all these cases, the value of the *offset* must be non-null and non-negative. Also, while the *offset* does not have to be a simple constant, it cannot contain variables, aggregate functions, or window functions.

The *frame_exclusion* option allows rows around the current row to be excluded from the frame, even if they would be included according to the frame start and frame end options. EXCLUDE CURRENT ROW excludes the current row from the frame. EXCLUDE GROUP excludes the current row and its ordering peers from the frame. EXCLUDE TIES excludes any peers of the current row from the frame, but not the current row itself. EXCLUDE NO OTHERS simply specifies explicitly the default behavior of not excluding the current row or its peers.

Beware that the ROWS mode can produce unpredictable results if the ORDER BY ordering does not order the rows uniquely. The RANGE and GROUPS modes are designed to ensure that rows that are peers in the ORDER BY ordering are treated alike: all rows of a given peer group will be in the frame or excluded from it.

The purpose of a WINDOW clause is to specify the behavior of *window functions* appearing in the query's SELECT list or ORDER BY clause. These functions can reference the WINDOW clause entries by name in their OVER clauses. A WINDOW clause entry does not have to be referenced anywhere, however; if it is not used in the query it is simply ignored. It is possible to use window functions without any WINDOW clause at all, since a window function call can specify its window definition directly in its OVER clause. However, the WINDOW clause saves typing when the same window definition is needed for more than one window function.

Currently, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE and FOR KEY SHARE cannot be specified with WINDOW.

Window functions are described in detail in Section 3.5, Section 4.2.8, and Section 7.2.5.

SELECT List

The SELECT list (between the key words SELECT and FROM) specifies expressions that form the output rows of the SELECT statement. The expressions can (and usually do) refer to columns computed in the FROM clause.

Just as in a table, every output column of a SELECT has a name. In a simple SELECT this name is just used to label the column for display, but when the SELECT is a sub-query of a larger query, the name is seen by the larger query as the column name of the virtual table produced by the sub-query. To specify the name to use for an output column, write AS *output_name* after the column's expression. (You can omit AS, but only if the desired output name does not match any Postgres Pro keyword (see Appendix C). For protection against possible future keyword additions, it is recommended that you always either write AS or double-quote the output name.) If you do not specify a column name, a name is chosen automatically by Postgres Pro. If the column's expression is a simple column reference then the chosen name is the same as that column's name. In more complex cases a function or type name may be used, or the system may fall back on a generated name such as ?column?.

An output column's name can be used to refer to the column's value in ORDER BY and GROUP BY clauses, but not in the WHERE or HAVING clauses; there you must write out the expression instead.

Instead of an expression, * can be written in the output list as a shorthand for all the columns of the selected rows. Also, you can write *table_name*.* as a shorthand for the columns coming from just that table. In these cases it is not possible to specify new names with AS; the output column names will be the same as the table columns' names.

According to the SQL standard, the expressions in the output list should be computed before applying DISTINCT, ORDER BY, or LIMIT. This is obviously necessary when using DISTINCT, since otherwise it's not clear what values are being made distinct. However, in many cases it is convenient if output expressions are computed after ORDER BY and LIMIT; particularly if the output list contains any volatile or expensive functions. With that behavior, the order of function evaluations is more intuitive and there will not be evaluations corresponding to rows that never appear in the output. Postgres Pro will effectively evaluate output expressions after sorting and limiting, so long as those expressions are not referenced in DISTINCT, ORDER BY or GROUP BY. (As a counterexample, SELECT f(x) FROM tab ORDER BY 1 clearly must evaluate f(x) before sorting.) Output expressions that contain set-returning functions are effectively evaluated after sorting and before limiting, so that LIMIT will act to cut off the output from a set-returning function.

> **Note**
>
> Postgres Pro versions before 9.6 did not provide any guarantees about the timing of evaluation of output expressions versus sorting and limiting; it depended on the form of the chosen query plan.

DISTINCT Clause

If SELECT DISTINCT is specified, all duplicate rows are removed from the result set (one row is kept from each group of duplicates). SELECT ALL specifies the opposite: all rows are kept; that is the default.

SELECT DISTINCT ON (*expression* [, ...]) keeps only the first row of each set of rows where the given expressions evaluate to equal. The DISTINCT ON expressions are interpreted using the same rules as for ORDER BY (see above). Note that the “first row” of each set is unpredictable unless ORDER BY is used to ensure that the desired row appears first. For example:

```
SELECT DISTINCT ON (location) location, time, report
    FROM weather_reports
    ORDER BY location, time DESC;
```

retrieves the most recent weather report for each location. But if we had not used ORDER BY to force descending order of time values for each location, we'd have gotten a report from an unpredictable time for each location.

The DISTINCT ON expression(s) must match the leftmost ORDER BY expression(s). The ORDER BY clause will normally contain additional expression(s) that determine the desired precedence of rows within each DISTINCT ON group.

Currently, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE and FOR KEY SHARE cannot be specified with DISTINCT.

UNION Clause

The UNION clause has this general form:

select_statement UNION [ALL | DISTINCT] *select_statement*

select_statement is any SELECT statement without an ORDER BY, LIMIT, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE, or FOR KEY SHARE clause. (ORDER BY and LIMIT can be attached to a subexpression if it is enclosed in parentheses. Without parentheses, these clauses will be taken to apply to the result of the UNION, not to its right-hand input expression.)

The UNION operator computes the set union of the rows returned by the involved SELECT statements. A row is in the set union of two result sets if it appears in at least one of the result sets. The two SELECT statements that represent the direct operands of the UNION must produce the same number of columns, and corresponding columns must be of compatible data types.

The result of UNION does not contain any duplicate rows unless the ALL option is specified. ALL prevents elimination of duplicates. (Therefore, UNION ALL is usually significantly quicker than UNION; use ALL when you can.) DISTINCT can be written to explicitly specify the default behavior of eliminating duplicate rows.

Multiple UNION operators in the same SELECT statement are evaluated left to right, unless otherwise indicated by parentheses.

Currently, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE and FOR KEY SHARE cannot be specified either for a UNION result or for any input of a UNION.

INTERSECT Clause

The INTERSECT clause has this general form:

select_statement INTERSECT [ALL | DISTINCT] *select_statement*

select_statement is any SELECT statement without an ORDER BY, LIMIT, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE, or FOR KEY SHARE clause.

The INTERSECT operator computes the set intersection of the rows returned by the involved SELECT statements. A row is in the intersection of two result sets if it appears in both result sets.

The result of INTERSECT does not contain any duplicate rows unless the ALL option is specified. With ALL, a row that has m duplicates in the left table and n duplicates in the right table will appear $\min(m,n)$ times in the result set. DISTINCT can be written to explicitly specify the default behavior of eliminating duplicate rows.

Multiple INTERSECT operators in the same SELECT statement are evaluated left to right, unless parentheses dictate otherwise. INTERSECT binds more tightly than UNION. That is, A UNION B INTERSECT C will be read as A UNION (B INTERSECT C).

Currently, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE and FOR KEY SHARE cannot be specified either for an INTERSECT result or for any input of an INTERSECT.

EXCEPT Clause

The EXCEPT clause has this general form:

select_statement EXCEPT [ALL | DISTINCT] *select_statement*

select_statement is any SELECT statement without an ORDER BY, LIMIT, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE, or FOR KEY SHARE clause.

The EXCEPT operator computes the set of rows that are in the result of the left SELECT statement but not in the result of the right one.

The result of EXCEPT does not contain any duplicate rows unless the ALL option is specified. With ALL, a row that has *m* duplicates in the left table and *n* duplicates in the right table will appear max(*m*-*n*,0) times in the result set. DISTINCT can be written to explicitly specify the default behavior of eliminating duplicate rows.

Multiple EXCEPT operators in the same SELECT statement are evaluated left to right, unless parentheses dictate otherwise. EXCEPT binds at the same level as UNION.

Currently, FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE and FOR KEY SHARE cannot be specified either for an EXCEPT result or for any input of an EXCEPT.

ORDER BY Clause

The optional ORDER BY clause has this general form:

```
ORDER BY expression [ ASC | DESC | USING operator ] [ NULLS { FIRST | LAST } ] [, ...]
```

The ORDER BY clause causes the result rows to be sorted according to the specified expression(s). If two rows are equal according to the leftmost expression, they are compared according to the next expression and so on. If they are equal according to all specified expressions, they are returned in an implementation-dependent order.

Each *expression* can be the name or ordinal number of an output column (SELECT list item), or it can be an arbitrary expression formed from input-column values.

The ordinal number refers to the ordinal (left-to-right) position of the output column. This feature makes it possible to define an ordering on the basis of a column that does not have a unique name. This is never absolutely necessary because it is always possible to assign a name to an output column using the AS clause.

It is also possible to use arbitrary expressions in the ORDER BY clause, including columns that do not appear in the SELECT output list. Thus the following statement is valid:

```
SELECT name FROM distributors ORDER BY code;
```

A limitation of this feature is that an ORDER BY clause applying to the result of a UNION, INTERSECT, or EXCEPT clause can only specify an output column name or number, not an expression.

If an ORDER BY expression is a simple name that matches both an output column name and an input column name, ORDER BY will interpret it as the output column name. This is the opposite of the choice that GROUP BY will make in the same situation. This inconsistency is made to be compatible with the SQL standard.

Optionally one can add the key word ASC (ascending) or DESC (descending) after any expression in the ORDER BY clause. If not specified, ASC is assumed by default. Alternatively, a specific ordering operator name can be specified in the USING clause. An ordering operator must be a less-than or greater-than member of some B-tree operator family. ASC is usually equivalent to USING < and DESC is usually equivalent to USING >. (But the creator of a user-defined data type can define exactly what the default sort ordering is, and it might correspond to operators with other names.)

If NULLS LAST is specified, null values sort after all non-null values; if NULLS FIRST is specified, null values sort before all non-null values. If neither is specified, the default behavior is NULLS LAST when ASC is specified or implied, and NULLS FIRST when DESC is specified (thus, the default is to act as though nulls are larger than non-nulls). When USING is specified, the default nulls ordering depends on whether the operator is a less-than or greater-than operator.

Note that ordering options apply only to the expression they follow; for example ORDER BY x, y DESC does not mean the same thing as ORDER BY x DESC, y DESC.

Character-string data is sorted according to the collation that applies to the column being sorted. That can be overridden at need by including a COLLATE clause in the *expression*, for example ORDER BY mycolumn COLLATE "en_US". For more information see Section 4.2.10 and Section 23.2.

LIMIT Clause

The LIMIT clause consists of two independent sub-clauses:

```
LIMIT { count | ALL }
OFFSET start
```

The parameter *count* specifies the maximum number of rows to return, while *start* specifies the number of rows to skip before starting to return rows. When both are specified, *start* rows are skipped before starting to count the *count* rows to be returned.

If the *count* expression evaluates to NULL, it is treated as LIMIT ALL, i.e., no limit. If *start* evaluates to NULL, it is treated the same as OFFSET 0.

SQL:2008 introduced a different syntax to achieve the same result, which Postgres Pro also supports. It is:

```
OFFSET start { ROW | ROWS }
FETCH { FIRST | NEXT } [ count ] { ROW | ROWS } { ONLY | WITH TIES }
```

In this syntax, the *start* or *count* value is required by the standard to be a literal constant, a parameter, or a variable name; as a Postgres Pro extension, other expressions are allowed, but will generally need to be enclosed in parentheses to avoid ambiguity. If *count* is omitted in a FETCH clause, it defaults to 1. The WITH TIES option is used to return any additional rows that tie for the last place in the result set according to the ORDER BY clause; ORDER BY is mandatory in this case, and SKIP LOCKED is not allowed. ROW and ROWS as well as FIRST and NEXT are noise words that don't influence the effects of these clauses. According to the standard, the OFFSET clause must come before the FETCH clause if both are present; but Postgres Pro is laxer and allows either order.

When using LIMIT, it is a good idea to use an ORDER BY clause that constrains the result rows into a unique order. Otherwise you will get an unpredictable subset of the query's rows — you might be asking for the tenth through twentieth rows, but tenth through twentieth in what ordering? You don't know what ordering unless you specify ORDER BY.

The query planner takes LIMIT into account when generating a query plan, so you are very likely to get different plans (yielding different row orders) depending on what you use for LIMIT and OFFSET. Thus, using different LIMIT/OFFSET values to select different subsets of a query result *will give inconsistent results* unless you enforce a predictable result ordering with ORDER BY. This is not a bug; it is an inherent consequence of the fact that SQL does not promise to deliver the results of a query in any particular order unless ORDER BY is used to constrain the order.

It is even possible for repeated executions of the same LIMIT query to return different subsets of the rows of a table, if there is not an ORDER BY to enforce selection of a deterministic subset. Again, this is not a bug; determinism of the results is simply not guaranteed in such a case.

The Locking Clause

FOR UPDATE, FOR NO KEY UPDATE, FOR SHARE and FOR KEY SHARE are *locking clauses*; they affect how SELECT locks rows as they are obtained from the table.

The locking clause has the general form

```
FOR lock_strength [ OF table_name [, ...] ] [ NOWAIT | SKIP LOCKED ]
```

where *lock_strength* can be one of

```
UPDATE
NO KEY UPDATE
SHARE
```

KEY SHARE

For more information on each row-level lock mode, refer to Section 13.3.2.

To prevent the operation from waiting for other transactions to commit, use either the NOWAIT or SKIP LOCKED option. With NOWAIT, the statement reports an error, rather than waiting, if a selected row cannot be locked immediately. With SKIP LOCKED, any selected rows that cannot be immediately locked are skipped. Skipping locked rows provides an inconsistent view of the data, so this is not suitable for general purpose work, but can be used to avoid lock contention with multiple consumers accessing a queue-like table. Note that NOWAIT and SKIP LOCKED apply only to the row-level lock(s) — the required ROW SHARE table-level lock is still taken in the ordinary way (see Chapter 13). You can use LOCK with the NOWAIT option first, if you need to acquire the table-level lock without waiting.

If specific tables are named in a locking clause, then only rows coming from those tables are locked; any other tables used in the SELECT are simply read as usual. A locking clause without a table list affects all tables used in the statement. If a locking clause is applied to a view or sub-query, it affects all tables used in the view or sub-query. However, these clauses do not apply to WITH queries referenced by the primary query. If you want row locking to occur within a WITH query, specify a locking clause within the WITH query.

Multiple locking clauses can be written if it is necessary to specify different locking behavior for different tables. If the same table is mentioned (or implicitly affected) by more than one locking clause, then it is processed as if it was only specified by the strongest one. Similarly, a table is processed as NOWAIT if that is specified in any of the clauses affecting it. Otherwise, it is processed as SKIP LOCKED if that is specified in any of the clauses affecting it.

The locking clauses cannot be used in contexts where returned rows cannot be clearly identified with individual table rows; for example they cannot be used with aggregation.

When a locking clause appears at the top level of a SELECT query, the rows that are locked are exactly those that are returned by the query; in the case of a join query, the rows locked are those that contribute to returned join rows. In addition, rows that satisfied the query conditions as of the query snapshot will be locked, although they will not be returned if they were updated after the snapshot and no longer satisfy the query conditions. If a LIMIT is used, locking stops once enough rows have been returned to satisfy the limit (but note that rows skipped over by OFFSET will get locked). Similarly, if a locking clause is used in a cursor's query, only rows actually fetched or stepped past by the cursor will be locked.

When a locking clause appears in a sub-SELECT, the rows locked are those returned to the outer query by the sub-query. This might involve fewer rows than inspection of the sub-query alone would suggest, since conditions from the outer query might be used to optimize execution of the sub-query. For example,

```
SELECT * FROM (SELECT * FROM mytable FOR UPDATE) ss WHERE col1 = 5;
```

will lock only rows having col1 = 5, even though that condition is not textually within the sub-query.

Previous releases failed to preserve a lock which is upgraded by a later savepoint. For example, this code:

```
BEGIN;
SELECT * FROM mytable WHERE key = 1 FOR UPDATE;
SAVEPOINT s;
UPDATE mytable SET ... WHERE key = 1;
ROLLBACK TO s;
```

would fail to preserve the FOR UPDATE lock after the ROLLBACK TO. This has been fixed in release 9.3.

Caution

It is possible for a SELECT command running at the READ COMMITTED transaction isolation level and using ORDER BY and a locking clause to return rows out of order. This is because ORDER BY is applied first. The command sorts the result, but might then block trying to obtain a lock on one or more of the rows. Once the SELECT unblocks, some of the ordering column values might have been

modified, leading to those rows appearing to be out of order (though they are in order in terms of the original column values). This can be worked around at need by placing the FOR UPDATE/SHARE clause in a sub-query, for example

```
SELECT * FROM (SELECT * FROM mytable FOR UPDATE) ss ORDER BY column1;
```

Note that this will result in locking all rows of mytable, whereas FOR UPDATE at the top level would lock only the actually returned rows. This can make for a significant performance difference, particularly if the ORDER BY is combined with LIMIT or other restrictions. So this technique is recommended only if concurrent updates of the ordering columns are expected and a strictly sorted result is required.

At the REPEATABLE READ or SERIALIZABLE transaction isolation level this would cause a serialization failure (with a SQLSTATE of '40001'), so there is no possibility of receiving rows out of order under these isolation levels.

TABLE Command

The command

```
TABLE name
```

is equivalent to

```
SELECT * FROM name
```

It can be used as a top-level command or as a space-saving syntax variant in parts of complex queries. Only the WITH, UNION, INTERSECT, EXCEPT, ORDER BY, LIMIT, OFFSET, FETCH and FOR locking clauses can be used with TABLE; the WHERE clause and any form of aggregation cannot be used.

Examples

To join the table films with the table distributors:

```
SELECT f.title, f.did, d.name, f.date_prod, f.kind
    FROM distributors d JOIN films f USING (did);

       title       | did |     name     | date_prod  |   kind
-------------------+-----+--------------+------------+----------
 The Third Man     | 101 | British Lion | 1949-12-23 | Drama
 The African Queen | 101 | British Lion | 1951-08-11 | Romantic
 ...
```

To sum the column len of all films and group the results by kind:

```
SELECT kind, sum(len) AS total FROM films GROUP BY kind;

   kind   | total
----------+-------
 Action   | 07:34
 Comedy   | 02:58
 Drama    | 14:28
 Musical  | 06:42
 Romantic | 04:38
```

To sum the column len of all films, group the results by kind and show those group totals that are less than 5 hours:

```
SELECT kind, sum(len) AS total
    FROM films
    GROUP BY kind
    HAVING sum(len) < interval '5 hours';
```

```
   kind   | total
----------+-------
 Comedy   | 02:58
 Romantic | 04:38
```

The following two examples are identical ways of sorting the individual results according to the contents of the second column (`name`):

```
SELECT * FROM distributors ORDER BY name;
SELECT * FROM distributors ORDER BY 2;

 did |       name
-----+------------------
 109 | 20th Century Fox
 110 | Bavaria Atelier
 101 | British Lion
 107 | Columbia
 102 | Jean Luc Godard
 113 | Luso films
 104 | Mosfilm
 103 | Paramount
 106 | Toho
 105 | United Artists
 111 | Walt Disney
 112 | Warner Bros.
 108 | Westward
```

The next example shows how to obtain the union of the tables `distributors` and `actors`, restricting the results to those that begin with the letter W in each table. Only distinct rows are wanted, so the key word `ALL` is omitted.

```
distributors:               actors:
 did |     name              id |     name
-----+--------------        ----+----------------
 108 | Westward               1 | Woody Allen
 111 | Walt Disney            2 | Warren Beatty
 112 | Warner Bros.           3 | Walter Matthau
 ...                         ...

SELECT distributors.name
    FROM distributors
    WHERE distributors.name LIKE 'W%'
UNION
SELECT actors.name
    FROM actors
    WHERE actors.name LIKE 'W%';

      name
----------------
 Walt Disney
 Walter Matthau
 Warner Bros.
 Warren Beatty
 Westward
 Woody Allen
```

This example shows how to use a function in the `FROM` clause, both with and without a column definition list:

```
CREATE FUNCTION distributors(int) RETURNS SETOF distributors AS $$
```

```
    SELECT * FROM distributors WHERE did = $1;
$$ LANGUAGE SQL;

SELECT * FROM distributors(111);
 did |    name
-----+-------------
 111 | Walt Disney

CREATE FUNCTION distributors_2(int) RETURNS SETOF record AS $$
    SELECT * FROM distributors WHERE did = $1;
$$ LANGUAGE SQL;

SELECT * FROM distributors_2(111) AS (f1 int, f2 text);
 f1  |     f2
-----+-------------
 111 | Walt Disney
```

Here is an example of a function with an ordinality column added:

```
SELECT * FROM unnest(ARRAY['a','b','c','d','e','f']) WITH ORDINALITY;
 unnest | ordinality
--------+----------
 a      |        1
 b      |        2
 c      |        3
 d      |        4
 e      |        5
 f      |        6
(6 rows)
```

This example shows how to use a simple `WITH` clause:

```
WITH t AS (
    SELECT random() as x FROM generate_series(1, 3)
  )
SELECT * FROM t
UNION ALL
SELECT * FROM t;
         x
--------------------
  0.534150459803641
  0.520092216785997
 0.0735620250925422
  0.534150459803641
  0.520092216785997
 0.0735620250925422
```

Notice that the `WITH` query was evaluated only once, so that we got two sets of the same three random values.

This example uses `WITH RECURSIVE` to find all subordinates (direct or indirect) of the employee Mary, and their level of indirectness, from a table that shows only direct subordinates:

```
WITH RECURSIVE employee_recursive(distance, employee_name, manager_name) AS (
    SELECT 1, employee_name, manager_name
    FROM employee
    WHERE manager_name = 'Mary'
  UNION ALL
    SELECT er.distance + 1, e.employee_name, e.manager_name
    FROM employee_recursive er, employee e
    WHERE er.employee_name = e.manager_name
```

```
  )
SELECT distance, employee_name FROM employee_recursive;
```

Notice the typical form of recursive queries: an initial condition, followed by `UNION`, followed by the recursive part of the query. Be sure that the recursive part of the query will eventually return no tuples, or else the query will loop indefinitely. (See Section 7.8 for more examples.)

This example uses `LATERAL` to apply a set-returning function `get_product_names()` for each row of the `manufacturers` table:

```
SELECT m.name AS mname, pname
FROM manufacturers m, LATERAL get_product_names(m.id) pname;
```

Manufacturers not currently having any products would not appear in the result, since it is an inner join. If we wished to include the names of such manufacturers in the result, we could do:

```
SELECT m.name AS mname, pname
FROM manufacturers m LEFT JOIN LATERAL get_product_names(m.id) pname ON true;
```

Compatibility

Of course, the `SELECT` statement is compatible with the SQL standard. But there are some extensions and some missing features.

Omitted `FROM` Clauses

Postgres Pro allows one to omit the `FROM` clause. It has a straightforward use to compute the results of simple expressions:

```
SELECT 2+2;

 ?column?
----------
        4
```

Some other SQL databases cannot do this except by introducing a dummy one-row table from which to do the `SELECT`.

Empty `SELECT` Lists

The list of output expressions after `SELECT` can be empty, producing a zero-column result table. This is not valid syntax according to the SQL standard. Postgres Pro allows it to be consistent with allowing zero-column tables. However, an empty list is not allowed when `DISTINCT` is used.

Omitting the `AS` Key Word

In the SQL standard, the optional key word `AS` can be omitted before an output column name whenever the new column name is a valid column name (that is, not the same as any reserved keyword). Postgres Pro is slightly more restrictive: `AS` is required if the new column name matches any keyword at all, reserved or not. Recommended practice is to use `AS` or double-quote output column names, to prevent any possible conflict against future keyword additions.

In `FROM` items, both the standard and Postgres Pro allow `AS` to be omitted before an alias that is an unreserved keyword. But this is impractical for output column names, because of syntactic ambiguities.

`ONLY` and Inheritance

The SQL standard requires parentheses around the table name when writing `ONLY`, for example `SELECT * FROM ONLY (tab1), ONLY (tab2) WHERE ...`. Postgres Pro considers these parentheses to be optional.

Postgres Pro allows a trailing `*` to be written to explicitly specify the non-`ONLY` behavior of including child tables. The standard does not allow this.

(These points apply equally to all SQL commands supporting the `ONLY` option.)

TABLESAMPLE Clause Restrictions

The TABLESAMPLE clause is currently accepted only on regular tables and materialized views. According to the SQL standard it should be possible to apply it to any FROM item.

Function Calls in FROM

Postgres Pro allows a function call to be written directly as a member of the FROM list. In the SQL standard it would be necessary to wrap such a function call in a sub-SELECT; that is, the syntax FROM *func*(...) *alias* is approximately equivalent to FROM LATERAL (SELECT *func*(...)) *alias*. Note that LATERAL is considered to be implicit; this is because the standard requires LATERAL semantics for an UNNEST() item in FROM. Postgres Pro treats UNNEST() the same as other set-returning functions.

Namespace Available to GROUP BY and ORDER BY

In the SQL-92 standard, an ORDER BY clause can only use output column names or numbers, while a GROUP BY clause can only use expressions based on input column names. Postgres Pro extends each of these clauses to allow the other choice as well (but it uses the standard's interpretation if there is ambiguity). Postgres Pro also allows both clauses to specify arbitrary expressions. Note that names appearing in an expression will always be taken as input-column names, not as output-column names.

SQL:1999 and later use a slightly different definition which is not entirely upward compatible with SQL-92. In most cases, however, Postgres Pro will interpret an ORDER BY or GROUP BY expression the same way SQL:1999 does.

Functional Dependencies

Postgres Pro recognizes functional dependency (allowing columns to be omitted from GROUP BY) only when a table's primary key is included in the GROUP BY list. The SQL standard specifies additional conditions that should be recognized.

LIMIT and OFFSET

The clauses LIMIT and OFFSET are Postgres Pro-specific syntax, also used by MySQL. The SQL:2008 standard has introduced the clauses OFFSET ... FETCH {FIRST|NEXT} ... for the same functionality, as shown above in LIMIT Clause. This syntax is also used by IBM DB2. (Applications written for Oracle frequently use a workaround involving the automatically generated rownum column, which is not available in Postgres Pro, to implement the effects of these clauses.)

FOR NO KEY UPDATE, FOR UPDATE, FOR SHARE, FOR KEY SHARE

Although FOR UPDATE appears in the SQL standard, the standard allows it only as an option of DECLARE CURSOR. Postgres Pro allows it in any SELECT query as well as in sub-SELECTs, but this is an extension. The FOR NO KEY UPDATE, FOR SHARE and FOR KEY SHARE variants, as well as the NOWAIT and SKIP LOCKED options, do not appear in the standard.

Data-Modifying Statements in WITH

Postgres Pro allows INSERT, UPDATE, and DELETE to be used as WITH queries. This is not found in the SQL standard.

Nonstandard Clauses

DISTINCT ON (...) is an extension of the SQL standard.

ROWS FROM(...) is an extension of the SQL standard.

The MATERIALIZED and NOT MATERIALIZED options of WITH are extensions of the SQL standard.

SELECT INTO

SELECT INTO — define a new table from the results of a query

Synopsis

```
[ WITH [ RECURSIVE ] with_query [, ...] ]
SELECT [ ALL | DISTINCT [ ON ( expression [, ...] ) ] ]
    [ { * | expression [ [ AS ] output_name ] } [, ...] ]
    INTO [ TEMPORARY | TEMP | UNLOGGED | CONSTANT ] [ TABLE ] new_table
    [ FROM from_item [, ...] ]
    [ WHERE condition ]
    [ GROUP BY expression [, ...] ]
    [ HAVING condition ]
    [ WINDOW window_name AS ( window_definition ) [, ...] ]
    [ { UNION | INTERSECT | EXCEPT } [ ALL | DISTINCT ] select ]
    [ ORDER BY expression [ ASC | DESC | USING operator ] [ NULLS { FIRST | LAST } ]
 [, ...] ]
    [ LIMIT { count | ALL } ]
    [ OFFSET start [ ROW | ROWS ] ]
    [ FETCH { FIRST | NEXT } [ count ] { ROW | ROWS } ONLY ]
    [ FOR { UPDATE | SHARE } [ OF table_name [, ...] ] [ NOWAIT ] [...] ]
```

Description

`SELECT INTO` creates a new table and fills it with data computed by a query. The data is not returned to the client, as it is with a normal `SELECT`. The new table's columns have the names and data types associated with the output columns of the `SELECT`.

Parameters

`TEMPORARY` or `TEMP`

If specified, the table is created as a temporary table. Refer to CREATE TABLE for details.

`UNLOGGED`

If specified, the table is created as an unlogged table. Refer to CREATE TABLE for details.

`CONSTANT`

If specified, the table is created as read-only. Refer to CREATE TABLE for details.

`new_table`

The name (optionally schema-qualified) of the table to be created.

All other parameters are described in detail under SELECT.

Notes

`CREATE TABLE AS` is functionally similar to `SELECT INTO`. `CREATE TABLE AS` is the recommended syntax, since this form of `SELECT INTO` is not available in ECPG or PL/pgSQL, because they interpret the `INTO` clause differently. Furthermore, `CREATE TABLE AS` offers a superset of the functionality provided by `SELECT INTO`.

In contrast to `CREATE TABLE AS`, `SELECT INTO` does not allow specifying properties like a table's access method with `USING` *`method`* or the table's tablespace with `TABLESPACE` *`tablespace_name`*. Use `CREATE TABLE AS` if necessary. Therefore, the default table access method is chosen for the new table. See default_table_access_method for more information.

Examples

Create a new table `films_recent` consisting of only recent entries from the table `films`:

```
SELECT * INTO films_recent FROM films WHERE date_prod >= '2002-01-01';
```

Compatibility

The SQL standard uses `SELECT INTO` to represent selecting values into scalar variables of a host program, rather than creating a new table. This indeed is the usage found in ECPG (see Chapter 38) and PL/pgSQL (see Chapter 45). The Postgres Pro usage of `SELECT INTO` to represent table creation is historical. Some other SQL implementations also use `SELECT INTO` in this way (but most SQL implementations support `CREATE TABLE AS` instead). Apart from such compatibility considerations, it is best to use `CREATE TABLE AS` for this purpose in new code.

See Also

CREATE TABLE AS

SET

SET — change a run-time parameter

Synopsis

```
SET [ SESSION | LOCAL ] configuration_parameter { TO | = } { value | 'value' |
 DEFAULT }
SET [ SESSION | LOCAL ] TIME ZONE { value | 'value' | LOCAL | DEFAULT }
```

Description

The SET command changes run-time configuration parameters. Many of the run-time parameters listed in Chapter 19 can be changed on-the-fly with SET. (But some require superuser privileges to change, and others cannot be changed after server or session start.) SET only affects the value used by the current session.

If SET (or equivalently SET SESSION) is issued within a transaction that is later aborted, the effects of the SET command disappear when the transaction is rolled back. Once the surrounding transaction is committed, the effects will persist until the end of the session, unless overridden by another SET.

The effects of SET LOCAL last only till the end of the current transaction, whether committed or not. A special case is SET followed by SET LOCAL within a single transaction: the SET LOCAL value will be seen until the end of the transaction, but afterwards (if the transaction is committed) the SET value will take effect.

The effects of SET or SET LOCAL are also canceled by rolling back to a savepoint that is earlier than the command.

If SET LOCAL is used within a function that has a SET option for the same variable (see CREATE FUNCTION), the effects of the SET LOCAL command disappear at function exit; that is, the value in effect when the function was called is restored anyway. This allows SET LOCAL to be used for dynamic or repeated changes of a parameter within a function, while still having the convenience of using the SET option to save and restore the caller's value. However, a regular SET command overrides any surrounding function's SET option; its effects will persist unless rolled back.

> **Note**
>
> In PostgreSQL versions 8.0 through 8.2, the effects of a SET LOCAL would be canceled by releasing an earlier savepoint, or by successful exit from a PL/pgSQL exception block. This behavior has been changed because it was deemed unintuitive.

Parameters

SESSION

Specifies that the command takes effect for the current session. (This is the default if neither SESSION nor LOCAL appears.)

LOCAL

Specifies that the command takes effect for only the current transaction. After COMMIT or ROLLBACK, the session-level setting takes effect again. Issuing this outside of a transaction block emits a warning and otherwise has no effect.

configuration_parameter

Name of a settable run-time parameter. Available parameters are documented in Chapter 19 and below.

value

New value of parameter. Values can be specified as string constants, identifiers, numbers, or comma-separated lists of these, as appropriate for the particular parameter. DEFAULT can be written to specify resetting the parameter to its default value (that is, whatever value it would have had if no SET had been executed in the current session).

Besides the configuration parameters documented in Chapter 19, there are a few that can only be adjusted using the SET command or that have a special syntax:

SCHEMA

SET SCHEMA '*value*' is an alias for SET search_path TO *value*. Only one schema can be specified using this syntax.

NAMES

SET NAMES *value* is an alias for SET client_encoding TO *value*.

SEED

Sets the internal seed for the random number generator (the function random). Allowed values are floating-point numbers between -1 and 1 inclusive.

The seed can also be set by invoking the function setseed:

```
SELECT setseed(value);
```

TIME ZONE

SET TIME ZONE '*value*' is an alias for SET timezone TO '*value*'. The syntax SET TIME ZONE allows special syntax for the time zone specification. Here are examples of valid values:

'America/Los_Angeles'

The time zone for Berkeley, California.

'Europe/Rome'

The time zone for Italy.

-7

The time zone 7 hours west from UTC (equivalent to PDT). Positive values are east from UTC.

INTERVAL '-08:00' HOUR TO MINUTE

The time zone 8 hours west from UTC (equivalent to PST).

LOCAL
DEFAULT

Set the time zone to your local time zone (that is, the server's default value of timezone).

Timezone settings given as numbers or intervals are internally translated to POSIX timezone syntax. For example, after SET TIME ZONE -7, SHOW TIME ZONE would report <-07>+07.

Time zone abbreviations are not supported by SET; see Section 8.5.3 for more information about time zones.

Notes

The function set_config provides equivalent functionality; see Section 9.27.1. Also, it is possible to UPDATE the pg_settings system view to perform the equivalent of SET.

Examples

Set the schema search path:

```
SET search_path TO my_schema, public;
```

Set the style of date to traditional POSTGRES with “day before month” input convention:

```
SET datestyle TO postgres, dmy;
```

Set the time zone for Berkeley, California:

```
SET TIME ZONE 'America/Los_Angeles';
```

Set the time zone for Italy:

```
SET TIME ZONE 'Europe/Rome';
```

Compatibility

`SET TIME ZONE` extends syntax defined in the SQL standard. The standard allows only numeric time zone offsets while Postgres Pro allows more flexible time-zone specifications. All other `SET` features are Postgres Pro extensions.

See Also

RESET, SHOW

SET CONSTRAINTS

SET CONSTRAINTS — set constraint check timing for the current transaction

Synopsis

```
SET CONSTRAINTS { ALL | name [, ...] } { DEFERRED | IMMEDIATE }
```

Description

`SET CONSTRAINTS` sets the behavior of constraint checking within the current transaction. `IMMEDIATE` constraints are checked at the end of each statement. `DEFERRED` constraints are not checked until transaction commit. Each constraint has its own `IMMEDIATE` or `DEFERRED` mode.

Upon creation, a constraint is given one of three characteristics: `DEFERRABLE INITIALLY DEFERRED`, `DEFERRABLE INITIALLY IMMEDIATE`, or `NOT DEFERRABLE`. The third class is always `IMMEDIATE` and is not affected by the `SET CONSTRAINTS` command. The first two classes start every transaction in the indicated mode, but their behavior can be changed within a transaction by `SET CONSTRAINTS`.

`SET CONSTRAINTS` with a list of constraint names changes the mode of just those constraints (which must all be deferrable). Each constraint name can be schema-qualified. The current schema search path is used to find the first matching name if no schema name is specified. `SET CONSTRAINTS ALL` changes the mode of all deferrable constraints.

When `SET CONSTRAINTS` changes the mode of a constraint from `DEFERRED` to `IMMEDIATE`, the new mode takes effect retroactively: any outstanding data modifications that would have been checked at the end of the transaction are instead checked during the execution of the `SET CONSTRAINTS` command. If any such constraint is violated, the `SET CONSTRAINTS` fails (and does not change the constraint mode). Thus, `SET CONSTRAINTS` can be used to force checking of constraints to occur at a specific point in a transaction.

Currently, only `UNIQUE`, `PRIMARY KEY`, `REFERENCES` (foreign key), and `EXCLUDE` constraints are affected by this setting. `NOT NULL` and `CHECK` constraints are always checked immediately when a row is inserted or modified (*not* at the end of the statement). Uniqueness and exclusion constraints that have not been declared `DEFERRABLE` are also checked immediately.

The firing of triggers that are declared as “constraint triggers” is also controlled by this setting — they fire at the same time that the associated constraint should be checked.

Notes

Because Postgres Pro does not require constraint names to be unique within a schema (but only pertable), it is possible that there is more than one match for a specified constraint name. In this case `SET CONSTRAINTS` will act on all matches. For a non-schema-qualified name, once a match or matches have been found in some schema in the search path, schemas appearing later in the path are not searched.

This command only alters the behavior of constraints within the current transaction. Issuing this outside of a transaction block emits a warning and otherwise has no effect.

Compatibility

This command complies with the behavior defined in the SQL standard, except for the limitation that, in Postgres Pro, it does not apply to `NOT NULL` and `CHECK` constraints. Also, Postgres Pro checks nondeferrable uniqueness constraints immediately, not at end of statement as the standard would suggest.

SET ROLE

SET ROLE — set the current user identifier of the current session

Synopsis

```
SET [ SESSION | LOCAL ] ROLE role_name
SET [ SESSION | LOCAL ] ROLE NONE
RESET ROLE
```

Description

This command sets the current user identifier of the current SQL session to be *role_name*. The role name can be written as either an identifier or a string literal. After SET ROLE, permissions checking for SQL commands is carried out as though the named role were the one that had logged in originally.

The specified *role_name* must be a role that the current session user is a member of. (If the session user is a superuser, any role can be selected.)

The SESSION and LOCAL modifiers act the same as for the regular SET command.

SET ROLE NONE sets the current user identifier to the current session user identifier, as returned by session_user. RESET ROLE sets the current user identifier to the connection-time setting specified by the command-line options, ALTER ROLE, or ALTER DATABASE, if any such settings exist. Otherwise, RESET ROLE sets the current user identifier to the current session user identifier. These forms can be executed by any user.

Notes

Using this command, it is possible to either add privileges or restrict one's privileges. If the session user role has the INHERIT attribute, then it automatically has all the privileges of every role that it could SET ROLE to; in this case SET ROLE effectively drops all the privileges assigned directly to the session user and to the other roles it is a member of, leaving only the privileges available to the named role. On the other hand, if the session user role has the NOINHERIT attribute, SET ROLE drops the privileges assigned directly to the session user and instead acquires the privileges available to the named role.

In particular, when a superuser chooses to SET ROLE to a non-superuser role, they lose their superuser privileges.

SET ROLE has effects comparable to SET SESSION AUTHORIZATION, but the privilege checks involved are quite different. Also, SET SESSION AUTHORIZATION determines which roles are allowable for later SET ROLE commands, whereas changing roles with SET ROLE does not change the set of roles allowed to a later SET ROLE.

SET ROLE does not process session variables as specified by the role's ALTER ROLE settings; this only happens during login.

SET ROLE cannot be used within a SECURITY DEFINER function.

Examples

```
SELECT SESSION_USER, CURRENT_USER;

 session_user | current_user
--------------+--------------
 peter        | peter

SET ROLE 'paul';
```

```
SELECT SESSION_USER, CURRENT_USER;

 session_user | current_user
--------------+--------------
 peter        | paul
```

Compatibility

Postgres Pro allows identifier syntax ("*rolename*"), while the SQL standard requires the role name to be written as a string literal. SQL does not allow this command during a transaction; Postgres Pro does not make this restriction because there is no reason to. The `SESSION` and `LOCAL` modifiers are a Postgres Pro extension, as is the `RESET` syntax.

See Also

SET SESSION AUTHORIZATION

SET SESSION AUTHORIZATION

SET SESSION AUTHORIZATION — set the session user identifier and the current user identifier of the current session

Synopsis

```
SET [ SESSION | LOCAL ] SESSION AUTHORIZATION user_name
SET [ SESSION | LOCAL ] SESSION AUTHORIZATION DEFAULT
RESET SESSION AUTHORIZATION
```

Description

This command sets the session user identifier and the current user identifier of the current SQL session to be *user_name*. The user name can be written as either an identifier or a string literal. Using this command, it is possible, for example, to temporarily become an unprivileged user and later switch back to being a superuser.

The session user identifier is initially set to be the (possibly authenticated) user name provided by the client. The current user identifier is normally equal to the session user identifier, but might change temporarily in the context of SECURITY DEFINER functions and similar mechanisms; it can also be changed by SET ROLE. The current user identifier is relevant for permission checking.

The session user identifier can be changed only if the initial session user (the *authenticated user*) had the superuser privilege. Otherwise, the command is accepted only if it specifies the authenticated user name.

The SESSION and LOCAL modifiers act the same as for the regular SET command.

The DEFAULT and RESET forms reset the session and current user identifiers to be the originally authenticated user name. These forms can be executed by any user.

Notes

SET SESSION AUTHORIZATION cannot be used within a SECURITY DEFINER function.

Examples

```
SELECT SESSION_USER, CURRENT_USER;

 session_user | current_user
--------------+--------------
 peter        | peter

SET SESSION AUTHORIZATION 'paul';

SELECT SESSION_USER, CURRENT_USER;

 session_user | current_user
--------------+--------------
 paul         | paul
```

Compatibility

The SQL standard allows some other expressions to appear in place of the literal *user_name*, but these options are not important in practice. Postgres Pro allows identifier syntax ("*username*"), which SQL does not. SQL does not allow this command during a transaction; Postgres Pro does not make this restriction because there is no reason to. The SESSION and LOCAL modifiers are a Postgres Pro extension, as is the RESET syntax.

The privileges necessary to execute this command are left implementation-defined by the standard.

See Also

SET ROLE

SET TRANSACTION

SET TRANSACTION — set the characteristics of the current transaction

Synopsis

```
SET TRANSACTION transaction_mode [, ...]
SET TRANSACTION SNAPSHOT snapshot_id
SET SESSION CHARACTERISTICS AS TRANSACTION transaction_mode [, ...]

where transaction_mode is one of:

    ISOLATION LEVEL { SERIALIZABLE | REPEATABLE READ | READ COMMITTED | READ
 UNCOMMITTED }
    READ WRITE | READ ONLY
    [ NOT ] DEFERRABLE
```

Description

The `SET TRANSACTION` command sets the characteristics of the current transaction. It has no effect on any subsequent transactions. `SET SESSION CHARACTERISTICS` sets the default transaction characteristics for subsequent transactions of a session. These defaults can be overridden by `SET TRANSACTION` for an individual transaction.

The available transaction characteristics are the transaction isolation level, the transaction access mode (read/write or read-only), and the deferrable mode. In addition, a snapshot can be selected, though only for the current transaction, not as a session default.

The isolation level of a transaction determines what data the transaction can see when other transactions are running concurrently:

`READ COMMITTED`

A statement can only see rows committed before it began. This is the default.

`REPEATABLE READ`

All statements of the current transaction can only see rows committed before the first query or data-modification statement was executed in this transaction.

`SERIALIZABLE`

All statements of the current transaction can only see rows committed before the first query or data-modification statement was executed in this transaction. If a pattern of reads and writes among concurrent serializable transactions would create a situation which could not have occurred for any serial (one-at-a-time) execution of those transactions, one of them will be rolled back with a `serialization_failure` error.

The SQL standard defines one additional level, `READ UNCOMMITTED`. In Postgres Pro `READ UNCOMMITTED` is treated as `READ COMMITTED`.

The transaction isolation level cannot be changed after the first query or data-modification statement (`SELECT`, `INSERT`, `DELETE`, `UPDATE`, `FETCH`, or `COPY`) of a transaction has been executed. See Chapter 13 for more information about transaction isolation and concurrency control.

The transaction access mode determines whether the transaction is read/write or read-only. Read/write is the default. When a transaction is read-only, the following SQL commands are disallowed: `INSERT`, `UPDATE`, `DELETE`, and `COPY FROM` if the table they would write to is not a temporary table; all `CREATE`, `ALTER`, and `DROP` commands; `COMMENT`, `GRANT`, `REVOKE`, `TRUNCATE`; and `EXPLAIN ANALYZE` and `EXECUTE` if the command they would execute is among those listed. This is a high-level notion of read-only that does not prevent all writes to disk.

The DEFERRABLE transaction property has no effect unless the transaction is also SERIALIZABLE and READ ONLY. When all three of these properties are selected for a transaction, the transaction may block when first acquiring its snapshot, after which it is able to run without the normal overhead of a SERIALIZABLE transaction and without any risk of contributing to or being canceled by a serialization failure. This mode is well suited for long-running reports or backups.

The SET TRANSACTION SNAPSHOT command allows a new transaction to run with the same *snapshot* as an existing transaction. The pre-existing transaction must have exported its snapshot with the pg_export_snapshot function (see Section 9.27.5). That function returns a snapshot identifier, which must be given to SET TRANSACTION SNAPSHOT to specify which snapshot is to be imported. The identifier must be written as a string literal in this command, for example '00000003-0000001B-1'. SET TRANSACTION SNAPSHOT can only be executed at the start of a transaction, before the first query or data-modification statement (SELECT, INSERT, DELETE, UPDATE, FETCH, or COPY) of the transaction. Furthermore, the transaction must already be set to SERIALIZABLE or REPEATABLE READ isolation level (otherwise, the snapshot would be discarded immediately, since READ COMMITTED mode takes a new snapshot for each command). If the importing transaction uses SERIALIZABLE isolation level, then the transaction that exported the snapshot must also use that isolation level. Also, a non-read-only serializable transaction cannot import a snapshot from a read-only transaction.

Notes

If SET TRANSACTION is executed without a prior START TRANSACTION or BEGIN, it emits a warning and otherwise has no effect.

It is possible to dispense with SET TRANSACTION by instead specifying the desired *transaction_modes* in BEGIN or START TRANSACTION. But that option is not available for SET TRANSACTION SNAPSHOT.

The session default transaction modes can also be set or examined via the configuration parameters default_transaction_isolation, default_transaction_read_only, and default_transaction_deferrable. (In fact SET SESSION CHARACTERISTICS is just a verbose equivalent for setting these variables with SET.) This means the defaults can be set in the configuration file, via ALTER DATABASE, etc. Consult Chapter 19 for more information.

The current transaction's modes can similarly be set or examined via the configuration parameters transaction_isolation, transaction_read_only, and transaction_deferrable. Setting one of these parameters acts the same as the corresponding SET TRANSACTION option, with the same restrictions on when it can be done. However, these parameters cannot be set in the configuration file, or from any source other than live SQL.

Examples

To begin a new transaction with the same snapshot as an already existing transaction, first export the snapshot from the existing transaction. That will return the snapshot identifier, for example:

```
BEGIN TRANSACTION ISOLATION LEVEL REPEATABLE READ;
SELECT pg_export_snapshot();
 pg_export_snapshot
---------------------
 00000003-0000001B-1
(1 row)
```

Then give the snapshot identifier in a SET TRANSACTION SNAPSHOT command at the beginning of the newly opened transaction:

```
BEGIN TRANSACTION ISOLATION LEVEL REPEATABLE READ;
SET TRANSACTION SNAPSHOT '00000003-0000001B-1';
```

Compatibility

These commands are defined in the SQL standard, except for the DEFERRABLE transaction mode and the SET TRANSACTION SNAPSHOT form, which are Postgres Pro extensions.

`SERIALIZABLE` is the default transaction isolation level in the standard. In Postgres Pro the default is ordinarily `READ COMMITTED`, but you can change it as mentioned above.

In the SQL standard, there is one other transaction characteristic that can be set with these commands: the size of the diagnostics area. This concept is specific to embedded SQL, and therefore is not implemented in the Postgres Pro server.

The SQL standard requires commas between successive *`transaction_modes`*, but for historical reasons Postgres Pro allows the commas to be omitted.

SHOW

SHOW — show the value of a run-time parameter

Synopsis

```
SHOW name
SHOW ALL
```

Description

`SHOW` will display the current setting of run-time parameters. These variables can be set using the `SET` statement, by editing the `postgresql.conf` configuration file, through the `PGOPTIONS` environmental variable (when using libpq or a libpq-based application), or through command-line flags when starting the `postgres` server. See Chapter 19 for details.

Parameters

name

The name of a run-time parameter. Available parameters are documented in Chapter 19 and on the SET reference page. In addition, there are a few parameters that can be shown but not set:

`SERVER_VERSION`

Shows the server's version number.

`SERVER_ENCODING`

Shows the server-side character set encoding. At present, this parameter can be shown but not set, because the encoding is determined at database creation time.

`LC_COLLATE`

Shows the database's locale setting for collation (text ordering). At present, this parameter can be shown but not set, because the setting is determined at database creation time.

`LC_CTYPE`

Shows the database's locale setting for character classification. At present, this parameter can be shown but not set, because the setting is determined at database creation time.

`IS_SUPERUSER`

True if the current role has superuser privileges.

`ALL`

Show the values of all configuration parameters, with descriptions.

Notes

The function `current_setting` produces equivalent output; see Section 9.27.1. Also, the `pg_settings` system view produces the same information.

Examples

Show the current setting of the parameter `DateStyle`:

```
SHOW DateStyle;
 DateStyle
-----------
 ISO, MDY
```

```
(1 row)
```

Show the current setting of the parameter `geqo`:

```
SHOW geqo;
 geqo
------
 on
(1 row)
```

Show all settings:

```
SHOW ALL;
            name          | setting |                 description

--------------------------+---------+-------------------------------------------------
 allow_system_table_mods | off     | Allows modifications of the structure of ...
    .
    .
    .
 xmloption               | content | Sets whether XML data in implicit parsing ...
 zero_damaged_pages      | off     | Continues processing past damaged page headers.
(196 rows)
```

Compatibility

The `SHOW` command is a Postgres Pro extension.

See Also

SET, RESET

START TRANSACTION

START TRANSACTION — start a transaction block

Synopsis

```
START [ AUTONOMOUS ] TRANSACTION [ transaction_mode [, ...] ]

where transaction_mode is one of:

    ISOLATION LEVEL { SERIALIZABLE | REPEATABLE READ | READ COMMITTED | READ
 UNCOMMITTED }
    READ WRITE | READ ONLY
    [ NOT ] DEFERRABLE
```

Description

This command begins a new transaction block. If the isolation level, read/write mode, or deferrable mode is specified, the new transaction has those characteristics, as if `SET TRANSACTION` was executed. This is the same as the `BEGIN` command.

If you specify an optional `AUTONOMOUS` keyword, an autonomous transaction is started. Autonomous transactions can be started only within another transaction. For details, see Chapter 16.

Parameters

Refer to SET TRANSACTION for information on the meaning of the parameters to this statement.

Compatibility

In the standard, it is not necessary to issue `START TRANSACTION` to start a transaction block: any SQL command implicitly begins a block. Postgres Pro's behavior can be seen as implicitly issuing a `COMMIT` after each command that does not follow `START TRANSACTION` (or `BEGIN`), and it is therefore often called “autocommit”. Other relational database systems might offer an autocommit feature as a convenience.

The `DEFERRABLE` *`transaction_mode`* is a Postgres Pro language extension.

The SQL standard requires commas between successive *`transaction_modes`*, but for historical reasons Postgres Pro allows the commas to be omitted.

See also the compatibility section of SET TRANSACTION.

See Also

BEGIN, COMMIT, ROLLBACK, SAVEPOINT, SET TRANSACTION

TRUNCATE

TRUNCATE — empty a table or set of tables

Synopsis

```
TRUNCATE [ TABLE ] [ ONLY ] name [ * ] [, ... ]
    [ RESTART IDENTITY | CONTINUE IDENTITY ] [ CASCADE | RESTRICT ]
```

Description

`TRUNCATE` quickly removes all rows from a set of tables. It has the same effect as an unqualified `DELETE` on each table, but since it does not actually scan the tables it is faster. Furthermore, it reclaims disk space immediately, rather than requiring a subsequent `VACUUM` operation. This is most useful on large tables.

Parameters

name

The name (optionally schema-qualified) of a table to truncate. If `ONLY` is specified before the table name, only that table is truncated. If `ONLY` is not specified, the table and all its descendant tables (if any) are truncated. Optionally, `*` can be specified after the table name to explicitly indicate that descendant tables are included.

`RESTART IDENTITY`

Automatically restart sequences owned by columns of the truncated table(s).

`CONTINUE IDENTITY`

Do not change the values of sequences. This is the default.

`CASCADE`

Automatically truncate all tables that have foreign-key references to any of the named tables, or to any tables added to the group due to `CASCADE`.

`RESTRICT`

Refuse to truncate if any of the tables have foreign-key references from tables that are not listed in the command. This is the default.

Notes

You must have the `TRUNCATE` privilege on a table to truncate it.

`TRUNCATE` acquires an `ACCESS EXCLUSIVE` lock on each table it operates on, which blocks all other concurrent operations on the table. When `RESTART IDENTITY` is specified, any sequences that are to be restarted are likewise locked exclusively. If concurrent access to a table is required, then the `DELETE` command should be used instead.

`TRUNCATE` cannot be used on a table that has foreign-key references from other tables, unless all such tables are also truncated in the same command. Checking validity in such cases would require table scans, and the whole point is not to do one. The `CASCADE` option can be used to automatically include all dependent tables — but be very careful when using this option, or else you might lose data you did not intend to! Note in particular that when the table to be truncated is a partition, siblings partitions are left untouched, but cascading occurs to all referencing tables and all their partitions with no distinction.

`TRUNCATE` will not fire any `ON DELETE` triggers that might exist for the tables. But it will fire `ON TRUNCATE` triggers. If `ON TRUNCATE` triggers are defined for any of the tables, then all `BEFORE TRUNCATE` triggers are

fired before any truncation happens, and all `AFTER TRUNCATE` triggers are fired after the last truncation is performed and any sequences are reset. The triggers will fire in the order that the tables are to be processed (first those listed in the command, and then any that were added due to cascading).

`TRUNCATE` is not MVCC-safe. After truncation, the table will appear empty to concurrent transactions, if they are using a snapshot taken before the truncation occurred. See Section 13.5 for more details.

`TRUNCATE` is transaction-safe with respect to the data in the tables: the truncation will be safely rolled back if the surrounding transaction does not commit.

When `RESTART IDENTITY` is specified, the implied `ALTER SEQUENCE RESTART` operations are also done transactionally; that is, they will be rolled back if the surrounding transaction does not commit. Be aware that if any additional sequence operations are done on the restarted sequences before the transaction rolls back, the effects of these operations on the sequences will be rolled back, but not their effects on `currval()`; that is, after the transaction `currval()` will continue to reflect the last sequence value obtained inside the failed transaction, even though the sequence itself may no longer be consistent with that. This is similar to the usual behavior of `currval()` after a failed transaction.

`TRUNCATE` can be used for foreign tables if supported by the foreign data wrapper, for instance, see postgres_fdw.

Examples

Truncate the tables `bigtable` and `fattable`:

```
TRUNCATE bigtable, fattable;
```

The same, and also reset any associated sequence generators:

```
TRUNCATE bigtable, fattable RESTART IDENTITY;
```

Truncate the table `othertable`, and cascade to any tables that reference `othertable` via foreign-key constraints:

```
TRUNCATE othertable CASCADE;
```

Compatibility

The SQL:2008 standard includes a `TRUNCATE` command with the syntax `TRUNCATE TABLE` *`tablename`*. The clauses `CONTINUE IDENTITY`/`RESTART IDENTITY` also appear in that standard, but have slightly different though related meanings. Some of the concurrency behavior of this command is left implementation-defined by the standard, so the above notes should be considered and compared with other implementations if necessary.

See Also

DELETE

UNLISTEN

UNLISTEN — stop listening for a notification

Synopsis

```
UNLISTEN { channel | * }
```

Description

`UNLISTEN` is used to remove an existing registration for `NOTIFY` events. `UNLISTEN` cancels any existing registration of the current Postgres Pro session as a listener on the notification channel named *`channel`*. The special wildcard `*` cancels all listener registrations for the current session.

NOTIFY contains a more extensive discussion of the use of `LISTEN` and `NOTIFY`.

Parameters

`channel`

Name of a notification channel (any identifier).

`*`

All current listen registrations for this session are cleared.

Notes

You can unlisten something you were not listening for; no warning or error will appear.

At the end of each session, `UNLISTEN *` is automatically executed.

A transaction that has executed `UNLISTEN` cannot be prepared for two-phase commit.

Examples

To make a registration:

```
LISTEN virtual;
NOTIFY virtual;
Asynchronous notification "virtual" received from server process with PID 8448.
```

Once `UNLISTEN` has been executed, further `NOTIFY` messages will be ignored:

```
UNLISTEN virtual;
NOTIFY virtual;
-- no NOTIFY event is received
```

Compatibility

There is no `UNLISTEN` command in the SQL standard.

See Also

LISTEN, NOTIFY

UPDATE

UPDATE — update rows of a table

Synopsis

```
[ WITH [ RECURSIVE ] with_query [, ...] ]
UPDATE [ ONLY ] table_name [ * ] [ [ AS ] alias ]
    SET { column_name = { expression | DEFAULT } |
          ( column_name [, ...] ) = [ ROW ] ( { expression | DEFAULT } [, ...] ) |
          ( column_name [, ...] ) = ( sub-SELECT )
        } [, ...]
    [ FROM from_item [, ...] ]
    [ WHERE condition | WHERE CURRENT OF cursor_name ]
    [ RETURNING { * | output_expression [ [ AS ] output_name ] } [, ...] ]
```

Description

`UPDATE` changes the values of the specified columns in all rows that satisfy the condition. Only the columns to be modified need be mentioned in the `SET` clause; columns not explicitly modified retain their previous values.

There are two ways to modify a table using information contained in other tables in the database: using sub-selects, or specifying additional tables in the `FROM` clause. Which technique is more appropriate depends on the specific circumstances.

The optional `RETURNING` clause causes `UPDATE` to compute and return value(s) based on each row actually updated. Any expression using the table's columns, and/or columns of other tables mentioned in `FROM`, can be computed. The new (post-update) values of the table's columns are used. The syntax of the `RETURNING` list is identical to that of the output list of `SELECT`.

You must have the `UPDATE` privilege on the table, or at least on the column(s) that are listed to be updated. You must also have the `SELECT` privilege on any column whose values are read in the *expressions* or *condition*.

Parameters

with_query

The `WITH` clause allows you to specify one or more subqueries that can be referenced by name in the `UPDATE` query. See Section 7.8 and SELECT for details.

table_name

The name (optionally schema-qualified) of the table to update. If `ONLY` is specified before the table name, matching rows are updated in the named table only. If `ONLY` is not specified, matching rows are also updated in any tables inheriting from the named table. Optionally, `*` can be specified after the table name to explicitly indicate that descendant tables are included.

alias

A substitute name for the target table. When an alias is provided, it completely hides the actual name of the table. For example, given `UPDATE foo AS f`, the remainder of the `UPDATE` statement must refer to this table as `f` not `foo`.

column_name

The name of a column in the table named by *table_name*. The column name can be qualified with a subfield name or array subscript, if needed. Do not include the table's name in the specification of a target column — for example, `UPDATE table_name SET table_name.col = 1` is invalid.

expression

An expression to assign to the column. The expression can use the old values of this and other columns in the table.

DEFAULT

Set the column to its default value (which will be NULL if no specific default expression has been assigned to it). An identity column will be set to a new value generated by the associated sequence. For a generated column, specifying this is permitted but merely specifies the normal behavior of computing the column from its generation expression.

sub-SELECT

A SELECT sub-query that produces as many output columns as are listed in the parenthesized column list preceding it. The sub-query must yield no more than one row when executed. If it yields one row, its column values are assigned to the target columns; if it yields no rows, NULL values are assigned to the target columns. The sub-query can refer to old values of the current row of the table being updated.

from_item

A table expression allowing columns from other tables to appear in the WHERE condition and update expressions. This uses the same syntax as the FROM clause of a SELECT statement; for example, an alias for the table name can be specified. Do not repeat the target table as a *from_item* unless you intend a self-join (in which case it must appear with an alias in the *from_item*).

condition

An expression that returns a value of type boolean. Only rows for which this expression returns true will be updated.

cursor_name

The name of the cursor to use in a WHERE CURRENT OF condition. The row to be updated is the one most recently fetched from this cursor. The cursor must be a non-grouping query on the UPDATE's target table. Note that WHERE CURRENT OF cannot be specified together with a Boolean condition. See DECLARE for more information about using cursors with WHERE CURRENT OF.

output_expression

An expression to be computed and returned by the UPDATE command after each row is updated. The expression can use any column names of the table named by *table_name* or table(s) listed in FROM. Write * to return all columns.

output_name

A name to use for a returned column.

Outputs

On successful completion, an UPDATE command returns a command tag of the form

UPDATE *count*

The *count* is the number of rows updated, including matched rows whose values did not change. Note that the number may be less than the number of rows that matched the *condition* when updates were suppressed by a BEFORE UPDATE trigger. If *count* is 0, no rows were updated by the query (this is not considered an error).

If the UPDATE command contains a RETURNING clause, the result will be similar to that of a SELECT statement containing the columns and values defined in the RETURNING list, computed over the row(s) updated by the command.

Notes

When a FROM clause is present, what essentially happens is that the target table is joined to the tables mentioned in the *from_item* list, and each output row of the join represents an update operation for the target table. When using FROM you should ensure that the join produces at most one output row for each row to be modified. In other words, a target row shouldn't join to more than one row from the other table(s). If it does, then only one of the join rows will be used to update the target row, but which one will be used is not readily predictable.

Because of this indeterminacy, referencing other tables only within sub-selects is safer, though often harder to read and slower than using a join.

In the case of a partitioned table, updating a row might cause it to no longer satisfy the partition constraint of the containing partition. In that case, if there is some other partition in the partition tree for which this row satisfies its partition constraint, then the row is moved to that partition. If there is no such partition, an error will occur. Behind the scenes, the row movement is actually a DELETE and INSERT operation.

There is a possibility that a concurrent UPDATE or DELETE on the row being moved will get a serialization failure error. Suppose session 1 is performing an UPDATE on a partition key, and meanwhile a concurrent session 2 for which this row is visible performs an UPDATE or DELETE operation on this row. In such case, session 2's UPDATE or DELETE will detect the row movement and raise a serialization failure error (which always returns with an SQLSTATE code '40001'). Applications may wish to retry the transaction if this occurs. In the usual case where the table is not partitioned, or where there is no row movement, session 2 would have identified the newly updated row and carried out the UPDATE/DELETE on this new row version.

Note that while rows can be moved from local partitions to a foreign-table partition (provided the foreign data wrapper supports tuple routing), they cannot be moved from a foreign-table partition to another partition.

Examples

Change the word Drama to Dramatic in the column kind of the table films:

```
UPDATE films SET kind = 'Dramatic' WHERE kind = 'Drama';
```

Adjust temperature entries and reset precipitation to its default value in one row of the table weather:

```
UPDATE weather SET temp_lo = temp_lo+1, temp_hi = temp_lo+15, prcp = DEFAULT
  WHERE city = 'San Francisco' AND date = '2003-07-03';
```

Perform the same operation and return the updated entries:

```
UPDATE weather SET temp_lo = temp_lo+1, temp_hi = temp_lo+15, prcp = DEFAULT
  WHERE city = 'San Francisco' AND date = '2003-07-03'
  RETURNING temp_lo, temp_hi, prcp;
```

Use the alternative column-list syntax to do the same update:

```
UPDATE weather SET (temp_lo, temp_hi, prcp) = (temp_lo+1, temp_lo+15, DEFAULT)
  WHERE city = 'San Francisco' AND date = '2003-07-03';
```

Increment the sales count of the salesperson who manages the account for Acme Corporation, using the FROM clause syntax:

```
UPDATE employees SET sales_count = sales_count + 1 FROM accounts
  WHERE accounts.name = 'Acme Corporation'
  AND employees.id = accounts.sales_person;
```

Perform the same operation, using a sub-select in the WHERE clause:

```
UPDATE employees SET sales_count = sales_count + 1 WHERE id =
  (SELECT sales_person FROM accounts WHERE name = 'Acme Corporation');
```

Update contact names in an accounts table to match the currently assigned salesmen:

```
UPDATE accounts SET (contact_first_name, contact_last_name) =
    (SELECT first_name, last_name FROM salesmen
     WHERE salesmen.id = accounts.sales_id);
```

A similar result could be accomplished with a join:

```
UPDATE accounts SET contact_first_name = first_name,
                    contact_last_name = last_name
  FROM salesmen WHERE salesmen.id = accounts.sales_id;
```

However, the second query may give unexpected results if `salesmen.id` is not a unique key, whereas the first query is guaranteed to raise an error if there are multiple `id` matches. Also, if there is no match for a particular `accounts.sales_id` entry, the first query will set the corresponding name fields to NULL, whereas the second query will not update that row at all.

Update statistics in a summary table to match the current data:

```
UPDATE summary s SET (sum_x, sum_y, avg_x, avg_y) =
    (SELECT sum(x), sum(y), avg(x), avg(y) FROM data d
     WHERE d.group_id = s.group_id);
```

Attempt to insert a new stock item along with the quantity of stock. If the item already exists, instead update the stock count of the existing item. To do this without failing the entire transaction, use savepoints:

```
BEGIN;
-- other operations
SAVEPOINT sp1;
INSERT INTO wines VALUES('Chateau Lafite 2003', '24');
-- Assume the above fails because of a unique key violation,
-- so now we issue these commands:
ROLLBACK TO sp1;
UPDATE wines SET stock = stock + 24 WHERE winename = 'Chateau Lafite 2003';
-- continue with other operations, and eventually
COMMIT;
```

Change the `kind` column of the table `films` in the row on which the cursor `c_films` is currently positioned:

```
UPDATE films SET kind = 'Dramatic' WHERE CURRENT OF c_films;
```

Compatibility

This command conforms to the SQL standard, except that the `FROM` and `RETURNING` clauses are Postgres Pro extensions, as is the ability to use `WITH` with `UPDATE`.

Some other database systems offer a `FROM` option in which the target table is supposed to be listed again within `FROM`. That is not how Postgres Pro interprets `FROM`. Be careful when porting applications that use this extension.

According to the standard, the source value for a parenthesized sub-list of target column names can be any row-valued expression yielding the correct number of columns. Postgres Pro only allows the source value to be a row constructor or a sub-`SELECT`. An individual column's updated value can be specified as `DEFAULT` in the row-constructor case, but not inside a sub-`SELECT`.

VACUUM

VACUUM — garbage-collect and optionally analyze a database

Synopsis

```
VACUUM [ ( option [, ...] ) ] [ table_and_columns [, ...] ]
VACUUM [ FULL ] [ FREEZE ] [ VERBOSE ] [ ANALYZE ] [ table_and_columns [, ...] ]

where option can be one of:

    FULL [ boolean ]
    FREEZE [ boolean ]
    VERBOSE [ boolean ]
    ANALYZE [ boolean ]
    DISABLE_PAGE_SKIPPING [ boolean ]
    SKIP_LOCKED [ boolean ]
    INDEX_CLEANUP { AUTO | ON | OFF }
    PROCESS_TOAST [ boolean ]
    TRUNCATE [ boolean ]
    PARALLEL integer

and table_and_columns is:

    table_name [ ( column_name [, ...] ) ]
```

Description

VACUUM reclaims storage occupied by dead tuples. In normal Postgres Pro operation, tuples that are deleted or obsoleted by an update are not physically removed from their table; they remain present until a VACUUM is done. Therefore it's necessary to do VACUUM periodically, especially on frequently-updated tables.

Without a *table_and_columns* list, VACUUM processes every table and materialized view in the current database that the current user has permission to vacuum. With a list, VACUUM processes only those table(s).

VACUUM ANALYZE performs a VACUUM and then an ANALYZE for each selected table. This is a handy combination form for routine maintenance scripts. See ANALYZE for more details about its processing.

Plain VACUUM (without FULL) simply reclaims space and makes it available for re-use. This form of the command can operate in parallel with normal reading and writing of the table, as an exclusive lock is not obtained. However, extra space is not returned to the operating system (in most cases); it's just kept available for re-use within the same table. It also allows us to leverage multiple CPUs in order to process indexes. This feature is known as *parallel vacuum*. To disable this feature, one can use PARALLEL option and specify parallel workers as zero. VACUUM FULL rewrites the entire contents of the table into a new disk file with no extra space, allowing unused space to be returned to the operating system. This form is much slower and requires an ACCESS EXCLUSIVE lock on each table while it is being processed.

When the option list is surrounded by parentheses, the options can be written in any order. Without parentheses, options must be specified in exactly the order shown above. The parenthesized syntax was added in PostgreSQL 9.0; the unparenthesized syntax is deprecated.

Parameters

FULL

Selects “full” vacuum, which can reclaim more space, but takes much longer and exclusively locks the table. This method also requires extra disk space, since it writes a new copy of the table and

doesn't release the old copy until the operation is complete. Usually this should only be used when a significant amount of space needs to be reclaimed from within the table.

FREEZE

Selects aggressive “freezing” of tuples. Specifying FREEZE is equivalent to performing VACUUM with the vacuum_freeze_min_age and vacuum_freeze_table_age parameters set to zero. Aggressive freezing is always performed when the table is rewritten, so this option is redundant when FULL is specified.

VERBOSE

Prints a detailed vacuum activity report for each table.

ANALYZE

Updates statistics used by the planner to determine the most efficient way to execute a query.

DISABLE_PAGE_SKIPPING

Normally, VACUUM will skip pages based on the visibility map. Pages where all tuples are known to be frozen can always be skipped, and those where all tuples are known to be visible to all transactions may be skipped except when performing an aggressive vacuum. Furthermore, except when performing an aggressive vacuum, some pages may be skipped in order to avoid waiting for other sessions to finish using them. This option disables all page-skipping behavior, and is intended to be used only when the contents of the visibility map are suspect, which should happen only if there is a hardware or software issue causing database corruption.

SKIP_LOCKED

Specifies that VACUUM should not wait for any conflicting locks to be released when beginning work on a relation: if a relation cannot be locked immediately without waiting, the relation is skipped. Note that even with this option, VACUUM may still block when opening the relation's indexes. Additionally, VACUUM ANALYZE may still block when acquiring sample rows from partitions, table inheritance children, and some types of foreign tables. Also, while VACUUM ordinarily processes all partitions of specified partitioned tables, this option will cause VACUUM to skip all partitions if there is a conflicting lock on the partitioned table.

INDEX_CLEANUP

Normally, VACUUM will skip index vacuuming when there are very few dead tuples in the table. The cost of processing all of the table's indexes is expected to greatly exceed the benefit of removing dead index tuples when this happens. This option can be used to force VACUUM to process indexes when there are more than zero dead tuples. The default is AUTO, which allows VACUUM to skip index vacuuming when appropriate. If INDEX_CLEANUP is set to ON, VACUUM will conservatively remove all dead tuples from indexes. This may be useful for backwards compatibility with earlier releases of PostgreSQL where this was the standard behavior.

INDEX_CLEANUP can also be set to OFF to force VACUUM to *always* skip index vacuuming, even when there are many dead tuples in the table. This may be useful when it is necessary to make VACUUM run as quickly as possible to avoid imminent transaction ID wraparound (see Section 24.1.5). However, the wraparound failsafe mechanism controlled by vacuum_failsafe_age will generally trigger automatically to avoid transaction ID wraparound failure, and should be preferred. If index cleanup is not performed regularly, performance may suffer, because as the table is modified indexes will accumulate dead tuples and the table itself will accumulate dead line pointers that cannot be removed until index cleanup is completed.

This option has no effect for tables that have no index and is ignored if the FULL option is used. It also has no effect on the transaction ID wraparound failsafe mechanism. When triggered it will skip index vacuuming, even when INDEX_CLEANUP is set to ON.

PROCESS_TOAST

Specifies that VACUUM should attempt to process the corresponding TOAST table for each relation, if one exists. This is usually the desired behavior and is the default. Setting this option to false may be useful when it is only necessary to vacuum the main relation. This option is required when the FULL option is used.

TRUNCATE

Specifies that VACUUM should attempt to truncate off any empty pages at the end of the table and allow the disk space for the truncated pages to be returned to the operating system. This is normally the desired behavior and is the default unless the vacuum_truncate option has been set to false for the table to be vacuumed. Setting this option to false may be useful to avoid ACCESS EXCLUSIVE lock on the table that the truncation requires. This option is ignored if the FULL option is used.

PARALLEL

Perform index vacuum and index cleanup phases of VACUUM in parallel using *integer* background workers (for the details of each vacuum phase, please refer to Table 27.42). The number of workers used to perform the operation is equal to the number of indexes on the relation that support parallel vacuum which is limited by the number of workers specified with PARALLEL option if any which is further limited by max_parallel_maintenance_workers. An index can participate in parallel vacuum if and only if the size of the index is more than min_parallel_index_scan_size. Please note that it is not guaranteed that the number of parallel workers specified in *integer* will be used during execution. It is possible for a vacuum to run with fewer workers than specified, or even with no workers at all. Only one worker can be used per index. So parallel workers are launched only when there are at least 2 indexes in the table. Workers for vacuum are launched before the start of each phase and exit at the end of the phase. These behaviors might change in a future release. This option can't be used with the FULL option.

boolean

Specifies whether the selected option should be turned on or off. You can write TRUE, ON, or 1 to enable the option, and FALSE, OFF, or 0 to disable it. The *boolean* value can also be omitted, in which case TRUE is assumed.

integer

Specifies a non-negative integer value passed to the selected option.

table_name

The name (optionally schema-qualified) of a specific table or materialized view to vacuum. If the specified table is a partitioned table, all of its leaf partitions are vacuumed.

column_name

The name of a specific column to analyze. Defaults to all columns. If a column list is specified, ANALYZE must also be specified.

Outputs

When VERBOSE is specified, VACUUM emits progress messages to indicate which table is currently being processed. Various statistics about the tables are printed as well.

Notes

To vacuum a table, one must ordinarily be the table's owner or a superuser. However, database owners are allowed to vacuum all tables in their databases, except shared catalogs. (The restriction for shared catalogs means that a true database-wide VACUUM can only be performed by a superuser.) VACUUM will skip over any tables that the calling user does not have permission to vacuum.

VACUUM cannot be executed inside a transaction block.

For tables with GIN indexes, VACUUM (in any form) also completes any pending index insertions, by moving pending index entries to the appropriate places in the main GIN index structure. See Section 67.4.1 for details.

We recommend that active production databases be vacuumed frequently (at least nightly), in order to remove dead rows. After adding or deleting a large number of rows, it might be a good idea to issue a VACUUM ANALYZE command for the affected table. This will update the system catalogs with the results of all recent changes, and allow the Postgres Pro query planner to make better choices in planning queries.

The FULL option is not recommended for routine use, but might be useful in special cases. An example is when you have deleted or updated most of the rows in a table and would like the table to physically shrink to occupy less disk space and allow faster table scans. VACUUM FULL will usually shrink the table more than a plain VACUUM would.

The PARALLEL option is used only for vacuum purposes. If this option is specified with the ANALYZE option, it does not affect ANALYZE.

VACUUM causes a substantial increase in I/O traffic, which might cause poor performance for other active sessions. Therefore, it is sometimes advisable to use the cost-based vacuum delay feature. For parallel vacuum, each worker sleeps in proportion to the work done by that worker. See Section 19.4.4 for details.

Postgres Pro includes an “autovacuum” facility which can automate routine vacuum maintenance. For more information about automatic and manual vacuuming, see Section 24.1.

Each backend running VACUUM without the FULL option will report its progress in the pg_stat_progress_vacuum view. Backends running VACUUM FULL will instead report their progress in the pg_stat_progress_cluster view. See Section 27.4.3 and Section 27.4.4 for details.

Examples

To clean a single table onek, analyze it for the optimizer and print a detailed vacuum activity report:

```
VACUUM (VERBOSE, ANALYZE) onek;
```

Compatibility

There is no VACUUM statement in the SQL standard.

See Also

vacuumdb, Section 19.4.4, Section 24.1.6, Section 27.4.3, Section 27.4.4

VALUES

VALUES — compute a set of rows

Synopsis

```
VALUES ( expression [, ...] ) [, ...]
    [ ORDER BY sort_expression [ ASC | DESC | USING operator ] [, ...] ]
    [ LIMIT { count | ALL } ]
    [ OFFSET start [ ROW | ROWS ] ]
    [ FETCH { FIRST | NEXT } [ count ] { ROW | ROWS } ONLY ]
```

Description

`VALUES` computes a row value or set of row values specified by value expressions. It is most commonly used to generate a “constant table” within a larger command, but it can be used on its own.

When more than one row is specified, all the rows must have the same number of elements. The data types of the resulting table's columns are determined by combining the explicit or inferred types of the expressions appearing in that column, using the same rules as for `UNION` (see Section 10.5).

Within larger commands, `VALUES` is syntactically allowed anywhere that `SELECT` is. Because it is treated like a `SELECT` by the grammar, it is possible to use the `ORDER BY`, `LIMIT` (or equivalently `FETCH FIRST`), and `OFFSET` clauses with a `VALUES` command.

Parameters

expression

A constant or expression to compute and insert at the indicated place in the resulting table (set of rows). In a `VALUES` list appearing at the top level of an `INSERT`, an *expression* can be replaced by `DEFAULT` to indicate that the destination column's default value should be inserted. `DEFAULT` cannot be used when `VALUES` appears in other contexts.

sort_expression

An expression or integer constant indicating how to sort the result rows. This expression can refer to the columns of the `VALUES` result as `column1`, `column2`, etc. For more details see ORDER BY Clause in the SELECT documentation.

operator

A sorting operator. For details see ORDER BY Clause in the SELECT documentation.

count

The maximum number of rows to return. For details see LIMIT Clause in the SELECT documentation.

start

The number of rows to skip before starting to return rows. For details see LIMIT Clause in the SELECT documentation.

Notes

`VALUES` lists with very large numbers of rows should be avoided, as you might encounter out-of-memory failures or poor performance. `VALUES` appearing within `INSERT` is a special case (because the desired column types are known from the `INSERT`'s target table, and need not be inferred by scanning the `VALUES` list), so it can handle larger lists than are practical in other contexts.

Examples

A bare VALUES command:

```
VALUES (1, 'one'), (2, 'two'), (3, 'three');
```

This will return a table of two columns and three rows. It's effectively equivalent to:

```
SELECT 1 AS column1, 'one' AS column2
UNION ALL
SELECT 2, 'two'
UNION ALL
SELECT 3, 'three';
```

More usually, VALUES is used within a larger SQL command. The most common use is in INSERT:

```
INSERT INTO films (code, title, did, date_prod, kind)
    VALUES ('T_601', 'Yojimbo', 106, '1961-06-16', 'Drama');
```

In the context of INSERT, entries of a VALUES list can be DEFAULT to indicate that the column default should be used here instead of specifying a value:

```
INSERT INTO films VALUES
    ('UA502', 'Bananas', 105, DEFAULT, 'Comedy', '82 minutes'),
    ('T_601', 'Yojimbo', 106, DEFAULT, 'Drama', DEFAULT);
```

VALUES can also be used where a sub-SELECT might be written, for example in a FROM clause:

```
SELECT f.*
  FROM films f, (VALUES('MGM', 'Horror'), ('UA', 'Sci-Fi')) AS t (studio, kind)
  WHERE f.studio = t.studio AND f.kind = t.kind;

UPDATE employees SET salary = salary * v.increase
  FROM (VALUES(1, 200000, 1.2), (2, 400000, 1.4)) AS v (depno, target, increase)
  WHERE employees.depno = v.depno AND employees.sales >= v.target;
```

Note that an AS clause is required when VALUES is used in a FROM clause, just as is true for SELECT. It is not required that the AS clause specify names for all the columns, but it's good practice to do so. (The default column names for VALUES are column1, column2, etc in Postgres Pro, but these names might be different in other database systems.)

When VALUES is used in INSERT, the values are all automatically coerced to the data type of the corresponding destination column. When it's used in other contexts, it might be necessary to specify the correct data type. If the entries are all quoted literal constants, coercing the first is sufficient to determine the assumed type for all:

```
SELECT * FROM machines
WHERE ip_address IN (VALUES('192.168.0.1'::inet), ('192.168.0.10'), ('192.168.1.43'));
```

> **Tip**
>
> For simple IN tests, it's better to rely on the list-of-scalars form of IN than to write a VALUES query as shown above. The list of scalars method requires less writing and is often more efficient.

Compatibility

VALUES conforms to the SQL standard. LIMIT and OFFSET are Postgres Pro extensions; see also under SELECT.

See Also

INSERT, SELECT

Postgres Pro Client Applications

This part contains reference information for Postgres Pro client applications and utilities. Not all of these commands are of general utility; some might require special privileges. The common feature of these applications is that they can be run on any host, independent of where the database server resides.

When specified on the command line, user and database names have their case preserved — the presence of spaces or special characters might require quoting. Table names and other identifiers do not have their case preserved, except where documented, and might require quoting.

clusterdb

clusterdb — cluster a Postgres Pro database

Synopsis

`clusterdb` [*connection-option*...] [`--verbose` | `-v`] [`--table` | `-t` *table*] ... [*dbname*]

`clusterdb` [*connection-option*...] [`--verbose` | `-v`] `--all` | `-a`

Description

clusterdb is a utility for reclustering tables in a Postgres Pro database. It finds tables that have previously been clustered, and clusters them again on the same index that was last used. Tables that have never been clustered are not affected.

clusterdb is a wrapper around the SQL command CLUSTER. There is no effective difference between clustering databases via this utility and via other methods for accessing the server.

Options

clusterdb accepts the following command-line arguments:

`-a`
`--all`

Cluster all databases.

`[-d] dbname`
`[--dbname=]dbname`

Specifies the name of the database to be clustered, when `-a`/`--all` is not used. If this is not specified, the database name is read from the environment variable `PGDATABASE`. If that is not set, the user name specified for the connection is used. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options.

`-e`
`--echo`

Echo the commands that clusterdb generates and sends to the server.

`-q`
`--quiet`

Do not display progress messages.

`-t table`
`--table=table`

Cluster *table* only. Multiple tables can be clustered by writing multiple `-t` switches.

`-v`
`--verbose`

Print detailed information during processing.

`-V`
`--version`

Print the clusterdb version and exit.

`-?`
`--help`

Show help about clusterdb command line arguments, and exit.

clusterdb also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force clusterdb to prompt for a password before connecting to a database.

This option is never essential, since clusterdb will automatically prompt for a password if the server demands password authentication. However, clusterdb will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--maintenance-db=`*dbname*

When the `-a`/`--all` is used, connect to this database to gather the list of databases to cluster. If not specified, the `postgres` database will be used, or if that does not exist, `template1` will be used. This can be a connection string. If so, connection string parameters will override any conflicting command line options. Also, connection string parameters other than the database name itself will be re-used when connecting to other databases.

Environment

`PGDATABASE`
`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

In case of difficulty, see CLUSTER and psql for discussions of potential problems and error messages. The database server must be running at the targeted host. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Examples

To cluster the database `test`:

```
$ clusterdb test
```

To cluster a single table `foo` in a database named `xyzzy`:

```
$ clusterdb --table=foo xyzzy
```

See Also

CLUSTER

createdb

createdb — create a new Postgres Pro database

Synopsis

`createdb` [*connection-option*...] [*option*...] [*dbname* [*description*]]

Description

createdb creates a new Postgres Pro database.

Normally, the database user who executes this command becomes the owner of the new database. However, a different owner can be specified via the `-O` option, if the executing user has appropriate privileges.

createdb is a wrapper around the SQL command `CREATE DATABASE`. There is no effective difference between creating databases via this utility and via other methods for accessing the server.

Options

createdb accepts the following command-line arguments:

dbname

Specifies the name of the database to be created. The name must be unique among all Postgres Pro databases in this cluster. The default is to create a database with the same name as the current system user.

description

Specifies a comment to be associated with the newly created database.

`-D` *tablespace*
`--tablespace=`*tablespace*

Specifies the default tablespace for the database. (This name is processed as a double-quoted identifier.)

`-e`
`--echo`

Echo the commands that createdb generates and sends to the server.

`-E` *encoding*
`--encoding=`*encoding*

Specifies the character encoding scheme to be used in this database. The character sets supported by the Postgres Pro server are described in Section 23.3.1.

`-l` *locale*[`@`*provider*]
`--locale=`*locale*[`@`*provider*]

Specifies the locale to be used in this database. This is equivalent to specifying both `--lc-collate` and `--lc-ctype`.

Optionally, you can specify the provider of the default collation after the `@` symbol. Supported values are `icu` and `libc`. For details, see Section 23.2.2.

`--lc-collate=`*locale*[`@`*provider*]

Specifies the LC_COLLATE setting to be used in this database.

Optionally, you can specify the provider of the default collation after the `@` symbol. Supported values are `icu` and `libc`. For details, see Section 23.2.2.

`--lc-ctype=`*locale*

Specifies the LC_CTYPE setting to be used in this database.

`-O` *owner*
`--owner=`*owner*

Specifies the database user who will own the new database. (This name is processed as a double-quoted identifier.)

`-T` *template*
`--template=`*template*

Specifies the template database from which to build this database. (This name is processed as a double-quoted identifier.)

`-V`
`--version`

Print the createdb version and exit.

`-?`
`--help`

Show help about createdb command line arguments, and exit.

The options `-D`, `-l`, `-E`, `-O`, and `-T` correspond to options of the underlying SQL command `CREATE DATABASE`; see there for more information about them.

createdb also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or the local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force createdb to prompt for a password before connecting to a database.

This option is never essential, since createdb will automatically prompt for a password if the server demands password authentication. However, createdb will waste a connection attempt finding out

that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--maintenance-db=`*dbname*

Specifies the name of the database to connect to when creating the new database. If not specified, the `postgres` database will be used; if that does not exist (or if it is the name of the new database being created), `template1` will be used. This can be a connection string. If so, connection string parameters will override any conflicting command line options.

Environment

`PGDATABASE`

If set, the name of the database to create, unless overridden on the command line.

`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters. `PGUSER` also determines the name of the database to create, if it is not specified on the command line or by `PGDATABASE`.

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

In case of difficulty, see CREATE DATABASE and psql for discussions of potential problems and error messages. The database server must be running at the targeted host. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Examples

To create the database `demo` using the default database server:

```
$ createdb demo
```

To create the database `demo` using the server on host `eden`, port 5000, using the `template0` template database, here is the command-line command and the underlying SQL command:

```
$ createdb -p 5000 -h eden -T template0 -e demo
CREATE DATABASE demo TEMPLATE template0;
```

See Also

dropdb, CREATE DATABASE

createuser

createuser — define a new Postgres Pro user account

Synopsis

`createuser` [*connection-option*...] [*option*...] [*username*]

Description

createuser creates a new Postgres Pro user (or more precisely, a role). Only superusers and users with `CREATEROLE` privilege can create new users, so createuser must be invoked by someone who can connect as a superuser or a user with `CREATEROLE` privilege.

If you wish to create a role with the `SUPERUSER`, `REPLICATION`, or `BYPASSRLS` privilege, you must connect as a superuser, not merely with `CREATEROLE` privilege. Being a superuser implies the ability to bypass all access permission checks within the database, so superuser access should not be granted lightly. `CREATEROLE` also conveys very extensive privileges.

createuser is a wrapper around the SQL command `CREATE ROLE`. There is no effective difference between creating users via this utility and via other methods for accessing the server.

Options

createuser accepts the following command-line arguments:

username

Specifies the name of the Postgres Pro user to be created. This name must be different from all existing roles in this Postgres Pro installation.

`-c` *number*
`--connection-limit=`*number*

Set a maximum number of connections for the new user. The default is to set no limit.

`-d`
`--createdb`

The new user will be allowed to create databases.

`-D`
`--no-createdb`

The new user will not be allowed to create databases. This is the default.

`-e`
`--echo`

Echo the commands that createuser generates and sends to the server.

`-E`
`--encrypted`

This option is obsolete but still accepted for backward compatibility.

`-g` *role*
`--role=`*role*

Indicates role to which this role will be added immediately as a new member. Multiple roles to which this role will be added as a member can be specified by writing multiple `-g` switches.

`-i`
`--inherit`

The new role will automatically inherit privileges of roles it is a member of. This is the default.

`-I`
`--no-inherit`

The new role will not automatically inherit privileges of roles it is a member of.

`--interactive`

Prompt for the user name if none is specified on the command line, and also prompt for whichever of the options `-d`/`-D`, `-r`/`-R`, `-s`/`-S` is not specified on the command line. (This was the default behavior up to PostgreSQL 9.1.)

`-l`
`--login`

The new user will be allowed to log in (that is, the user name can be used as the initial session user identifier). This is the default.

`-L`
`--no-login`

The new user will not be allowed to log in. (A role without login privilege is still useful as a means of managing database permissions.)

`-P`
`--pwprompt`

If given, createuser will issue a prompt for the password of the new user. This is not necessary if you do not plan on using password authentication.

`-r`
`--createrole`

The new user will be allowed to create, alter, drop, comment on, change the security label for other roles; that is, this user will have `CREATEROLE` privilege. See role creation for more details about what capabilities are conferred by this privilege.

`-R`
`--no-createrole`

The new user will not be allowed to create new roles. This is the default.

`-s`
`--superuser`

The new user will be a superuser.

`-S`
`--no-superuser`

The new user will not be a superuser. This is the default.

`-V`
`--version`

Print the createuser version and exit.

`--profile=`*`profile`*

The new role will be assigned the profile that enforces password management policy. All restrictions of this profile will apply to the role.

`--replication`

The new user will have the `REPLICATION` privilege, which is described more fully in the documentation for CREATE ROLE.

`--no-replication`

The new user will not have the `REPLICATION` privilege, which is described more fully in the documentation for CREATE ROLE.

`-?`
`--help`

Show help about createuser command line arguments, and exit.

createuser also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as (not the user name to create).

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force createuser to prompt for a password (for connecting to the server, not for the password of the new user).

This option is never essential, since createuser will automatically prompt for a password if the server demands password authentication. However, createuser will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

Environment

`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

In case of difficulty, see CREATE ROLE and psql for discussions of potential problems and error messages. The database server must be running at the targeted host. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Examples

To create a user `joe` on the default database server:

```
$ createuser joe
```

To create a user `joe` on the default database server with prompting for some additional attributes:

```
$ createuser --interactive joe
Shall the new role be a superuser? (y/n) n
Shall the new role be allowed to create databases? (y/n) n
Shall the new role be allowed to create more new roles? (y/n) n
```

To create the same user `joe` using the server on host `eden`, port 5000, with attributes explicitly specified, taking a look at the underlying command:

```
$ createuser -h eden -p 5000 -S -D -R -e joe
CREATE ROLE joe NOSUPERUSER NOCREATEDB NOCREATEROLE INHERIT LOGIN;
```

To create the user `joe` as a superuser, and assign a password immediately:

```
$ createuser -P -s -e joe
Enter password for new role: xyzzy
Enter it again: xyzzy
CREATE ROLE joe PASSWORD 'md5b5f5ba1a423792b526f799ae4eb3d59e' SUPERUSER CREATEDB
 CREATEROLE INHERIT LOGIN;
```

In the above example, the new password isn't actually echoed when typed, but we show what was typed for clarity. As you see, the password is encrypted before it is sent to the client.

See Also

dropuser, CREATE ROLE

dropdb

dropdb — remove a Postgres Pro database

Synopsis

`dropdb` [*connection-option*...] [*option*...] *dbname*

Description

dropdb destroys an existing Postgres Pro database. The user who executes this command must be a database superuser or the owner of the database.

dropdb is a wrapper around the SQL command `DROP DATABASE`. There is no effective difference between dropping databases via this utility and via other methods for accessing the server.

Options

dropdb accepts the following command-line arguments:

dbname

Specifies the name of the database to be removed.

`-e`
`--echo`

Echo the commands that dropdb generates and sends to the server.

`-f`
`--force`

Attempt to terminate all existing connections to the target database before dropping it. See DROP DATABASE for more information on this option.

`-i`
`--interactive`

Issues a verification prompt before doing anything destructive.

`-V`
`--version`

Print the dropdb version and exit.

`--if-exists`

Do not throw an error if the database does not exist. A notice is issued in this case.

`-?`
`--help`

Show help about dropdb command line arguments, and exit.

dropdb also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force dropdb to prompt for a password before connecting to a database.

This option is never essential, since dropdb will automatically prompt for a password if the server demands password authentication. However, dropdb will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--maintenance-db=`*dbname*

Specifies the name of the database to connect to in order to drop the target database. If not specified, the `postgres` database will be used; if that does not exist (or is the database being dropped), `template1` will be used. This can be a connection string. If so, connection string parameters will override any conflicting command line options.

Environment

`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

In case of difficulty, see DROP DATABASE and psql for discussions of potential problems and error messages. The database server must be running at the targeted host. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Examples

To destroy the database `demo` on the default database server:

```
$ dropdb demo
```

To destroy the database `demo` using the server on host `eden`, port 5000, with verification and a peek at the underlying command:

```
$ dropdb -p 5000 -h eden -i -e demo
Database "demo" will be permanently deleted.
Are you sure? (y/n) y
DROP DATABASE demo;
```

See Also

createdb, DROP DATABASE

dropuser

dropuser — remove a Postgres Pro user account

Synopsis

`dropuser` [*connection-option*...] [*option*...] [*username*]

Description

dropuser removes an existing Postgres Pro user. Superusers can use this command to remove any role; otherwise, only non-superuser roles can be removed, and only by a user who possesses the `CREATEROLE` privilege and has been granted `ADMIN OPTION` on the target role.

dropuser is a wrapper around the SQL command `DROP ROLE`. There is no effective difference between dropping users via this utility and via other methods for accessing the server.

Options

dropuser accepts the following command-line arguments:

username

Specifies the name of the Postgres Pro user to be removed. You will be prompted for a name if none is specified on the command line and the `-i`/`--interactive` option is used.

`-e`
`--echo`

Echo the commands that dropuser generates and sends to the server.

`-i`
`--interactive`

Prompt for confirmation before actually removing the user, and prompt for the user name if none is specified on the command line.

`-V`
`--version`

Print the dropuser version and exit.

`--if-exists`

Do not throw an error if the user does not exist. A notice is issued in this case.

`-?`
`--help`

Show help about dropuser command line arguments, and exit.

dropuser also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as (not the user name to drop).

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force dropuser to prompt for a password before connecting to a database.

This option is never essential, since dropuser will automatically prompt for a password if the server demands password authentication. However, dropuser will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

Environment

`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

In case of difficulty, see DROP ROLE and psql for discussions of potential problems and error messages. The database server must be running at the targeted host. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Examples

To remove user `joe` from the default database server:

```
$ dropuser joe
```

To remove user `joe` using the server on host `eden`, port 5000, with verification and a peek at the underlying command:

```
$ dropuser -p 5000 -h eden -i -e joe
Role "joe" will be permanently removed.
Are you sure? (y/n) y
DROP ROLE joe;
```

See Also

createuser, DROP ROLE

ecpg

ecpg — embedded SQL C preprocessor

Synopsis

`ecpg` [*option*...] *file*...

Description

`ecpg` is the embedded SQL preprocessor for C programs. It converts C programs with embedded SQL statements to normal C code by replacing the SQL invocations with special function calls. The output files can then be processed with any C compiler tool chain.

`ecpg` will convert each input file given on the command line to the corresponding C output file. If an input file name does not have any extension, `.pgc` is assumed. The file's extension will be replaced by `.c` to construct the output file name. But the output file name can be overridden using the `-o` option.

If an input file name is just `-`, `ecpg` reads the program from standard input (and writes to standard output, unless that is overridden with `-o`).

This reference page does not describe the embedded SQL language. See Chapter 38 for more information on that topic.

Options

`ecpg` accepts the following command-line arguments:

`-c`

Automatically generate certain C code from SQL code. Currently, this works for `EXEC SQL TYPE`.

`-C` *mode*

Set a compatibility mode. *mode* can be `INFORMIX`, `INFORMIX_SE`, or `ORACLE`.

`-D` *symbol*`[=`*value*`]`

Define a preprocessor symbol, equivalently to the `EXEC SQL DEFINE` directive. If no *value* is specified, the symbol is defined with the value `1`.

`-h`

Process header files. When this option is specified, the output file extension becomes `.h` not `.c`, and the default input file extension is `.pgh` not `.pgc`. Also, the `-c` option is forced on.

`-i`

Parse system include files as well.

`-I` *directory*

Specify an additional include path, used to find files included via `EXEC SQL INCLUDE`. Defaults are `.` (current directory), `/usr/local/include`, the Postgres Pro include directory which is defined at compile time (default: `/usr/local/pgsql/include`), and `/usr/include`, in that order.

`-o` *filename*

Specifies that `ecpg` should write all its output to the given *filename*. Write `-o -` to send all output to standard output.

`-r` *option*

Selects run-time behavior. *Option* can be one of the following:

`no_indicator`

Do not use indicators but instead use special values to represent null values. Historically there have been databases using this approach.

`prepare`

Prepare all statements before using them. Libecpg will keep a cache of prepared statements and reuse a statement if it gets executed again. If the cache runs full, libecpg will free the least used statement.

`questionmarks`

Allow question mark as placeholder for compatibility reasons. This used to be the default long ago.

`-t`

Turn on autocommit of transactions. In this mode, each SQL command is automatically committed unless it is inside an explicit transaction block. In the default mode, commands are committed only when `EXEC SQL COMMIT` is issued.

`-v`

Print additional information including the version and the "include" path.

`--version`

Print the ecpg version and exit.

`-?`
`--help`

Show help about ecpg command line arguments, and exit.

Notes

When compiling the preprocessed C code files, the compiler needs to be able to find the ECPG header files in the Postgres Pro include directory. Therefore, you might have to use the `-I` option when invoking the compiler (e.g., `-I/usr/local/pgsql/include`).

Programs using C code with embedded SQL have to be linked against the `libecpg` library, for example using the linker options `-L/usr/local/pgsql/lib -lecpg`.

The value of either of these directories that is appropriate for the installation can be found out using pg_config.

Examples

If you have an embedded SQL C source file named `prog1.pgc`, you can create an executable program using the following sequence of commands:

```
ecpg prog1.pgc
cc -I/usr/local/pgsql/include -c prog1.c
cc -o prog1 prog1.o -L/usr/local/pgsql/lib -lecpg
```

pg_amcheck

pg_amcheck — checks for corruption in one or more PostgreSQL databases

Synopsis

`pg_amcheck` [*option*...] [*dbname*]

Description

pg_amcheck supports running amcheck's corruption checking functions against one or more databases, with options to select which schemas, tables and indexes to check, which kinds of checking to perform, and whether to perform the checks in parallel, and if so, the number of parallel connections to establish and use.

Only table relations and btree indexes are currently supported. Other relation types are silently skipped.

If `dbname` is specified, it should be the name of a single database to check, and no other database selection options should be present. Otherwise, if any database selection options are present, all matching databases will be checked. If no such options are present, the default database will be checked. Database selection options include `--all`, `--database` and `--exclude-database`. They also include `--relation`, `--exclude-relation`, `--table`, `--exclude-table`, `--index`, and `--exclude-index`, but only when such options are used with a three-part pattern (e.g. `mydb*.myschema*.myrel*`). Finally, they include `--schema` and `--exclude-schema` when such options are used with a two-part pattern (e.g. `mydb*.myschema*`).

dbname can also be a connection string.

Options

The following command-line options control what is checked:

`-a`
`--all`

Check all databases, except for any excluded via `--exclude-database`.

`-d` *pattern*
`--database=`*pattern*

Check databases matching the specified *pattern*, except for any excluded by `--exclude-database`. This option can be specified more than once.

`-D` *pattern*
`--exclude-database=`*pattern*

Exclude databases matching the given *pattern*. This option can be specified more than once.

`-i` *pattern*
`--index=`*pattern*

Check indexes matching the specified *pattern*, unless they are otherwise excluded. This option can be specified more than once.

This is similar to the `--relation` option, except that it applies only to indexes, not tables.

`-I` *pattern*
`--exclude-index=`*pattern*

Exclude indexes matching the specified *pattern*. This option can be specified more than once.

This is similar to the `--exclude-relation` option, except that it applies only to indexes, not tables.

`-r` *pattern*
`--relation=`*pattern*

Check relations matching the specified *pattern*, unless they are otherwise excluded. This option can be specified more than once.

Patterns may be unqualified, e.g. `myrel*`, or they may be schema-qualified, e.g. `myschema*.myrel*` or database-qualified and schema-qualified, e.g. `mydb*.myschema*.myrel*`. A database-qualified pattern will add matching databases to the list of databases to be checked.

`-R` *pattern*
`--exclude-relation=`*pattern*

Exclude relations matching the specified *pattern*. This option can be specified more than once.

As with `--relation`, the *pattern* may be unqualified, schema-qualified, or database- and schema-qualified.

`-s` *pattern*
`--schema=`*pattern*

Check tables and indexes in schemas matching the specified *pattern*, unless they are otherwise excluded. This option can be specified more than once.

To select only tables in schemas matching a particular pattern, consider using something like `--table=SCHEMAPAT.* --no-dependent-indexes`. To select only indexes, consider using something like `--index=SCHEMAPAT.*`.

A schema pattern may be database-qualified. For example, you may write `--schema=mydb*.myschema*` to select schemas matching `myschema*` in databases matching `mydb*`.

`-S` *pattern*
`--exclude-schema=`*pattern*

Exclude tables and indexes in schemas matching the specified *pattern*. This option can be specified more than once.

As with `--schema`, the pattern may be database-qualified.

`-t` *pattern*
`--table=`*pattern*

Check tables matching the specified *pattern*, unless they are otherwise excluded. This option can be specified more than once.

This is similar to the `--relation` option, except that it applies only to tables, not indexes.

`-T` *pattern*
`--exclude-table=`*pattern*

Exclude tables matching the specified *pattern*. This option can be specified more than once.

This is similar to the `--exclude-relation` option, except that it applies only to tables, not indexes.

`--no-dependent-indexes`

By default, if a table is checked, any btree indexes of that table will also be checked, even if they are not explicitly selected by an option such as `--index` or `--relation`. This option suppresses that behavior.

`--no-dependent-toast`

By default, if a table is checked, its toast table, if any, will also be checked, even if it is not explicitly selected by an option such as `--table` or `--relation`. This option suppresses that behavior.

`--no-strict-names`

By default, if an argument to `--database`, `--table`, `--index`, or `--relation` matches no objects, it is a fatal error. This option downgrades that error to a warning.

The following command-line options control checking of tables:

`--exclude-toast-pointers`

By default, whenever a toast pointer is encountered in a table, a lookup is performed to ensure that it references apparently-valid entries in the toast table. These checks can be quite slow, and this option can be used to skip them.

`--on-error-stop`

After reporting all corruptions on the first page of a table where corruption is found, stop processing that table relation and move on to the next table or index.

Note that index checking always stops after the first corrupt page. This option only has meaning relative to table relations.

`--skip=`*`option`*

If `all-frozen` is given, table corruption checks will skip over pages in all tables that are marked as all frozen.

If `all-visible` is given, table corruption checks will skip over pages in all tables that are marked as all visible.

By default, no pages are skipped. This can be specified as `none`, but since this is the default, it need not be mentioned.

`--startblock=`*`block`*

Start checking at the specified block number. An error will occur if the table relation being checked has fewer than this number of blocks. This option does not apply to indexes, and is probably only useful when checking a single table relation. See `--endblock` for further caveats.

`--endblock=`*`block`*

End checking at the specified block number. An error will occur if the table relation being checked has fewer than this number of blocks. This option does not apply to indexes, and is probably only useful when checking a single table relation. If both a regular table and a toast table are checked, this option will apply to both, but higher-numbered toast blocks may still be accessed while validating toast pointers, unless that is suppressed using `--exclude-toast-pointers`.

The following command-line options control checking of B-tree indexes:

`--heapallindexed`

For each index checked, verify the presence of all heap tuples as index tuples in the index using amcheck's `heapallindexed` option.

`--parent-check`

For each btree index checked, use amcheck's `bt_index_parent_check` function, which performs additional checks of parent/child relationships during index checking.

The default is to use amcheck's `bt_index_check` function, but note that use of the `--rootdescend` option implicitly selects `bt_index_parent_check`.

`--rootdescend`

For each index checked, re-find tuples on the leaf level by performing a new search from the root page for each tuple using amcheck's `rootdescend` option.

Use of this option implicitly also selects the `--parent-check` option.

This form of verification was originally written to help in the development of btree index features. It may be of limited use or even of no use in helping detect the kinds of corruption that occur in practice. It may also cause corruption checking to take considerably longer and consume considerably more resources on the server.

> **Warning**
>
> The extra checks performed against B-tree indexes when the `--parent-check` option or the `--rootdescend` option is specified require relatively strong relation-level locks. These checks are the only checks that will block concurrent data modification from `INSERT`, `UPDATE`, and `DELETE` commands.

The following command-line options control the connection to the server:

`-h` *hostname*
`--host=`*hostname*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U`
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force pg_amcheck to prompt for a password before connecting to a database.

This option is never essential, since pg_amcheck will automatically prompt for a password if the server demands password authentication. However, pg_amcheck will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--maintenance-db=`*dbname*

Specifies a database or connection string to be used to discover the list of databases to be checked. If neither `--all` nor any option including a database pattern is used, no such connection is required and this option does nothing. Otherwise, any connection string parameters other than the database name which are included in the value for this option will also be used when connecting to the databases being checked. If this option is omitted, the default is `postgres` or, if that fails, `template1`.

Other options are also available:

`-e`
`--echo`

Echo to stdout all SQL sent to the server.

`-j` *num*
`--jobs=`*num*

Use *num* concurrent connections to the server, or one per object to be checked, whichever is less.

The default is to use a single connection.

`-P`
`--progress`

Show progress information. Progress information includes the number of relations for which checking has been completed, and the total size of those relations. It also includes the total number of relations that will eventually be checked, and the estimated size of those relations.

`-v`
`--verbose`

Print more messages. In particular, this will print a message for each relation being checked, and will increase the level of detail shown for server errors.

`-V`
`--version`

Print the pg_amcheck version and exit.

`--install-missing`
`--install-missing=`*schema*

Install any missing extensions that are required to check the database(s). If not yet installed, each extension's objects will be installed into the given *schema*, or if not specified into schema `pg_catalog`.

At present, the only required extension is amcheck.

`-?`
`--help`

Show help about pg_amcheck command line arguments, and exit.

Notes

pg_amcheck is designed to work with PostgreSQL 14.0 and later.

See Also

amcheck

pg_basebackup

pg_basebackup — take a base backup of a Postgres Pro cluster

Synopsis

`pg_basebackup` [*option*...]

Description

pg_basebackup is used to take a base backup of a running Postgres Pro database cluster. The backup is taken without affecting other clients of the database, and can be used both for point-in-time recovery (see Section 25.3) and as the starting point for a log-shipping or streaming-replication standby server (see Section 26.2).

pg_basebackup makes an exact copy of the database cluster's files, while making sure the server is put into and out of backup mode automatically. Backups are always taken of the entire database cluster; it is not possible to back up individual databases or database objects. For selective backups, another tool such as pg_dump must be used.

The backup is made over a regular Postgres Pro connection that uses the replication protocol. The connection must be made with a user ID that has `REPLICATION` permissions (see Section 21.2) or is a superuser, and `pg_hba.conf` must permit the replication connection. The server must also be configured with max_wal_senders set high enough to provide at least one walsender for the backup plus one for WAL streaming (if used).

There can be multiple `pg_basebackup`s running at the same time, but it is usually better from a performance point of view to take only one backup, and copy the result.

pg_basebackup can make a base backup from not only a primary server but also a standby. To take a backup from a standby, set up the standby so that it can accept replication connections (that is, set `max_wal_senders` and hot_standby, and configure its `pg_hba.conf` appropriately). You will also need to enable full_page_writes on the primary.

Note that there are some limitations in taking a backup from a standby:

- The backup history file is not created in the database cluster backed up.
- pg_basebackup cannot force the standby to switch to a new WAL file at the end of backup. When you are using `-X none`, if write activity on the primary is low, pg_basebackup may need to wait a long time for the last WAL file required for the backup to be switched and archived. In this case, it may be useful to run `pg_switch_wal` on the primary in order to trigger an immediate WAL file switch.
- If the standby is promoted to be primary during backup, the backup fails.
- All WAL records required for the backup must contain sufficient full-page writes, which requires you to enable `full_page_writes` on the primary and not to use a tool like pg_compresslog as `archive_command` to remove full-page writes from WAL files.

Whenever pg_basebackup is taking a base backup, the server's `pg_stat_progress_basebackup` view will report the progress of the backup. See Section 27.4.5 for details.

Options

The following command-line options control the location and format of the output:

`-D` *directory*
`--pgdata=`*directory*

Sets the target directory to write the output to. pg_basebackup will create this directory (and any missing parent directories) if it does not exist. If it already exists, it must be empty.

When the backup is in tar format, the target directory may be specified as - (dash), causing the tar file to be written to stdout.

This option is required.

-F *format*
--format=*format*

Selects the format for the output. *format* can be one of the following:

p
plain

Write the output as plain files, with the same layout as the source server's data directory and tablespaces. When the cluster has no additional tablespaces, the whole database will be placed in the target directory. If the cluster contains additional tablespaces, the main data directory will be placed in the target directory, but all other tablespaces will be placed in the same absolute path as they have on the source server. (See --tablespace-mapping to change that.)

This is the default format.

t
tar

Write the output as tar files in the target directory. The main data directory's contents will be written to a file named base.tar, and each other tablespace will be written to a separate tar file named after that tablespace's OID.

If the target directory is specified as - (dash), the tar contents will be written to standard output, suitable for piping to (for example) gzip. This is only allowed if the cluster has no additional tablespaces and WAL streaming is not used.

-R
--write-recovery-conf

Creates a standby.signal file and appends connection settings to the postgresql.auto.conf file in the target directory (or within the base archive file when using tar format). This eases setting up a standby server using the results of the backup.

The postgresql.auto.conf file will record the connection settings and, if specified, the replication slot that pg_basebackup is using, so that streaming replication will use the same settings later on.

-T *olddir=newdir*
--tablespace-mapping=*olddir=newdir*

Relocates the tablespace in directory *olddir* to *newdir* during the backup. To be effective, *olddir* must exactly match the path specification of the tablespace as it is defined on the source server. (But it is not an error if there is no tablespace in *olddir* on the source server.) Meanwhile *newdir* is a directory in the receiving host's filesystem. As with the main target directory, *newdir* need not exist already, but if it does exist it must be empty. Both *olddir* and *newdir* must be absolute paths. If either path needs to contain an equal sign (=), precede that with a backslash. This option can be specified multiple times for multiple tablespaces.

If a tablespace is relocated in this way, the symbolic links inside the main data directory are updated to point to the new location. So the new data directory is ready to be used for a new server instance with all tablespaces in the updated locations.

Currently, this option only works with plain output format; it is ignored if tar format is selected.

--waldir=*waldir*

Sets the directory to write WAL (write-ahead log) files to. By default WAL files will be placed in the pg_wal subdirectory of the target directory, but this option can be used to place them elsewhere.

waldir must be an absolute path. As with the main target directory, *waldir* need not exist already, but if it does exist it must be empty. This option can only be specified when the backup is in plain format.

`-X` *method*
`--wal-method=`*method*

Includes the required WAL (write-ahead log) files in the backup. This will include all write-ahead logs generated during the backup. Unless the method `none` is specified, it is possible to start a post-master in the target directory without the need to consult the log archive, thus making the output a completely standalone backup.

The following *method*s for collecting the write-ahead logs are supported:

`n`
`none`

Don't include write-ahead logs in the backup.

`f`
`fetch`

The write-ahead log files are collected at the end of the backup. Therefore, it is necessary for the source server's wal_keep_size parameter to be set high enough that the required log data is not removed before the end of the backup. If the required log data has been recycled before it's time to transfer it, the backup will fail and be unusable.

When tar format is used, the write-ahead log files will be included in the `base.tar` file.

`s`
`stream`

Stream write-ahead log data while the backup is being taken. This method will open a second connection to the server and start streaming the write-ahead log in parallel while running the backup. Therefore, it will require two replication connections not just one. As long as the client can keep up with the write-ahead log data, using this method requires no extra write-ahead logs to be saved on the source server.

When tar format is used, the write-ahead log files will be written to a separate file named `pg_wal.tar` (if the server is a version earlier than 10, the file will be named `pg_xlog.tar`).

This value is the default.

`-z`
`--gzip`

Enables gzip compression of tar file output, with the default compression level. Compression is only available when using the tar format, and the suffix `.gz` will automatically be added to all tar filenames.

`-Z` *level*
`--compress=`*level*

Enables gzip compression of tar file output, and specifies the compression level (0 through 9, 0 being no compression and 9 being best compression). Compression is only available when using the tar format, and the suffix `.gz` will automatically be added to all tar filenames.

The following command-line options control the generation of the backup and the invocation of the program:

`-c` *fast|spread*
`--checkpoint=`*fast|spread*

Sets checkpoint mode to fast (immediate) or spread (the default) (see Section 25.3.3).

`-C`
`--create-slot`

Specifies that the replication slot named by the `--slot` option should be created before starting the backup. An error is raised if the slot already exists.

`-l` *label*
`--label=`*label*

Sets the label for the backup. If none is specified, a default value of "`pg_basebackup base backup`" will be used.

`-n`
`--no-clean`

By default, when `pg_basebackup` aborts with an error, it removes any directories it might have created before discovering that it cannot finish the job (for example, the target directory and write-ahead log directory). This option inhibits tidying-up and is thus useful for debugging.

Note that tablespace directories are not cleaned up either way.

`-N`
`--no-sync`

By default, `pg_basebackup` will wait for all files to be written safely to disk. This option causes `pg_basebackup` to return without waiting, which is faster, but means that a subsequent operating system crash can leave the base backup corrupt. Generally, this option is useful for testing but should not be used when creating a production installation.

`-P`
`--progress`

Enables progress reporting. Turning this on will deliver an approximate progress report during the backup. Since the database may change during the backup, this is only an approximation and may not end at exactly `100%`. In particular, when WAL log is included in the backup, the total amount of data cannot be estimated in advance, and in this case the estimated target size will increase once it passes the total estimate without WAL.

`-r` *rate*
`--max-rate=`*rate*

Sets the maximum transfer rate at which data is collected from the source server. This can be useful to limit the impact of pg_basebackup on the server. Values are in kilobytes per second. Use a suffix of `M` to indicate megabytes per second. A suffix of `k` is also accepted, and has no effect. Valid values are between 32 kilobytes per second and 1024 megabytes per second.

This option always affects transfer of the data directory. Transfer of WAL files is only affected if the collection method is `fetch`.

`-S` *slotname*
`--slot=`*slotname*

This option can only be used together with `-X stream`. It causes WAL streaming to use the specified replication slot. If the base backup is intended to be used as a streaming-replication standby using a replication slot, the standby should then use the same replication slot name as primary_slot_name. This ensures that the primary server does not remove any necessary WAL data in the time between the end of the base backup and the start of streaming replication on the new standby.

The specified replication slot has to exist unless the option `-C` is also used.

If this option is not specified and the server supports temporary replication slots (version 10 and later), then a temporary replication slot is automatically used for WAL streaming.

`-v`
`--verbose`

Enables verbose mode. Will output some extra steps during startup and shutdown, as well as show the exact file name that is currently being processed if progress reporting is also enabled.

`--manifest-checksums=`*algorithm*

Specifies the checksum algorithm that should be applied to each file included in the backup manifest. Currently, the available algorithms are `NONE`, `CRC32C`, `SHA224`, `SHA256`, `SHA384`, and `SHA512`. The default is `CRC32C`.

If `NONE` is selected, the backup manifest will not contain any checksums. Otherwise, it will contain a checksum of each file in the backup using the specified algorithm. In addition, the manifest will always contain a `SHA256` checksum of its own contents. The `SHA` algorithms are significantly more CPU-intensive than `CRC32C`, so selecting one of them may increase the time required to complete the backup.

Using a SHA hash function provides a cryptographically secure digest of each file for users who wish to verify that the backup has not been tampered with, while the CRC32C algorithm provides a checksum that is much faster to calculate; it is good at catching errors due to accidental changes but is not resistant to malicious modifications. Note that, to be useful against an adversary who has access to the backup, the backup manifest would need to be stored securely elsewhere or otherwise verified not to have been modified since the backup was taken.

pg_verifybackup can be used to check the integrity of a backup against the backup manifest.

`--manifest-force-encode`

Forces all filenames in the backup manifest to be hex-encoded. If this option is not specified, only non-UTF8 filenames are hex-encoded. This option is mostly intended to test that tools which read a backup manifest file properly handle this case.

`--no-estimate-size`

Prevents the server from estimating the total amount of backup data that will be streamed, resulting in the `backup_total` column in the `pg_stat_progress_basebackup` view always being `NULL`.

Without this option, the backup will start by enumerating the size of the entire database, and then go back and send the actual contents. This may make the backup take slightly longer, and in particular it will take longer before the first data is sent. This option is useful to avoid such estimation time if it's too long.

This option is not allowed when using `--progress`.

`--no-manifest`

Disables generation of a backup manifest. If this option is not specified, the server will generate and send a backup manifest which can be verified using pg_verifybackup. The manifest is a list of every file present in the backup with the exception of any WAL files that may be included. It also stores the size, last modification time, and an optional checksum for each file.

`--no-slot`

Prevents the creation of a temporary replication slot for the backup.

By default, if log streaming is selected but no slot name is given with the `-S` option, then a temporary replication slot is created (if supported by the source server).

The main purpose of this option is to allow taking a base backup when the server has no free replication slots. Using a replication slot is almost always preferred, because it prevents needed WAL from being removed by the server during the backup.

`--no-verify-checksums`

Disables verification of checksums, if they are enabled on the server the base backup is taken from.

By default, checksums are verified and checksum failures will result in a non-zero exit status. However, the base backup will not be removed in such a case, as if the `--no-clean` option had been used. Checksum verification failures will also be reported in the `pg_stat_database` view.

The following command-line options control the connection to the source server:

`-d` *connstr*
`--dbname=`*connstr*

Specifies parameters used to connect to the server, as a connection string; these will override any conflicting command line options.

The option is called `--dbname` for consistency with other client applications, but because pg_basebackup doesn't connect to any particular database in the cluster, any database name in the connection string will be ignored.

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for a Unix domain socket. The default is taken from the `PGHOST` environment variable, if set, else a Unix domain socket connection is attempted.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections. Defaults to the `PGPORT` environment variable, if set, or a compiled-in default.

`-s` *interval*
`--status-interval=`*interval*

Specifies the number of seconds between status packets sent back to the source server. Smaller values allow more accurate monitoring of backup progress from the server. A value of zero disables periodic status updates completely, although an update will still be sent when requested by the server, to avoid timeout-based disconnects. The default value is 10 seconds.

`-U` *username*
`--username=`*username*

Specifies the user name to connect as.

`-w`
`--no-password`

Prevents issuing a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Forces pg_basebackup to prompt for a password before connecting to the source server.

This option is never essential, since pg_basebackup will automatically prompt for a password if the server demands password authentication. However, pg_basebackup will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

Other options are also available:

`-V`
`--version`

Prints the pg_basebackup version and exits.

`-?`
`--help`

Shows help about pg_basebackup command line arguments, and exits.

Environment

This utility, like most other Postgres Pro utilities, uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

At the beginning of the backup, a checkpoint needs to be performed on the source server. This can take some time (especially if the option `--checkpoint=fast` is not used), during which pg_basebackup will appear to be idle.

The backup will include all files in the data directory and tablespaces, including the configuration files and any additional files placed in the directory by third parties, except certain temporary files managed by Postgres Pro. But only regular files and directories are copied, except that symbolic links used for tablespaces are preserved. Symbolic links pointing to certain directories known to Postgres Pro are copied as empty directories. Other symbolic links and special device files are skipped. See Section 55.4 for the precise details.

In plain format, tablespaces will be backed up to the same path they have on the source server, unless the option `--tablespace-mapping` is used. Without this option, running a plain format base backup on the same host as the server will not work if tablespaces are in use, because the backup would have to be written to the same directory locations as the original tablespaces.

When tar format is used, it is the user's responsibility to unpack each tar file before starting a Postgres Pro server that uses the data. If there are additional tablespaces, the tar files for them need to be unpacked in the correct locations. In this case the symbolic links for those tablespaces will be created by the server according to the contents of the `tablespace_map` file that is included in the `base.tar` file.

pg_basebackup works with servers of the same or an older major version, down to 9.1. However, WAL streaming mode (`-X stream`) only works with server version 9.3 and later, and tar format (`--format=tar`) only works with server version 9.5 and later.

pg_basebackup will preserve group permissions for data files if group permissions are enabled on the source cluster.

Examples

To create a base backup of the server at `mydbserver` and store it in the local directory `/usr/local/pgsql/data`:

```
$ pg_basebackup -h mydbserver -D /usr/local/pgsql/data
```

To create a backup of the local server with one compressed tar file for each tablespace, and store it in the directory `backup`, showing a progress report while running:

```
$ pg_basebackup -D backup -Ft -z -P
```

To create a backup of a single-tablespace local database and compress this with bzip2:

```
$ pg_basebackup -D - -Ft -X fetch | bzip2 > backup.tar.bz2
```

(This command will fail if there are multiple tablespaces in the database.)

To create a backup of a local database where the tablespace in `/opt/ts` is relocated to `./backup/ts`:

```
$ pg_basebackup -D backup/data -T /opt/ts=$(pwd)/backup/ts
```

See Also

pg_dump, Section 27.4.5

pgbench

pgbench — run a benchmark test on Postgres Pro

Synopsis

`pgbench -i` [*option*...] [*dbname*]

`pgbench` [*option*...] [*dbname*]

Description

pgbench is a simple program for running benchmark tests on Postgres Pro. It runs the same sequence of SQL commands over and over, possibly in multiple concurrent database sessions, and then calculates the average transaction rate (transactions per second). By default, pgbench tests a scenario that is loosely based on TPC-B, involving five `SELECT`, `UPDATE`, and `INSERT` commands per transaction. However, it is easy to test other cases by writing your own transaction script files.

Typical output from pgbench looks like:

```
transaction type: <builtin: TPC-B (sort of)>
default transaction isolation level: read committed
transaction maximum tries number: 1
scaling factor: 10
query mode: simple
number of clients: 10
number of threads: 1
number of transactions per client: 1000
number of transactions actually processed: 10000/10000
latency average = 11.013 ms
latency stddev = 7.351 ms
initial connection time = 45.758 ms
tps = 896.967014 (without initial connection time)
```

The first eight lines report some of the most important parameter settings. The next line reports the number of transactions completed and intended (the latter being just the product of number of clients and number of transactions per client); these will be equal unless the run failed before completion or some clients got serialization/deadlock failures. (In `-T` mode, only the actual number of transactions is printed.) (See the section called “Serialization/Deadlock Failures and Retries” for more information about serialization/deadlock failures.) The last line reports the number of transactions per second.

The default TPC-B-like transaction test requires specific tables to be set up beforehand. pgbench should be invoked with the `-i` (initialize) option to create and populate these tables. (When you are testing a custom script, you don't need this step, but will instead need to do whatever setup your test needs.) Initialization looks like:

```
pgbench -i [ other-options ] dbname
```

where *dbname* is the name of the already-created database to test in. (You may also need `-h`, `-p`, and/or `-U` options to specify how to connect to the database server.)

> **Caution**
>
> `pgbench -i` creates four tables `pgbench_accounts`, `pgbench_branches`, `pgbench_history`, and `pgbench_tellers`, destroying any existing tables of these names. Be very careful to use another database if you have tables having these names!

At the default “scale factor” of 1, the tables initially contain this many rows:

```
table                   # of rows
---------------------------------
pgbench_branches        1
pgbench_tellers         10
pgbench_accounts        100000
pgbench_history         0
```

You can (and, for most purposes, probably should) increase the number of rows by using the `-s` (scale factor) option. The `-F` (fillfactor) option might also be used at this point.

Once you have done the necessary setup, you can run your benchmark with a command that doesn't include `-i`, that is

```
pgbench [ options ] dbname
```

In nearly all cases, you'll need some options to make a useful test. The most important options are `-c` (number of clients), `-t` (number of transactions), `-T` (time limit), and `-f` (specify a custom script file). See below for a full list.

Options

The following is divided into three subsections. Different options are used during database initialization and while running benchmarks, but some options are useful in both cases.

Initialization Options

pgbench accepts the following command-line initialization arguments:

dbname

Specifies the name of the database to test in. If this is not specified, the environment variable `PGDATABASE` is used. If that is not set, the user name specified for the connection is used.

`-i`
`--initialize`

Required to invoke initialization mode.

`-I` *init_steps*
`--init-steps=`*init_steps*

Perform just a selected set of the normal initialization steps. *init_steps* specifies the initialization steps to be performed, using one character per step. Each step is invoked in the specified order. The default is `dtgvp`. The available steps are:

`d` (Drop)

Drop any existing pgbench tables.

`t` (create Tables)

Create the tables used by the standard pgbench scenario, namely `pgbench_accounts`, `pgbench_branches`, `pgbench_history`, and `pgbench_tellers`.

`g` or `G` (Generate data, client-side or server-side)

Generate data and load it into the standard tables, replacing any data already present.

With `g` (client-side data generation), data is generated in `pgbench` client and then sent to the server. This uses the client/server bandwidth extensively through a `COPY`. Using `g` causes logging to print one message every 100,000 rows while generating data for the `pgbench_accounts` table.

With `G` (server-side data generation), only small queries are sent from the `pgbench` client and then data is actually generated in the server. No significant bandwidth is required for this variant, but the server will do more work. Using `G` causes logging not to print any progress message while generating data.

The default initialization behavior uses client-side data generation (equivalent to `g`).

`v` (Vacuum)

Invoke `VACUUM` on the standard tables.

`p` (create Primary keys)

Create primary key indexes on the standard tables.

`f` (create Foreign keys)

Create foreign key constraints between the standard tables. (Note that this step is not performed by default.)

`-F` *fillfactor*
`--fillfactor=`*fillfactor*

Create the `pgbench_accounts`, `pgbench_tellers` and `pgbench_branches` tables with the given fillfactor. Default is 100.

`-n`
`--no-vacuum`

Perform no vacuuming during initialization. (This option suppresses the `v` initialization step, even if it was specified in `-I`.)

`-q`
`--quiet`

Switch logging to quiet mode, producing only one progress message per 5 seconds. The default logging prints one message each 100,000 rows, which often outputs many lines per second (especially on good hardware).

This setting has no effect if `G` is specified in `-I`.

`-s` *scale_factor*
`--scale=`*scale_factor*

Multiply the number of rows generated by the scale factor. For example, `-s 100` will create 10,000,000 rows in the `pgbench_accounts` table. Default is 1. When the scale is 20,000 or larger, the columns used to hold account identifiers (`aid` columns) will switch to using larger integers (`bigint`), in order to be big enough to hold the range of account identifiers.

`--foreign-keys`

Create foreign key constraints between the standard tables. (This option adds the `f` step to the initialization step sequence, if it is not already present.)

`--index-tablespace=`*index_tablespace*

Create indexes in the specified tablespace, rather than the default tablespace.

`--partition-method=`*NAME*

Create a partitioned `pgbench_accounts` table with *NAME* method. Expected values are `range` or `hash`. This option requires that `--partitions` is set to non-zero. If unspecified, default is `range`.

`--partitions=`*`NUM`*

Create a partitioned `pgbench_accounts` table with *`NUM`* partitions of nearly equal size for the scaled number of accounts. Default is `0`, meaning no partitioning.

`--tablespace=`*`tablespace`*

Create tables in the specified tablespace, rather than the default tablespace.

`--unlogged-tables`

Create all tables as unlogged tables, rather than permanent tables.

Benchmarking Options

pgbench accepts the following command-line benchmarking arguments:

`-b` *`scriptname[@weight]`*
`--builtin=`*`scriptname[@weight]`*

Add the specified built-in script to the list of scripts to be executed. Available built-in scripts are: `tpcb-like`, `simple-update` and `select-only`. Unambiguous prefixes of built-in names are accepted. With the special name `list`, show the list of built-in scripts and exit immediately.

Optionally, write an integer weight after `@` to adjust the probability of selecting this script versus other ones. The default weight is 1. See below for details.

`-c` *`clients`*
`--client=`*`clients`*

Number of clients simulated, that is, number of concurrent database sessions. Default is 1.

`-C`
`--connect`

Establish a new connection for each transaction, rather than doing it just once per client session. This is useful to measure the connection overhead.

`-d`
`--debug`

Print debugging output.

`-D` *`varname=value`*
`--define=`*`varname=value`*

Define a variable for use by a custom script (see below). Multiple `-D` options are allowed.

`-f` *`filename[@weight]`*
`--file=`*`filename[@weight]`*

Add a transaction script read from *`filename`* to the list of scripts to be executed.

Optionally, write an integer weight after `@` to adjust the probability of selecting this script versus other ones. The default weight is 1. (To use a script file name that includes an `@` character, append a weight so that there is no ambiguity, for example `filen@me@1`.) See below for details.

`-j` *`threads`*
`--jobs=`*`threads`*

Number of worker threads within pgbench. Using more than one thread can be helpful on multi-CPU machines. Clients are distributed as evenly as possible among available threads. Default is 1.

`-l`
`--log`

Write information about each transaction to a log file. See below for details.

`-L` *limit*
`--latency-limit=`*limit*

Transactions that last more than *limit* milliseconds are counted and reported separately, as *late*.

When throttling is used (`--rate=...`), transactions that lag behind schedule by more than *limit* ms, and thus have no hope of meeting the latency limit, are not sent to the server at all. They are counted and reported separately as *skipped*.

You can use this option together with the `--max-tries` option, which enables retries for transactions with serialization/deadlock errors. A transaction is retried only within the specified limit. See the section called “Serialization/Deadlock Failures and Retries” for details.

`-M` *querymode*
`--protocol=`*querymode*

Protocol to use for submitting queries to the server:

- `simple`: use simple query protocol.
- `extended`: use extended query protocol.
- `prepared`: use extended query protocol with prepared statements.

In the `prepared` mode, pgbench reuses the parse analysis result starting from the second query iteration, so pgbench runs faster than in other modes.

The default is simple query protocol. (See Chapter 55 for more information.)

`-n`
`--no-vacuum`

Perform no vacuuming before running the test. This option is *necessary* if you are running a custom test scenario that does not include the standard tables `pgbench_accounts`, `pgbench_branches`, `pgbench_history`, and `pgbench_tellers`.

`-N`
`--skip-some-updates`

Run built-in simple-update script. Shorthand for `-b simple-update`.

`-P` *sec*
`--progress=`*sec*

Show progress report every *sec* seconds. The report includes the time since the beginning of the run, the TPS since the last report, and the transaction latency average and standard deviation since the last report. If any transactions ended with serialization/deadlock failures since the last report, they are also reported as failed (see the section called “Serialization/Deadlock Failures and Retries” for more information). Under throttling (`-R`), the latency is computed with respect to the transaction scheduled start time, not the actual transaction beginning time. Thus, the latency also includes the average schedule lag time. If any transactions have been rolled back and retried after a serialization/deadlock error since the last report, the report includes the number of such transactions and the sum of all retries. Use the `--max-tries` to enable transactions retries after serialization/deadlock errors.

`-r`
`--report-per-command`

Report the following statistics for each command after the benchmark finishes: the average per-statement latency (execution time from the perspective of the client), the number of serialization

failures and retries, the number of deadlock failures and retries. The report displays the columns with statistics on failures and retries only if the current pgbench run has a failure or retry of any type, respectively. See below for details.

`-R` *rate*
`--rate=`*rate*

Execute transactions targeting the specified rate instead of running as fast as possible (the default). The rate is given in transactions per second. If the targeted rate is above the maximum possible rate, the rate limit won't impact the results.

The rate is targeted by starting transactions along a Poisson-distributed schedule time line. The expected start time schedule moves forward based on when the client first started, not when the previous transaction ended. That approach means that when transactions go past their original scheduled end time, it is possible for later ones to catch up again.

When throttling is active, the transaction latency reported at the end of the run is calculated from the scheduled start times, so it includes the time each transaction had to wait for the previous transaction to finish. The wait time is called the schedule lag time, and its average and maximum are also reported separately. The transaction latency with respect to the actual transaction start time, i.e., the time spent executing the transaction in the database, can be computed by subtracting the schedule lag time from the reported latency.

If `--latency-limit` is used together with `--rate`, a transaction can lag behind so much that it is already over the latency limit when the previous transaction ends, because the latency is calculated from the scheduled start time. Such transactions are not sent to the server, but are skipped altogether and counted separately.

A high schedule lag time is an indication that the system cannot process transactions at the specified rate, with the chosen number of clients and threads. When the average transaction execution time is longer than the scheduled interval between each transaction, each successive transaction will fall further behind, and the schedule lag time will keep increasing the longer the test run is. When that happens, you will have to reduce the specified transaction rate.

`-s` *scale_factor*
`--scale=`*scale_factor*

Report the specified scale factor in pgbench's output. With the built-in tests, this is not necessary; the correct scale factor will be detected by counting the number of rows in the `pgbench_branches` table. However, when testing only custom benchmarks (`-f` option), the scale factor will be reported as 1 unless this option is used.

`-S`
`--select-only`

Run built-in select-only script. Shorthand for `-b select-only`.

`-t` *transactions*
`--transactions=`*transactions*

Number of transactions each client runs. Default is 10.

`-T` *seconds*
`--time=`*seconds*

Run the test for this many seconds, rather than a fixed number of transactions per client. `-t` and `-T` are mutually exclusive.

You can use this option together with the `--max-tries` option, which enables retries for transactions with serialization/deadlock errors. Transactions are retried only within the time limit specified by `--time`. See the section called “Serialization/Deadlock Failures and Retries” for details.

`-v`
`--vacuum-all`

Vacuum all four standard tables before running the test. With neither `-n` nor `-v`, pgbench will vacuum the `pgbench_tellers` and `pgbench_branches` tables, and will truncate `pgbench_history`.

`--aggregate-interval=`*seconds*

Length of aggregation interval (in seconds). May be used only with `-l` option. With this option, the log contains per-interval summary data, as described below.

`--default-isolation-level=`*isolation_level*

Set the default transaction isolation level:

- `RUC`: Read Uncommitted
- `RC`: Read Committed
- `RR`: Repeatable Read
- `S`: Serializable

By default, Read Committed isolation level is used. For more information, see Section 13.2.

`--log-prefix=`*prefix*

Set the filename prefix for the log files created by `--log`. The default is `pgbench_log`.

`--max-tries=`*tries_number*

Enable retries for transactions with serialization/deadlock errors and set the maximum number of transaction tries. The default value is 1, so such transactions are not retried.

This option can be used together with `--latency-limit` and/or `--time`, which limit the total time of all transaction tries. In these cases, transactions can be retried only within the specified time limits. The `--max-tries=0` setting allows an unlimited number of tries within the allotted time; this value can be used only together with the `--latency-limit` and/or `--time` options.

See the section called “Serialization/Deadlock Failures and Retries” for more information about retrying transactions with serialization/deadlock errors.

`--progress-timestamp`

When showing progress (option `-P`), use a timestamp (Unix epoch) instead of the number of seconds since the beginning of the run. The unit is in seconds, with millisecond precision after the dot. This helps compare logs generated by various tools.

`--random-seed=`*seed*

Set random generator seed. Seeds the system random number generator, which then produces a sequence of initial generator states, one for each thread. Values for *seed* may be: `time` (the default, the seed is based on the current time), `rand` (use a strong random source, failing if none is available), or an unsigned decimal integer value. The random generator is invoked explicitly from a pgbench script (`random...` functions) or implicitly (for instance option `--rate` uses it to schedule transactions). When explicitly set, the value used for seeding is shown on the terminal. Any value allowed for *seed* may also be provided through the environment variable `PGBENCH_RANDOM_SEED`. To ensure that the provided seed impacts all possible uses, put this option first or use the environment variable.

Setting the seed explicitly allows to reproduce a `pgbench` run exactly, as far as random numbers are concerned. As the random state is managed per thread, this means the exact same `pgbench` run for an identical invocation if there is one client per thread and there are no external or data dependencies. From a statistical viewpoint reproducing runs exactly is a bad idea because it can hide the performance variability or improve performance unduly, e.g., by hitting the same pages as

a previous run. However, it may also be of great help for debugging, for instance re-running a tricky case which leads to an error. Use wisely.

`--sampling-rate=`*rate*

Sampling rate, used when writing data into the log, to reduce the amount of log generated. If this option is given, only the specified fraction of transactions are logged. 1.0 means all transactions will be logged, 0.05 means only 5% of the transactions will be logged.

Remember to take the sampling rate into account when processing the log file. For example, when computing TPS values, you need to multiply the numbers accordingly (e.g., with 0.01 sample rate, you'll only get 1/100 of the actual TPS).

`--show-script=`*scriptname*

Show the actual code of builtin script *scriptname* on stderr, and exit immediately.

Common Options

pgbench also accepts the following common command-line arguments for connection parameters:

`-h` *hostname*
`--host=`*hostname*

The database server's host name

`-p` *port*
`--port=`*port*

The database server's port number

`-U` *login*
`--username=`*login*

The user name to connect as

`-V`
`--version`

Print the pgbench version and exit.

`-?`
`--help`

Show help about pgbench command line arguments, and exit.

Exit Status

A successful run will exit with status 0. Exit status 1 indicates static problems such as invalid command-line options. Errors during the run such as database errors or problems in the script will result in exit status 2. In the latter case, pgbench will print partial results.

Environment

`PGDATABASE`
`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters.

This utility, like most other Postgres Pro utilities, uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

What Is the “Transaction” Actually Performed in pgbench?

pgbench executes test scripts chosen randomly from a specified list. The scripts may include built-in scripts specified with `-b` and user-provided scripts specified with `-f`. Each script may be given a relative weight specified after an `@` so as to change its selection probability. The default weight is `1`. Scripts with a weight of `0` are ignored.

The default built-in transaction script (also invoked with `-b tpcb-like`) issues seven commands per transaction over randomly chosen `aid`, `tid`, `bid` and `delta`. The scenario is inspired by the TPC-B benchmark, but is not actually TPC-B, hence the name.

1. `BEGIN;`
2. `UPDATE pgbench_accounts SET abalance = abalance + :delta WHERE aid = :aid;`
3. `SELECT abalance FROM pgbench_accounts WHERE aid = :aid;`
4. `UPDATE pgbench_tellers SET tbalance = tbalance + :delta WHERE tid = :tid;`
5. `UPDATE pgbench_branches SET bbalance = bbalance + :delta WHERE bid = :bid;`
6. `INSERT INTO pgbench_history (tid, bid, aid, delta, mtime) VALUES (:tid, :bid, :aid, :delta, CURRENT_TIMESTAMP);`
7. `END;`

If you select the `simple-update` built-in (also `-N`), steps 4 and 5 aren't included in the transaction. This will avoid update contention on these tables, but it makes the test case even less like TPC-B.

If you select the `select-only` built-in (also `-S`), only the `SELECT` is issued.

Custom Scripts

pgbench has support for running custom benchmark scenarios by replacing the default transaction script (described above) with a transaction script read from a file (`-f` option). In this case a “transaction” counts as one execution of a script file.

A script file contains one or more SQL commands terminated by semicolons. Empty lines and lines beginning with `--` are ignored. Script files can also contain “meta commands”, which are interpreted by pgbench itself, as described below.

> **Note**
>
> Before Postgres Pro 9.6, SQL commands in script files were terminated by newlines, and so they could not be continued across lines. Now a semicolon is *required* to separate consecutive SQL commands (though an SQL command does not need one if it is followed by a meta command). If you need to create a script file that works with both old and new versions of pgbench, be sure to write each SQL command on a single line ending with a semicolon.

There is a simple variable-substitution facility for script files. Variable names must consist of letters (including non-Latin letters), digits, and underscores, with the first character not being a digit. Variables can be set by the command-line `-D` option, explained above, or by the meta commands explained below. In addition to any variables preset by `-D` command-line options, there are a few variables that are preset automatically, listed in Table 290. A value specified for these variables using `-D` takes precedence over

the automatic presets. Once set, a variable's value can be inserted into an SQL command by writing `:variablename`. When running more than one client session, each session has its own set of variables. pgbench supports up to 255 variable uses in one statement.

Table 290. pgbench Automatic Variables

Variable	Description
client_id	unique number identifying the client session (starts from zero)
default_seed	seed used in hash and pseudorandom permutation functions by default
random_seed	random generator seed (unless overwritten with -D)
scale	current scale factor

Script file meta commands begin with a backslash (\) and normally extend to the end of the line, although they can be continued to additional lines by writing backslash-return. Arguments to a meta command are separated by white space. These meta commands are supported:

\gset [*prefix*] \aset [*prefix*]

These commands may be used to end SQL queries, taking the place of the terminating semicolon (;).

When the \gset command is used, the preceding SQL query is expected to return one row, the columns of which are stored into variables named after column names, and prefixed with *prefix* if provided.

When the \aset command is used, all combined SQL queries (separated by \;) have their columns stored into variables named after column names, and prefixed with *prefix* if provided. If a query returns no row, no assignment is made and the variable can be tested for existence to detect this. If a query returns more than one row, the last value is kept.

\gset and \aset cannot be used in pipeline mode, since the query results are not yet available by the time the commands would need them.

The following example puts the final account balance from the first query into variable *abalance*, and fills variables *p_two* and *p_three* with integers from the third query. The result of the second query is discarded. The result of the two last combined queries are stored in variables *four* and *five*.

```
UPDATE pgbench_accounts
  SET abalance = abalance + :delta
  WHERE aid = :aid
  RETURNING abalance \gset
-- compound of two queries
SELECT 1 \;
SELECT 2 AS two, 3 AS three \gset p_
SELECT 4 AS four \; SELECT 5 AS five \aset
```

\if *expression*
\elif *expression*
\else
\endif

This group of commands implements nestable conditional blocks, similarly to psql's \if *expression*. Conditional expressions are identical to those with \set, with non-zero values interpreted as true.

\set *varname expression*

Sets variable *varname* to a value calculated from *expression*. The expression may contain the NULL constant, Boolean constants TRUE and FALSE, integer constants such as 5432, double constants such

as `3.14159`, references to variables `:variablename`, operators with their usual SQL precedence and associativity, function calls, SQL `CASE` generic conditional expressions and parentheses.

Functions and most operators return `NULL` on `NULL` input.

For conditional purposes, non zero numerical values are `TRUE`, zero numerical values and `NULL` are `FALSE`.

Too large or small integer and double constants, as well as integer arithmetic operators (`+`, `-`, `*` and `/`) raise errors on overflows.

When no final `ELSE` clause is provided to a `CASE`, the default value is `NULL`.

Examples:

```
\set ntellers 10 * :scale
\set aid (1021 * random(1, 100000 * :scale)) % \
           (100000 * :scale) + 1
\set divx CASE WHEN :x <> 0 THEN :y/:x ELSE NULL END
```

`\sleep` *number* [us | ms | s]

Causes script execution to sleep for the specified duration in microseconds (`us`), milliseconds (`ms`) or seconds (`s`). If the unit is omitted then seconds are the default. *number* can be either an integer constant or a `:`*variablename* reference to a variable having an integer value.

Example:

```
\sleep 10 ms
```

`\setshell` *varname command* [*argument* ...]

Sets variable *varname* to the result of the shell command *command* with the given *argument*(s). The command must return an integer value through its standard output.

command and each *argument* can be either a text constant or a `:`*variablename* reference to a variable. If you want to use an *argument* starting with a colon, write an additional colon at the beginning of *argument*.

Example:

```
\setshell variable_to_be_assigned command
 literal_argument :variable ::literal_starting_with_colon
```

`\shell` *command* [*argument* ...]

Same as `\setshell`, but the result of the command is discarded.

Example:

```
\shell command literal_argument :variable ::literal_starting_with_colon
```

```
\startpipeline
\endpipeline
```

These commands delimit the start and end of a pipeline of SQL statements. In pipeline mode, statements are sent to the server without waiting for the results of previous statements. See Section 36.5 for more details. Pipeline mode requires the use of extended query protocol.

Built-in Operators

The arithmetic, bitwise, comparison and logical operators listed in Table 291 are built into pgbench and may be used in expressions appearing in `\set`. The operators are listed in increasing precedence

order. Except as noted, operators taking two numeric inputs will produce a double value if either input is double, otherwise they produce an integer result.

Table 291. pgbench Operators

Operator **Description** **Example(s)**
boolean OR *boolean* → *boolean* Logical OR `5 or 0` → `TRUE`
boolean AND *boolean* → *boolean* Logical AND `3 and 0` → `FALSE`
NOT *boolean* → *boolean* Logical NOT `not false` → `TRUE`
boolean IS [NOT] (NULL|TRUE|FALSE) → *boolean* Boolean value tests `1 is null` → `FALSE`
value ISNULL|NOTNULL → *boolean* Nullness tests `1 notnull` → `TRUE`
number = *number* → *boolean* Equal `5 = 4` → `FALSE`
number <> *number* → *boolean* Not equal `5 <> 4` → `TRUE`
number != *number* → *boolean* Not equal `5 != 5` → `FALSE`
number < *number* → *boolean* Less than `5 < 4` → `FALSE`
number <= *number* → *boolean* Less than or equal to `5 <= 4` → `FALSE`
number > *number* → *boolean* Greater than `5 > 4` → `TRUE`
number >= *number* → *boolean* Greater than or equal to `5 >= 4` → `TRUE`
integer | *integer* → *integer* Bitwise OR `1 | 2` → `3`

Operator **Description** **Example(s)**
integer # *integer* → *integer* Bitwise XOR 1 # 3 → 2
integer & *integer* → *integer* Bitwise AND 1 & 3 → 1
~ *integer* → *integer* Bitwise NOT ~ 1 → -2
integer << *integer* → *integer* Bitwise shift left 1 << 2 → 4
integer >> *integer* → *integer* Bitwise shift right 8 >> 2 → 2
number + *number* → *number* Addition 5 + 4 → 9
number - *number* → *number* Subtraction 3 - 2.0 → 1.0
number * *number* → *number* Multiplication 5 * 4 → 20
number / *number* → *number* Division (truncates the result towards zero if both inputs are integers) 5 / 3 → 1
integer % *integer* → *integer* Modulo (remainder) 3 % 2 → 1
- *number* → *number* Negation - 2.0 → -2.0

Built-In Functions

The functions listed in Table 292 are built into pgbench and may be used in expressions appearing in \set.

Table 292. pgbench Functions

Function **Description** **Example(s)**
abs (*number*) → same type as input Absolute value

Function **Description** **Example(s)**
`abs(-17)` → `17`
`debug` (*number*) → same type as input Prints the argument to stderr, and returns the argument. `debug(5432.1)` → `5432.1`

`double` (*number*) → `double`
Casts to double.
`double(5432)` → `5432.0`

`exp` (*number*) → `double`
Exponential (`e` raised to the given power)
`exp(1.0)` → `2.718281828459045`

`greatest` (*number* [, ...]) → `double` if any argument is double, else `integer`
Selects the largest value among the arguments.
`greatest(5, 4, 3, 2)` → `5`

`hash` (*value* [, *seed*]) → `integer`
This is an alias for `hash_murmur2` .
`hash(10, 5432)` → `-5817877081768721676`

`hash_fnv1a` (*value* [, *seed*]) → `integer`
Computes *FNV-1a hash*.
`hash_fnv1a(10, 5432)` → `-7793829335365542153`

`hash_murmur2` (*value* [, *seed*]) → `integer`
Computes *MurmurHash2 hash*.
`hash_murmur2(10, 5432)` → `-5817877081768721676`

`int` (*number*) → `integer`
Casts to integer.
`int(5.4 + 3.8)` → `9`

`least` (*number* [, ...]) → `double` if any argument is double, else `integer`
Selects the smallest value among the arguments.
`least(5, 4, 3, 2.1)` → `2.1`

`ln` (*number*) → `double`
Natural logarithm
`ln(2.718281828459045)` → `1.0`

`mod` (*integer*, *integer*) → `integer`
Modulo (remainder)
`mod(54, 32)` → `22`

`permute` (*i*, *size* [, *seed*]) → `integer`
Permuted value of *i*, in the range `[0, size)` . This is the new position of *i* (modulo *size*) in a pseudorandom permutation of the integers `0...size-1`, parameterized by *seed*, see below.
`permute(0, 4)` → `an integer between 0 and 3`

`pi` () → `double`
Approximate value of π
`pi()` → `3.14159265358979323846`

`pow` (*x*, *y*) → `double`

Function **Description** **Example(s)**

`power` (*x*, *y*) → `double`
x raised to the power of *y*
`pow(2.0, 10)` → `1024.0`

`random` (*lb*, *ub*) → `integer`
Computes a uniformly-distributed random integer in `[lb, ub]` .
`random(1, 10)` → `an integer between 1 and 10`

`random_exponential` (*lb*, *ub*, *parameter*) → `integer`
Computes an exponentially-distributed random integer in `[lb, ub]` , see below.
`random_exponential(1, 10, 3.0)` → `an integer between 1 and 10`

`random_gaussian` (*lb*, *ub*, *parameter*) → `integer`
Computes a Gaussian-distributed random integer in `[lb, ub]` , see below.
`random_gaussian(1, 10, 2.5)` → `an integer between 1 and 10`

`random_zipfian` (*lb*, *ub*, *parameter*) → `integer`
Computes a Zipfian-distributed random integer in `[lb, ub]` , see below.
`random_zipfian(1, 10, 1.5)` → `an integer between 1 and 10`

`sqrt` (*number*) → `double`
Square root
`sqrt(2.0)` → `1.414213562`

The `random` function generates values using a uniform distribution, that is all the values are drawn within the specified range with equal probability. The `random_exponential`, `random_gaussian` and `random_zipfian` functions require an additional double parameter which determines the precise shape of the distribution.

- For an exponential distribution, *parameter* controls the distribution by truncating a quickly-decreasing exponential distribution at *parameter*, and then projecting onto integers between the bounds. To be precise, with

  f(x) = exp(-parameter * (x - min) / (max - min + 1)) / (1 - exp(-parameter))

  Then value *i* between *min* and *max* inclusive is drawn with probability: `f(i) - f(i + 1)`.

  Intuitively, the larger the *parameter*, the more frequently values close to *min* are accessed, and the less frequently values close to *max* are accessed. The closer to 0 *parameter* is, the flatter (more uniform) the access distribution. A crude approximation of the distribution is that the most frequent 1% values in the range, close to *min*, are drawn *parameter*% of the time. The *parameter* value must be strictly positive.

- For a Gaussian distribution, the interval is mapped onto a standard normal distribution (the classical bell-shaped Gaussian curve) truncated at `-parameter` on the left and `+parameter` on the right. Values in the middle of the interval are more likely to be drawn. To be precise, if `PHI(x)` is the cumulative distribution function of the standard normal distribution, with mean `mu` defined as `(max + min) / 2.0`, with

  f(x) = PHI(2.0 * parameter * (x - mu) / (max - min + 1)) /
  (2.0 * PHI(parameter) - 1)

  then value *i* between *min* and *max* inclusive is drawn with probability: `f(i + 0.5) - f(i - 0.5)`. Intuitively, the larger the *parameter*, the more frequently values close to the middle of the interval are drawn, and the less frequently values close to the *min* and *max* bounds. About 67% of values are drawn from the middle `1.0 / parameter`, that is a relative `0.5 / parameter` around the mean, and 95% in the middle `2.0 / parameter`, that is a relative `1.0 / parameter` around the mean; for in-

stance, if *parameter* is 4.0, 67% of values are drawn from the middle quarter (1.0 / 4.0) of the interval (i.e., from `3.0 / 8.0` to `5.0 / 8.0`) and 95% from the middle half (`2.0 / 4.0`) of the interval (second and third quartiles). The minimum allowed *parameter* value is 2.0.

- `random_zipfian` generates a bounded Zipfian distribution. *parameter* defines how skewed the distribution is. The larger the *parameter*, the more frequently values closer to the beginning of the interval are drawn. The distribution is such that, assuming the range starts from 1, the ratio of the probability of drawing *k* versus drawing *k+1* is `((`*k*`+1)/`*k*`)**`*parameter*. For example, `random_zipfian(1, ..., 2.5)` produces the value `1` about `(2/1)**2.5 = 5.66` times more frequently than `2`, which itself is produced `(3/2)**2.5 = 2.76` times more frequently than `3`, and so on.

  pgbench's implementation is based on "Non-Uniform Random Variate Generation", Luc Devroye, p. 550-551, Springer 1986. Due to limitations of that algorithm, the *parameter* value is restricted to the range [1.001, 1000].

> **Note**
>
> When designing a benchmark which selects rows non-uniformly, be aware that the rows chosen may be correlated with other data such as IDs from a sequence or the physical row ordering, which may skew performance measurements.
>
> To avoid this, you may wish to use the `permute` function, or some other additional step with similar effect, to shuffle the selected rows and remove such correlations.

Hash functions `hash`, `hash_murmur2` and `hash_fnv1a` accept an input value and an optional seed parameter. In case the seed isn't provided the value of `:default_seed` is used, which is initialized randomly unless set by the command-line `-D` option.

`permute` accepts an input value, a size, and an optional seed parameter. It generates a pseudorandom permutation of integers in the range `[0, size)`, and returns the index of the input value in the permuted values. The permutation chosen is parameterized by the seed, which defaults to `:default_seed`, if not specified. Unlike the hash functions, `permute` ensures that there are no collisions or holes in the output values. Input values outside the interval are interpreted modulo the size. The function raises an error if the size is not positive. `permute` can be used to scatter the distribution of non-uniform random functions such as `random_zipfian` or `random_exponential` so that values drawn more often are not trivially correlated. For instance, the following pgbench script simulates a possible real world workload typical for social media and blogging platforms where a few accounts generate excessive load:

```
\set size 1000000
\set r random_zipfian(1, :size, 1.07)
\set k 1 + permute(:r, :size)
```

In some cases several distinct distributions are needed which don't correlate with each other and this is when the optional seed parameter comes in handy:

```
\set k1 1 + permute(:r, :size, :default_seed + 123)
\set k2 1 + permute(:r, :size, :default_seed + 321)
```

A similar behavior can also be approximated with `hash`:

```
\set size 1000000
\set r random_zipfian(1, 100 * :size, 1.07)
\set k 1 + abs(hash(:r)) % :size
```

However, since `hash` generates collisions, some values will not be reachable and others will be more frequent than expected from the original distribution.

As an example, the full definition of the built-in TPC-B-like transaction is:

```
\set aid random(1, 100000 * :scale)
\set bid random(1, 1 * :scale)
\set tid random(1, 10 * :scale)
```

```
\set delta random(-5000, 5000)
BEGIN;
UPDATE pgbench_accounts SET abalance = abalance + :delta WHERE aid = :aid;
SELECT abalance FROM pgbench_accounts WHERE aid = :aid;
UPDATE pgbench_tellers SET tbalance = tbalance + :delta WHERE tid = :tid;
UPDATE pgbench_branches SET bbalance = bbalance + :delta WHERE bid = :bid;
INSERT INTO pgbench_history (tid, bid, aid, delta, mtime) VALUES
 (:tid, :bid, :aid, :delta, CURRENT_TIMESTAMP);
END;
```

This script allows each iteration of the transaction to reference different, randomly-chosen rows. (This example also shows why it's important for each client session to have its own variables — otherwise they'd not be independently touching different rows.)

Per-Transaction Logging

With the `-l` option (but without the `--aggregate-interval` option), pgbench writes information about each transaction to a log file. The log file will be named *`prefix`*`.`*`nnn`*, where *`prefix`* defaults to `pgbench_log`, and *`nnn`* is the PID of the pgbench process. The prefix can be changed by using the `--log-prefix` option. If the `-j` option is 2 or higher, so that there are multiple worker threads, each will have its own log file. The first worker will use the same name for its log file as in the standard single worker case. The additional log files for the other workers will be named *`prefix`*`.`*`nnn`*`.`*`mmm`*, where *`mmm`* is a sequential number for each worker starting with 1.

The format of the log is:

```
client_id transaction_no time script_no time_epoch time_us [ schedule_lag ]
 [ serialization_retries deadlock_retries ]
```

where *`client_id`* indicates which client session ran the transaction, *`transaction_no`* counts how many transactions have been run by that session, *`time`* is the total elapsed transaction time in microseconds, *`script_no`* identifies which script file was used (useful when multiple scripts were specified with `-f` or `-b`), and *`time_epoch`*/*`time_us`* are a Unix-epoch time stamp and an offset in microseconds (suitable for creating an ISO 8601 time stamp with fractional seconds) showing when the transaction completed. The *`schedule_lag`* field is the difference between the transaction's scheduled start time, and the time it actually started, in microseconds. It is only present when the `--rate` option is used. When both `--rate` and `--latency-limit` are used, the *`time`* for a skipped transaction will be reported as `skipped`. *`serialization_retries`* and *`deadlock_retries`* are the sums of all retries after the corresponding errors during the current script execution. They are only present when the maximum number of tries for transactions is not equal to 1 (`--max-tries`). If the transaction ended with a serialization/deadlock failure, its *`time`* will be reported as `failed` (see the section called “Serialization/Deadlock Failures and Retries” for more information).

Here is a snippet of a log file generated in a single-client run:

```
0 199 2241 0 1175850568 995598
0 200 2465 0 1175850568 998079
0 201 2513 0 1175850569 608
0 202 2038 0 1175850569 2663
```

Another example with `--rate=100` and `--latency-limit=5` (note the additional *`schedule_lag`* column):

```
0 81 4621 0 1412881037 912698 3005
0 82 6173 0 1412881037 914578 4304
0 83 skipped 0 1412881037 914578 5217
0 83 skipped 0 1412881037 914578 5099
0 83 4722 0 1412881037 916203 3108
0 84 4142 0 1412881037 918023 2333
0 85 2465 0 1412881037 919759 740
```

In this example, transaction 82 was late, because its latency (6.173 ms) was over the 5 ms limit. The next two transactions were skipped, because they were already late before they were even started.

The following example shows a snippet of a log file with failures and retries, with the maximum number of tries set to 10:

```
3 0 47423 0 1499414498 34501 3 0
3 1 8333 0 1499414498 42848 0 0
3 2 8358 0 1499414498 51219 0 0
4 0 72345 0 1499414498 59433 6 0
1 3 41718 0 1499414498 67879 4 0
1 4 8416 0 1499414498 76311 0 0
3 3 33235 0 1499414498 84469 3 0
0 0 failed 0 1499414498 84905 9 0
2 0 failed 0 1499414498 86248 9 0
3 4 8307 0 1499414498 92788 0 0
```

When running a long test on hardware that can handle a lot of transactions, the log files can become very large. The `--sampling-rate` option can be used to log only a random sample of transactions.

Aggregated Logging

With the `--aggregate-interval` option, a different format is used for the log files:

```
interval_start num_transactions  sum_latency sum_latency_2 min_latency max_latency
  failed_tx [ sum_lag sum_lag_2 min_lag max_lag [ skipped ] ]
 [ retried_tx serialization_retries deadlock_retries ]
```

where *`interval_start`* is the start of the interval (as a Unix epoch time stamp), *`num_transactions`* is the number of transactions within the interval, *`sum_latency`* is the sum of the transaction latencies within the interval, *`sum_latency_2`* is the sum of squares of the transaction latencies within the interval, *`min_latency`* is the minimum latency within the interval, *`max_latency`* is the maximum latency within the interval, and *`failed_tx`* is the number of transactions ended with serialization/deadlock failures within the interval (see the section called “Serialization/Deadlock Failures and Retries” for more information). The next fields, *`sum_lag`*, *`sum_lag_2`*, *`min_lag`*, and *`max_lag`*, are only present if the `--rate` option is used. They provide statistics about the time each transaction had to wait for the previous one to finish, i.e., the difference between each transaction's scheduled start time and the time it actually started. The next field, *`skipped`*, is only present if the `--latency-limit` option is used, too. It counts the number of transactions skipped because they would have started too late. The *`retried_tx`*, *`serialization_retries`*, and *`deadlock_retries`* fields are only present if the maximum number of tries for transactions is not equal to 1 (`--max-tries`). They report the number of retried transactions and the sum of all retries after the corresponding errors within the interval. Each transaction is counted in the interval when it was committed.

Here is some example output:

```
1345828501 5601 1542744 483552416 61 2573 0
1345828503 7884 1979812 565806736 60 1479 0
1345828505 7208 1979422 567277552 59 1391 0
1345828507 7685 1980268 569784714 60 1398 0
1345828509 7073 1979779 573489941 236 1411 0
```

Notice that while the plain (unaggregated) log file shows which script was used for each transaction, the aggregated log does not. Therefore if you need per-script data, you need to aggregate the data on your own.

Per-Statement Report

With the `-r` option, pgbench collects the following statistics for each statement:

- `latency` — elapsed transaction time for each statement. pgbench reports an average value of all successful runs of the statement.
- The number of serialization and deadlock failures. See the section called “Serialization/Deadlock Failures and Retries” for more information.

- The number of retries after a serialization/deadlock error in this statement; they are reported as serialization/deadlock retries, respectively.

The report displays the columns with statistics on failures and retries only if the current pgbench run has a failure or retry of any type, respectively.

All values are computed for each statement executed by every client and are reported after the benchmark has finished.

For the default script, the output will look similar to this:

```
starting vacuum...end.
transaction type: <builtin: TPC-B (sort of)>
default transaction isolation level: read committed
transaction maximum tries number: 1
scaling factor: 1
query mode: simple
number of clients: 10
number of threads: 1
number of transactions per client: 1000
number of transactions actually processed: 10000/10000
latency average = 10.870 ms
latency stddev = 7.341 ms
initial connection time = 30.954 ms
tps = 907.949122 (without initial connection time)
statement latencies in milliseconds:
    0.001  \set aid random(1, 100000 * :scale)
    0.001  \set bid random(1, 1 * :scale)
    0.001  \set tid random(1, 10 * :scale)
    0.000  \set delta random(-5000, 5000)
    0.046  BEGIN;
    0.151  UPDATE pgbench_accounts SET abalance = abalance + :delta WHERE aid = :aid;
    0.107  SELECT abalance FROM pgbench_accounts WHERE aid = :aid;
    4.241  UPDATE pgbench_tellers SET tbalance = tbalance + :delta WHERE tid = :tid;
    5.245  UPDATE pgbench_branches SET bbalance = bbalance + :delta WHERE bid = :bid;
    0.102  INSERT INTO pgbench_history (tid, bid, aid, delta, mtime) VALUES
 (:tid, :bid, :aid, :delta, CURRENT_TIMESTAMP);
    0.974  END;
```

Another example of output for the default script using serializable default transaction isolation level (`--default-isolation-level S`):

```
starting vacuum...end.
transaction type: <builtin: TPC-B (sort of)>
default transaction isolation level: serializable
transaction maximum tries number: 100
scaling factor: 1
query mode: simple
number of clients: 10
number of threads: 1
number of transactions per client: 1000
number of transactions actually processed: 9676/10000
number of transactions failed: 324 (3.240 %)
number of transactions retried: 5629 (56.290 %)
number of retries: 103299 (serialization: 103299, deadlocks: 0)
number of transactions above the 100.0 ms latency limit: 21/9676 (0.217 %)
latency average = 16.138 ms
latency stddev = 21.017 ms
tps = 413.650224 (including connections establishing)
tps = 413.686560 (excluding connections establishing)
```

```
statement latencies in milliseconds, serialization failures and retries,
deadlock failures and retries:
  0.002     0       0   0   0  \set aid random(1, 100000 * :scale)
  0.000     0       0   0   0  \set bid random(1, 1 * :scale)
  0.000     0       0   0   0  \set tid random(1, 10 * :scale)
  0.000     0       0   0   0  \set delta random(-5000, 5000)
  0.121     0       0   0   0  BEGIN;
  0.290     0       2   0   0  UPDATE pgbench_accounts
                               SET abalance = abalance + :delta WHERE aid = :aid;
  0.221     0       0   0   0  SELECT abalance FROM pgbench_accounts
                               WHERE aid = :aid;
  0.266   212   72127   0   0  UPDATE pgbench_tellers
                               SET tbalance = tbalance + :delta WHERE tid = :tid;
  0.222   112   31170   0   0  UPDATE pgbench_branches
                               SET bbalance = bbalance + :delta WHERE bid = :bid;
  0.178     0       0   0   0  INSERT INTO pgbench_history
                                      (tid, bid, aid, delta, mtime)
                               VALUES (:tid, :bid, :aid, :delta, CURRENT_TIMESTAMP);
  1.210     0       0   0   0  END;
```

If multiple script files are specified, all statistics are reported separately for each script file.

Note that collecting the additional timing information needed for per-statement latency computation adds some overhead. This will slow average execution speed and lower the computed TPS. The amount of slowdown varies significantly depending on platform and hardware. Comparing average TPS values with and without latency reporting enabled is a good way to measure if the timing overhead is significant.

Serialization/Deadlock Failures and Retries

Transactions with serialization or deadlock errors are rolled back and repeated until they complete successfully or reach the maximum number of tries specified by the `--max-tries` option. You can also limit the time of tries using the `--latency-limit` and/or `--time` options; in these cases, you can allow an unlimited number of tries within the specified time limits by setting the `--max-tries` option to zero. If the last transaction run fails, this transaction will be reported as failed. (It is assumed that one transaction script contains only one transaction; see the section called “What Is the “Transaction” Actually Performed in pgbench?” for more information.)

Note

Be careful when repeating scripts that contain multiple transactions: the script is always retried completely, so the successful transactions can be performed several times.

Be careful when repeating transactions with shell commands. Unlike the results of SQL commands, the results of shell commands are not rolled back, except for the variable value of the `\setshell` command. If a shell command fails, its client is aborted without a restart.

The latency of a successful transaction includes the entire time of transaction execution with rollbacks and retries. The latency for failed transactions and commands is not computed separately.

The main report contains the number of failed transactions if it is non-zero. If the total number of retried transactions is non-zero, the main report also contains the statistics related to retries: the total number of retried transactions, the total number of retries, and the number of retries after each kind of error. The per-statement report inherits all columns from the main report.

Good Practices

It is very easy to use pgbench to produce completely meaningless numbers. Here are some guidelines to help you get useful results.

In the first place, *never* believe any test that runs for only a few seconds. Use the `-t` or `-T` option to make the run last at least a few minutes, so as to average out noise. In some cases you could need hours to get numbers that are reproducible. It's a good idea to try the test run a few times, to find out if your numbers are reproducible or not.

For the default TPC-B-like test scenario, the initialization scale factor (`-s`) should be at least as large as the largest number of clients you intend to test (`-c`); else you'll mostly be measuring update contention. There are only `-s` rows in the `pgbench_branches` table, and every transaction wants to update one of them, so `-c` values in excess of `-s` will undoubtedly result in lots of transactions blocked waiting for other transactions.

The default test scenario is also quite sensitive to how long it's been since the tables were initialized: accumulation of dead rows and dead space in the tables changes the results. To understand the results you must keep track of the total number of updates and when vacuuming happens. If autovacuum is enabled it can result in unpredictable changes in measured performance.

A limitation of pgbench is that it can itself become the bottleneck when trying to test a large number of client sessions. This can be alleviated by running pgbench on a different machine from the database server, although low network latency will be essential. It might even be useful to run several pgbench instances concurrently, on several client machines, against the same database server.

Security

If untrusted users have access to a database that has not adopted a secure schema usage pattern, do not run pgbench in that database. pgbench uses unqualified names and does not manipulate the search path.

pg_config

pg_config — retrieve information about the installed version of Postgres Pro

Synopsis

`pg_config` [*option*...]

Description

The pg_config utility prints configuration parameters of the currently installed version of Postgres Pro. It is intended, for example, to be used by software packages that want to interface to Postgres Pro to facilitate finding the required header files and libraries.

Options

To use pg_config, supply one or more of the following options:

`--bindir`

Print the location of user executables. Use this, for example, to find the `psql` program. This is normally also the location where the `pg_config` program resides.

`--docdir`

Print the location of documentation files.

`--htmldir`

Print the location of HTML documentation files.

`--includedir`

Print the location of C header files of the client interfaces.

`--pkgincludedir`

Print the location of other C header files.

`--includedir-server`

Print the location of C header files for server programming.

`--libdir`

Print the location of object code libraries.

`--pkglibdir`

Print the location of dynamically loadable modules, or where the server would search for them. (Other architecture-dependent data files might also be installed in this directory.)

`--localedir`

Print the location of locale support files. (This will be an empty string if locale support was not configured when Postgres Pro was built.)

`--mandir`

Print the location of manual pages.

`--sharedir`

Print the location of architecture-independent support files.

`--sysconfdir`

Print the location of system-wide configuration files.

`--pgxs`

Print the location of extension makefiles.

`--configure`

Print the options that were given to the `configure` script when Postgres Pro was configured for building. This can be used to reproduce the identical configuration, or to find out with what options a binary package was built. (Note however that binary packages often contain vendor-specific custom patches.) See also the examples below.

`--cc`

Print the value of the `CC` variable that was used for building Postgres Pro. This shows the C compiler used.

`--cppflags`

Print the value of the `CPPFLAGS` variable that was used for building Postgres Pro. This shows C compiler switches needed at preprocessing time (typically, `-I` switches).

`--cflags`

Print the value of the `CFLAGS` variable that was used for building Postgres Pro. This shows C compiler switches.

`--cflags_sl`

Print the value of the `CFLAGS_SL` variable that was used for building Postgres Pro. This shows extra C compiler switches used for building shared libraries.

`--ldflags`

Print the value of the `LDFLAGS` variable that was used for building Postgres Pro. This shows linker switches.

`--ldflags_ex`

Print the value of the `LDFLAGS_EX` variable that was used for building Postgres Pro. This shows linker switches used for building executables only.

`--ldflags_sl`

Print the value of the `LDFLAGS_SL` variable that was used for building Postgres Pro. This shows linker switches used for building shared libraries only.

`--libs`

Print the value of the `LIBS` variable that was used for building Postgres Pro. This normally contains `-l` switches for external libraries linked into Postgres Pro.

`--version`

Print the PostgreSQL version on which Postgres Pro is based.

`--pgpro-version`

Print the version of Postgres Pro.

`--pgpro-edition`

Print the edition of Postgres Pro.

`-?`
`--help`

Show help about pg_config command line arguments, and exit.

If more than one option is given, the information is printed in that order, one item per line. If no options are given, all available information is printed, with labels.

Notes

The options `--docdir`, `--pkgincludedir`, `--localedir`, `--mandir`, `--sharedir`, `--sysconfdir`, `--cc`, `--cppflags`, `--cflags`, `--cflags_sl`, `--ldflags`, `--ldflags_sl`, and `--libs` were added in PostgreSQL 8.1. The option `--htmldir` was added in PostgreSQL 8.4. The option `--ldflags_ex` was added in PostgreSQL 9.0.

Example

To reproduce the build configuration of the current Postgres Pro installation, run the following command:

```
eval ./configure `pg_config --configure`
```

The output of `pg_config --configure` contains shell quotation marks so arguments with spaces are represented correctly. Therefore, using `eval` is required for proper results.

pg_dump

pg_dump — extract a Postgres Pro database into a script file or other archive file

Synopsis

`pg_dump` [*connection-option*...] [*option*...] [*dbname*]

Description

pg_dump is a utility for backing up a Postgres Pro database. It makes consistent backups even if the database is being used concurrently. pg_dump does not block other users accessing the database (readers or writers).

pg_dump only dumps a single database. To back up an entire cluster, or to back up global objects that are common to all databases in a cluster (such as roles and tablespaces), use pg_dumpall.

Dumps can be output in script or archive file formats. Script dumps are plain-text files containing the SQL commands required to reconstruct the database to the state it was in at the time it was saved. To restore from such a script, feed it to psql. Script files can be used to reconstruct the database even on other machines and other architectures; with some modifications, even on other SQL database products.

The alternative archive file formats must be used with pg_restore to rebuild the database. They allow pg_restore to be selective about what is restored, or even to reorder the items prior to being restored. The archive file formats are designed to be portable across architectures.

When used with one of the archive file formats and combined with pg_restore, pg_dump provides a flexible archival and transfer mechanism. pg_dump can be used to backup an entire database, then pg_restore can be used to examine the archive and/or select which parts of the database are to be restored. The most flexible output file formats are the “custom” format (`-Fc`) and the “directory” format (`-Fd`). They allow for selection and reordering of all archived items, support parallel restoration, and are compressed by default. The “directory” format is the only format that supports parallel dumps.

While running pg_dump, one should examine the output for any warnings (printed on standard error), especially in light of the limitations listed below.

Options

The following command-line options control the content and format of the output.

dbname

Specifies the name of the database to be dumped. If this is not specified, the environment variable `PGDATABASE` is used. If that is not set, the user name specified for the connection is used.

`-a`
`--data-only`

Dump only the data, not the schema (data definitions). Table data, large objects, and sequence values are dumped.

This option is similar to, but for historical reasons not identical to, specifying `--section=data`.

`-b`
`--blobs`

Include large objects in the dump. This is the default behavior except when `--schema`, `--table`, or `--schema-only` is specified. The `-b` switch is therefore only useful to add large objects to dumps where a specific schema or table has been requested. Note that blobs are considered data and therefore will be included when `--data-only` is used, but not when `--schema-only` is.

`-B`
`--no-blobs`

Exclude large objects in the dump.

When both `-b` and `-B` are given, the behavior is to output large objects, when data is being dumped, see the `-b` documentation.

`-c`
`--clean`

Output commands to `DROP` all the dumped database objects prior to outputting the commands for creating them. This option is useful when the restore is to overwrite an existing database. If any of the objects do not exist in the destination database, ignorable error messages will be reported during restore, unless `--if-exists` is also specified.

This option is ignored when emitting an archive (non-text) output file. For the archive formats, you can specify the option when you call `pg_restore`.

`-C`
`--create`

Begin the output with a command to create the database itself and reconnect to the created database. (With a script of this form, it doesn't matter which database in the destination installation you connect to before running the script.) If `--clean` is also specified, the script drops and recreates the target database before reconnecting to it.

With `--create`, the output also includes the database's comment if any, and any configuration variable settings that are specific to this database, that is, any `ALTER DATABASE ... SET ...` and `ALTER ROLE ... IN DATABASE ... SET ...` commands that mention this database. Access privileges for the database itself are also dumped, unless `--no-acl` is specified.

This option is ignored when emitting an archive (non-text) output file. For the archive formats, you can specify the option when you call `pg_restore`.

`-e` *pattern*
`--extension=`*pattern*

Dump only extensions matching *pattern*. When this option is not specified, all non-system extensions in the target database will be dumped. Multiple extensions can be selected by writing multiple `-e` switches. The *pattern* parameter is interpreted as a pattern according to the same rules used by psql's `\d` commands (see Patterns), so multiple extensions can also be selected by writing wildcard characters in the pattern. When using wildcards, be careful to quote the pattern if needed to prevent the shell from expanding the wildcards.

Any configuration relation registered by `pg_extension_config_dump` is included in the dump if its extension is specified by `--extension`.

> **Note**
>
> When `-e` is specified, pg_dump makes no attempt to dump any other database objects that the selected extension(s) might depend upon. Therefore, there is no guarantee that the results of a specific-extension dump can be successfully restored by themselves into a clean database.

`-E` *encoding*
`--encoding=`*encoding*

Create the dump in the specified character set encoding. By default, the dump is created in the database encoding. (Another way to get the same result is to set the `PGCLIENTENCODING` environment variable to the desired dump encoding.) The supported encodings are described in Section 23.3.1.

`-f` *file*
`--file=`*file*

Send output to the specified file. This parameter can be omitted for file based output formats, in which case the standard output is used. It must be given for the directory output format however, where it specifies the target directory instead of a file. In this case the directory is created by `pg_dump` and must not exist before.

`-F` *format*
`--format=`*format*

Selects the format of the output. *format* can be one of the following:

`p`
`plain`

Output a plain-text SQL script file (the default).

`c`
`custom`

Output a custom-format archive suitable for input into pg_restore. Together with the directory output format, this is the most flexible output format in that it allows manual selection and reordering of archived items during restore. This format is also compressed by default.

`d`
`directory`

Output a directory-format archive suitable for input into pg_restore. This will create a directory with one file for each table and blob being dumped, plus a so-called Table of Contents file describing the dumped objects in a machine-readable format that pg_restore can read. A directory format archive can be manipulated with standard Unix tools; for example, files in an uncompressed archive can be compressed with the gzip tool. This format is compressed by default and also supports parallel dumps.

`t`
`tar`

Output a `tar`-format archive suitable for input into pg_restore. The tar format is compatible with the directory format: extracting a tar-format archive produces a valid directory-format archive. However, the tar format does not support compression. Also, when using tar format the relative order of table data items cannot be changed during restore.

`-j` *njobs*
`--jobs=`*njobs*

Run the dump in parallel by dumping *njobs* tables simultaneously. This option may reduce the time needed to perform the dump but it also increases the load on the database server. You can only use this option with the directory output format because this is the only output format where multiple processes can write their data at the same time.

pg_dump will open *njobs* + 1 connections to the database, so make sure your max_connections setting is high enough to accommodate all connections.

Requesting exclusive locks on database objects while running a parallel dump could cause the dump to fail. The reason is that the pg_dump leader process requests shared locks (ACCESS SHARE) on the objects that the worker processes are going to dump later in order to make sure that nobody deletes them and makes them go away while the dump is running. If another client then requests an exclusive lock on a table, that lock will not be granted but will be queued waiting for the shared lock of the leader process to be released. Consequently any other access to the table will not be granted either and will queue after the exclusive lock request. This includes the worker process trying to dump the table. Without any precautions this would be a classic deadlock situation. To detect this

conflict, the pg_dump worker process requests another shared lock using the NOWAIT option. If the worker process is not granted this shared lock, somebody else must have requested an exclusive lock in the meantime and there is no way to continue with the dump, so pg_dump has no choice but to abort the dump.

For a consistent backup, the database server needs to support synchronized snapshots, a feature that was introduced in PostgreSQL 9.2 for primary servers and 10 for standbys. With this feature, database clients can ensure they see the same data set even though they use different connections. pg_dump -j uses multiple database connections; it connects to the database once with the leader process and once again for each worker job. Without the synchronized snapshot feature, the different worker jobs wouldn't be guaranteed to see the same data in each connection, which could lead to an inconsistent backup.

If you want to run a parallel dump of a pre-9.2 server, you need to make sure that the database content doesn't change from between the time the leader connects to the database until the last worker job has connected to the database. The easiest way to do this is to halt any data modifying processes (DDL and DML) accessing the database before starting the backup. You also need to specify the --no-synchronized-snapshots parameter when running pg_dump -j against a pre-9.2 PostgreSQL server.

-n *pattern*
--schema=*pattern*

Dump only schemas matching *pattern*; this selects both the schema itself, and all its contained objects. When this option is not specified, all non-system schemas in the target database will be dumped. Multiple schemas can be selected by writing multiple -n switches. The *pattern* parameter is interpreted as a pattern according to the same rules used by psql's \d commands (see Patterns below), so multiple schemas can also be selected by writing wildcard characters in the pattern. When using wildcards, be careful to quote the pattern if needed to prevent the shell from expanding the wildcards; see Examples below.

> **Note**
>
> When -n is specified, pg_dump makes no attempt to dump any other database objects that the selected schema(s) might depend upon. Therefore, there is no guarantee that the results of a specific-schema dump can be successfully restored by themselves into a clean database.

> **Note**
>
> Non-schema objects such as blobs are not dumped when -n is specified. You can add blobs back to the dump with the --blobs switch.

-N *pattern*
--exclude-schema=*pattern*

Do not dump any schemas matching *pattern*. The pattern is interpreted according to the same rules as for -n. -N can be given more than once to exclude schemas matching any of several patterns.

When both -n and -N are given, the behavior is to dump just the schemas that match at least one -n switch but no -N switches. If -N appears without -n, then schemas matching -N are excluded from what is otherwise a normal dump.

-O
--no-owner

Do not output commands to set ownership of objects to match the original database. By default, pg_dump issues ALTER OWNER or SET SESSION AUTHORIZATION statements to set ownership of created

database objects. These statements will fail when the script is run unless it is started by a superuser (or the same user that owns all of the objects in the script). To make a script that can be restored by any user, but will give that user ownership of all the objects, specify `-O`.

This option is ignored when emitting an archive (non-text) output file. For the archive formats, you can specify the option when you call `pg_restore`.

`-R`
`--no-reconnect`

This option is obsolete but still accepted for backwards compatibility.

`-s`
`--schema-only`

Dump only the object definitions (schema), not data.

This option is the inverse of `--data-only`. It is similar to, but for historical reasons not identical to, specifying `--section=pre-data --section=post-data`.

(Do not confuse this with the `--schema` option, which uses the word “schema” in a different meaning.)

To exclude table data for only a subset of tables in the database, see `--exclude-table-data`.

`-S` *username*
`--superuser=`*username*

Specify the superuser user name to use when disabling triggers. This is relevant only if `--disable-triggers` is used. (Usually, it's better to leave this out, and instead start the resulting script as superuser.)

`-t` *pattern*
`--table=`*pattern*

Dump only tables with names matching *pattern*. Multiple tables can be selected by writing multiple `-t` switches. The *pattern* parameter is interpreted as a pattern according to the same rules used by psql's `\d` commands (see Patterns below), so multiple tables can also be selected by writing wildcard characters in the pattern. When using wildcards, be careful to quote the pattern if needed to prevent the shell from expanding the wildcards; see Examples below.

As well as tables, this option can be used to dump the definition of matching views, materialized views, foreign tables, and sequences. It will not dump the contents of views or materialized views, and the contents of foreign tables will only be dumped if the corresponding foreign server is specified with `--include-foreign-data`.

The `-n` and `-N` switches have no effect when `-t` is used, because tables selected by `-t` will be dumped regardless of those switches, and non-table objects will not be dumped.

> **Note**
>
> When `-t` is specified, pg_dump makes no attempt to dump any other database objects that the selected table(s) might depend upon. Therefore, there is no guarantee that the results of a specific-table dump can be successfully restored by themselves into a clean database.

`-T` *pattern*
`--exclude-table=`*pattern*

Do not dump any tables matching *pattern*. The pattern is interpreted according to the same rules as for `-t`. `-T` can be given more than once to exclude tables matching any of several patterns.

When both -t and -T are given, the behavior is to dump just the tables that match at least one -t switch but no -T switches. If -T appears without -t, then tables matching -T are excluded from what is otherwise a normal dump.

-v
--verbose

Specifies verbose mode. This will cause pg_dump to output detailed object comments and start/stop times to the dump file, and progress messages to standard error. Repeating the option causes additional debug-level messages to appear on standard error.

-V
--version

Print the pg_dump version and exit.

-x
--no-privileges
--no-acl

Prevent dumping of access privileges (grant/revoke commands).

-Z *0..9*
--compress=*0..9*

Specify the compression level to use. Zero means no compression. For the custom and directory archive formats, this specifies compression of individual table-data segments, and the default is to compress at a moderate level. For plain text output, setting a nonzero compression level causes the entire output file to be compressed, as though it had been fed through gzip; but the default is not to compress. The tar archive format currently does not support compression at all.

--add-collprovider

If the provider for the default collation of the database to be dumped is implicit, explicitly specifies this provider in the dump. This option is recommended if you are using pg_dump and pg_restore to upgrade from previous versions of Postgres Pro or any version of PostgreSQL. It allows to preserve the original provider of the default collation if the template0 database in the new cluster uses different collation settings. Otherwise, check constraints that use the default collation may change and the COPY command may end with a failure. For binary upgrades, this option is used automatically.

--binary-upgrade

This option is for use by in-place upgrade utilities. Its use for other purposes is not recommended or supported. The behavior of the option may change in future releases without notice.

--column-inserts
--attribute-inserts

Dump data as INSERT commands with explicit column names (INSERT INTO *table* (*column*, ...) VALUES ...). This will make restoration very slow; it is mainly useful for making dumps that can be loaded into non-Postgres Pro databases. Any error during restoring will cause only rows that are part of the problematic INSERT to be lost, rather than the entire table contents.

--disable-dollar-quoting

This option disables the use of dollar quoting for function bodies, and forces them to be quoted using SQL standard string syntax.

--disable-triggers

This option is relevant only when creating a data-only dump. It instructs pg_dump to include commands to temporarily disable triggers on the target tables while the data is restored. Use this if

you have referential integrity checks or other triggers on the tables that you do not want to invoke during data restore.

Presently, the commands emitted for `--disable-triggers` must be done as superuser. So, you should also specify a superuser name with `-S`, or preferably be careful to start the resulting script as a superuser.

This option is ignored when emitting an archive (non-text) output file. For the archive formats, you can specify the option when you call `pg_restore`.

`--enable-large-mem-buffers`

Dump large `bytea` values exceeding 0.5 GB (up to 1 GB) and records with several `text` values exceeding 1 GB in total (up to 2 GB). This option cannot be used with `--inserts`, `--column-inserts`, or `--rows-per-insert`.

`--enable-row-security`

This option is relevant only when dumping the contents of a table which has row security. By default, pg_dump will set row_security to off, to ensure that all data is dumped from the table. If the user does not have sufficient privileges to bypass row security, then an error is thrown. This parameter instructs pg_dump to set row_security to on instead, allowing the user to dump the parts of the contents of the table that they have access to.

Note that if you use this option currently, you probably also want the dump be in `INSERT` format, as the `COPY FROM` during restore does not support row security.

`--exclude-table-data=`*`pattern`*

Do not dump data for any tables matching *`pattern`*. The pattern is interpreted according to the same rules as for `-t`. `--exclude-table-data` can be given more than once to exclude tables matching any of several patterns. This option is useful when you need the definition of a particular table even though you do not need the data in it.

To exclude data for all tables in the database, see `--schema-only`.

`--extra-float-digits=`*`ndigits`*

Use the specified value of `extra_float_digits` when dumping floating-point data, instead of the maximum available precision. Routine dumps made for backup purposes should not use this option.

`--if-exists`

Use `DROP ... IF EXISTS` commands to drop objects in `--clean` mode. This suppresses “does not exist” errors that might otherwise be reported. This option is not valid unless `--clean` is also specified.

`--include-foreign-data=`*`foreignserver`*

Dump the data for any foreign table with a foreign server matching *`foreignserver`* pattern. Multiple foreign servers can be selected by writing multiple `--include-foreign-data` switches. Also, the *`foreignserver`* parameter is interpreted as a pattern according to the same rules used by psql's `\d` commands (see Patterns below), so multiple foreign servers can also be selected by writing wildcard characters in the pattern. When using wildcards, be careful to quote the pattern if needed to prevent the shell from expanding the wildcards; see Examples below. The only exception is that an empty pattern is disallowed.

> **Note**
>
> Using wildcards in `--include-foreign-data` may result in access to unexpected foreign servers. Also, to use this option securely, make sure that the named server must have a trusted owner.

> **Note**
>
> When `--include-foreign-data` is specified, pg_dump does not check that the foreign table is writable. Therefore, there is no guarantee that the results of a foreign table dump can be successfully restored.

`--inserts`

Dump data as `INSERT` commands (rather than `COPY`). This will make restoration very slow; it is mainly useful for making dumps that can be loaded into non-Postgres Pro databases. Any error during restoring will cause only rows that are part of the problematic `INSERT` to be lost, rather than the entire table contents. Note that the restore might fail altogether if you have rearranged column order. The `--column-inserts` option is safe against column order changes, though even slower.

`--load-via-partition-root`

When dumping data for a table partition, make the `COPY` or `INSERT` statements target the root of the partitioning hierarchy that contains it, rather than the partition itself. This causes the appropriate partition to be re-determined for each row when the data is loaded. This may be useful when restoring data on a server where rows do not always fall into the same partitions as they did on the original server. That could happen, for example, if the partitioning column is of type text and the two systems have different definitions of the collation used to sort the partitioning column.

`--lock-wait-timeout=`*`timeout`*

Do not wait forever to acquire shared table locks at the beginning of the dump. Instead fail if unable to lock a table within the specified *`timeout`*. The timeout may be specified in any of the formats accepted by `SET statement_timeout`. (Allowed formats vary depending on the server version you are dumping from, but an integer number of milliseconds is accepted by all versions.)

`--no-comments`

Do not dump comments.

`--no-publications`

Do not dump publications.

`--no-security-labels`

Do not dump security labels.

`--no-subscriptions`

Do not dump subscriptions.

`--no-sync`

By default, `pg_dump` will wait for all files to be written safely to disk. This option causes `pg_dump` to return without waiting, which is faster, but means that a subsequent operating system crash can leave the dump corrupt. Generally, this option is useful for testing but should not be used when dumping data from production installation.

`--no-synchronized-snapshots`

This option allows running `pg_dump -j` against a pre-9.2 server, see the documentation of the `-j` parameter for more details.

`--no-tablespaces`

Do not output commands to select tablespaces. With this option, all objects will be created in whichever tablespace is the default during restore.

This option is ignored when emitting an archive (non-text) output file. For the archive formats, you can specify the option when you call pg_restore.

--no-toast-compression

Do not output commands to set TOAST compression methods. With this option, all columns will be restored with the default compression setting.

--no-unlogged-table-data

Do not dump the contents of unlogged tables. This option has no effect on whether or not the table definitions (schema) are dumped; it only suppresses dumping the table data. Data in unlogged tables is always excluded when dumping from a standby server.

--on-conflict-do-nothing

Add ON CONFLICT DO NOTHING to INSERT commands. This option is not valid unless --inserts, --column-inserts or --rows-per-insert is also specified.

--quote-all-identifiers

Force quoting of all identifiers. This option is recommended when dumping a database from a server whose PostgreSQL major version is different from pg_dump's, or when the output is intended to be loaded into a server of a different major version. By default, pg_dump quotes only identifiers that are reserved words in its own major version. This sometimes results in compatibility issues when dealing with servers of other versions that may have slightly different sets of reserved words. Using --quote-all-identifiers prevents such issues, at the price of a harder-to-read dump script.

--rows-per-insert=*nrows*

Dump data as INSERT commands (rather than COPY). Controls the maximum number of rows per INSERT command. The value specified must be a number greater than zero. Any error during restoring will cause only rows that are part of the problematic INSERT to be lost, rather than the entire table contents.

--section=*sectionname*

Only dump the named section. The section name can be pre-data, data, or post-data. This option can be specified more than once to select multiple sections. The default is to dump all sections.

The data section contains actual table data, large-object contents, and sequence values. Post-data items include definitions of indexes, triggers, rules, and constraints other than validated check constraints. Pre-data items include all other data definition items.

--serializable-deferrable

Use a serializable transaction for the dump, to ensure that the snapshot used is consistent with later database states; but do this by waiting for a point in the transaction stream at which no anomalies can be present, so that there isn't a risk of the dump failing or causing other transactions to roll back with a serialization_failure. See Chapter 13 for more information about transaction isolation and concurrency control.

This option is not beneficial for a dump which is intended only for disaster recovery. It could be useful for a dump used to load a copy of the database for reporting or other read-only load sharing while the original database continues to be updated. Without it the dump may reflect a state which is not consistent with any serial execution of the transactions eventually committed. For example, if batch processing techniques are used, a batch may show as closed in the dump without all of the items which are in the batch appearing.

This option will make no difference if there are no read-write transactions active when pg_dump is started. If read-write transactions are active, the start of the dump may be delayed for an indeterminate length of time. Once running, performance with or without the switch is the same.

`--snapshot=`*snapshotname*

Use the specified synchronized snapshot when making a dump of the database (see Table 9.90 for more details).

This option is useful when needing to synchronize the dump with a logical replication slot (see Chapter 51) or with a concurrent session.

In the case of a parallel dump, the snapshot name defined by this option is used rather than taking a new snapshot.

`--strict-names`

Require that each extension (`-e`/`--extension`), schema (`-n`/`--schema`) and table (`-t`/`--table`) qualifier match at least one extension/schema/table in the database to be dumped. Note that if none of the extension/schema/table qualifiers find matches, pg_dump will generate an error even without `--strict-names`.

This option has no effect on `-N`/`--exclude-schema`, `-T`/`--exclude-table`, or `--exclude-table-data`. An exclude pattern failing to match any objects is not considered an error.

`--use-set-session-authorization`

Output SQL-standard `SET SESSION AUTHORIZATION` commands instead of `ALTER OWNER` commands to determine object ownership. This makes the dump more standards-compatible, but depending on the history of the objects in the dump, might not restore properly. Also, a dump using `SET SESSION AUTHORIZATION` will certainly require superuser privileges to restore correctly, whereas `ALTER OWNER` requires lesser privileges.

`-?`
`--help`

Show help about pg_dump command line arguments, and exit.

The following command-line options control data transfer between databases when pg_transfer extension is used.

`--copy-mode-transfer`

Use this option to physically copy files, for example when database files and directory specified by `--transfer-dir` are located on different file systems.

`--transfer-dir`

Directory to transfer data files to. Data files includes that of the table, its indexes and TOAST. By default hard links are created instead of copying files. Note that deleting the table by `DROP` command makes such links invalid.

The following command-line options control the database connection parameters.

`-d` *dbname*
`--dbname=`*dbname*

Specifies the name of the database to connect to. This is equivalent to specifying *dbname* as the first non-option argument on the command line. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options.

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket. The default is taken from the `PGHOST` environment variable, if set, else a Unix domain socket connection is attempted.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections. Defaults to the `PGPORT` environment variable, if set, or a compiled-in default.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force pg_dump to prompt for a password before connecting to a database.

This option is never essential, since pg_dump will automatically prompt for a password if the server demands password authentication. However, pg_dump will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--role=`*rolename*

Specifies a role name to be used to create the dump. This option causes pg_dump to issue a `SET ROLE` *rolename* command after connecting to the database. It is useful when the authenticated user (specified by `-U`) lacks privileges needed by pg_dump, but can switch to a role with the required rights. Some installations have a policy against logging in directly as a superuser, and use of this option allows dumps to be made without violating the policy.

Environment

`PGDATABASE`
`PGHOST`
`PGOPTIONS`
`PGPORT`
`PGUSER`

Default connection parameters.

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

pg_dump internally executes `SELECT` statements. If you have problems running pg_dump, make sure you are able to select information from the database using, for example, psql. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

The database activity of pg_dump is normally collected by the statistics collector. If this is undesirable, you can set parameter `track_counts` to false via `PGOPTIONS` or the `ALTER USER` command.

Notes

If your database cluster has any local additions to the `template1` database, be careful to restore the output of pg_dump into a truly empty database; otherwise you are likely to get errors due to duplicate definitions of the added objects. To make an empty database without any local additions, copy from `template0` not `template1`, for example:

```
CREATE DATABASE foo WITH TEMPLATE template0;
```

When a data-only dump is chosen and the option `--disable-triggers` is used, pg_dump emits commands to disable triggers on user tables before inserting the data, and then commands to re-enable them after the data has been inserted. If the restore is stopped in the middle, the system catalogs might be left in the wrong state.

The dump file produced by pg_dump does not contain the statistics used by the optimizer to make query planning decisions. Therefore, it is wise to run `ANALYZE` after restoring from a dump file to ensure optimal performance; see Section 24.1.3 and Section 24.1.6 for more information.

Because pg_dump is used to transfer data to newer versions of Postgres Pro, the output of pg_dump can be expected to load into Postgres Pro server versions newer than pg_dump's version. pg_dump can also dump from Postgres Pro servers older than its own version. (Currently, servers back to version 8.0 are supported.) However, pg_dump cannot dump from Postgres Pro servers newer than its own major version; it will refuse to even try, rather than risk making an invalid dump. Also, it is not guaranteed that pg_dump's output can be loaded into a server of an older major version — not even if the dump was taken from a server of that version. Loading a dump file into an older server may require manual editing of the dump file to remove syntax not understood by the older server. Use of the `--quote-all-identifiers` option is recommended in cross-version cases, as it can prevent problems arising from varying reserved-word lists in different PostgreSQL versions.

When dumping logical replication subscriptions, pg_dump will generate `CREATE SUBSCRIPTION` commands that use the `connect = false` option, so that restoring the subscription does not make remote connections for creating a replication slot or for initial table copy. That way, the dump can be restored without requiring network access to the remote servers. It is then up to the user to reactivate the subscriptions in a suitable way. If the involved hosts have changed, the connection information might have to be changed. It might also be appropriate to truncate the target tables before initiating a new full table copy.

It is generally recommended to use the `-X` (`--no-psqlrc`) option when restoring a database from a plain-text pg_dump script to ensure a clean restore process and prevent potential conflicts with non-default psql configurations.

Examples

To dump a database called `mydb` into an SQL-script file:

```
$ pg_dump mydb > db.sql
```

To reload such a script into a (freshly created) database named `newdb`:

```
$ psql -X -d newdb -f db.sql
```

To dump a database into a custom-format archive file:

```
$ pg_dump -Fc mydb > db.dump
```

To dump a database into a directory-format archive:

```
$ pg_dump -Fd mydb -f dumpdir
```

To dump a database into a directory-format archive in parallel with 5 worker jobs:

```
$ pg_dump -Fd mydb -j 5 -f dumpdir
```

To reload an archive file into a (freshly created) database named `newdb`:

```
$ pg_restore -d newdb db.dump
```

To reload an archive file into the same database it was dumped from, discarding the current contents of that database:

```
$ pg_restore -d postgres --clean --create db.dump
```

To dump a single table named `mytab`:

```
$ pg_dump -t mytab mydb > db.sql
```

To dump all tables whose names start with `emp` in the `detroit` schema, except for the table named `employee_log`:

```
$ pg_dump -t 'detroit.emp*' -T detroit.employee_log mydb > db.sql
```

To dump all schemas whose names start with `east` or `west` and end in `gsm`, excluding any schemas whose names contain the word `test`:

```
$ pg_dump -n 'east*gsm' -n 'west*gsm' -N '*test*' mydb > db.sql
```

The same, using regular expression notation to consolidate the switches:

```
$ pg_dump -n '(east|west)*gsm' -N '*test*' mydb > db.sql
```

To dump all database objects except for tables whose names begin with `ts_`:

```
$ pg_dump -T 'ts_*' mydb > db.sql
```

To specify an upper-case or mixed-case name in `-t` and related switches, you need to double-quote the name; else it will be folded to lower case (see Patterns below). But double quotes are special to the shell, so in turn they must be quoted. Thus, to dump a single table with a mixed-case name, you need something like

```
$ pg_dump -t "\"MixedCaseName\"" mydb > mytab.sql
```

See Also

pg_dumpall, pg_restore, psql

pg_dumpall

pg_dumpall — extract a Postgres Pro database cluster into a script file

Synopsis

`pg_dumpall` [*connection-option*...] [*option*...]

Description

pg_dumpall is a utility for writing out (“dumping”) all Postgres Pro databases of a cluster into one script file. The script file contains SQL commands that can be used as input to psql to restore the databases. It does this by calling pg_dump for each database in the cluster. pg_dumpall also dumps global objects that are common to all databases, that is, database roles and tablespaces. (pg_dump does not save these objects.)

Since pg_dumpall reads tables from all databases you will most likely have to connect as a database superuser in order to produce a complete dump. Also you will need superuser privileges to execute the saved script in order to be allowed to add roles and create databases.

The SQL script will be written to the standard output. Use the `-f`/`--file` option or shell operators to redirect it into a file.

pg_dumpall needs to connect several times to the Postgres Pro server (once per database). If you use password authentication it will ask for a password each time. It is convenient to have a `~/.pgpass` file in such cases. See Section 36.16 for more information.

Options

The following command-line options control the content and format of the output.

`-a`
`--data-only`

Dump only the data, not the schema (data definitions).

`-c`
`--clean`

Emit SQL commands to `DROP` all the dumped databases, roles, and tablespaces before recreating them. This option is useful when the restore is to overwrite an existing cluster. If any of the objects do not exist in the destination cluster, ignorable error messages will be reported during restore, unless `--if-exists` is also specified.

`-E` *encoding*
`--encoding=`*encoding*

Create the dump in the specified character set encoding. By default, the dump is created in the database encoding. (Another way to get the same result is to set the `PGCLIENTENCODING` environment variable to the desired dump encoding.)

`-f` *filename*
`--file=`*filename*

Send output to the specified file. If this is omitted, the standard output is used.

`-g`
`--globals-only`

Dump only global objects (roles and tablespaces), no databases.

`-O`
`--no-owner`

Do not output commands to set ownership of objects to match the original database. By default, pg_dumpall issues `ALTER OWNER` or `SET SESSION AUTHORIZATION` statements to set ownership of created schema elements. These statements will fail when the script is run unless it is started by a superuser (or the same user that owns all of the objects in the script). To make a script that can be restored by any user, but will give that user ownership of all the objects, specify `-O`.

`-r`
`--roles-only`

Dump only roles, no databases or tablespaces.

`-s`
`--schema-only`

Dump only the object definitions (schema), not data.

`-S` *username*
`--superuser=`*username*

Specify the superuser user name to use when disabling triggers. This is relevant only if `--disable-triggers` is used. (Usually, it's better to leave this out, and instead start the resulting script as superuser.)

`-t`
`--tablespaces-only`

Dump only tablespaces, no databases or roles.

`-v`
`--verbose`

Specifies verbose mode. This will cause pg_dumpall to output start/stop times to the dump file, and progress messages to standard error. Repeating the option causes additional debug-level messages to appear on standard error. The option is also passed down to pg_dump.

`-V`
`--version`

Print the pg_dumpall version and exit.

`-x`
`--no-privileges`
`--no-acl`

Prevent dumping of access privileges (grant/revoke commands).

`--add-collprovider`

If the provider for the default collation of the database to be dumped is implicit, explicitly specifies this provider in the dump. This option is recommended if you are using pg_dumpall and pg_restore to upgrade from previous versions of Postgres Pro or any version of PostgreSQL. It allows to preserve the original provider of the default collation if the `template0` database in the new cluster uses different collation settings. Otherwise, check constraints that use the default collation may change and the `COPY` command may end with a failure. For binary upgrades, this option is used automatically.

`--binary-upgrade`

This option is for use by in-place upgrade utilities. Its use for other purposes is not recommended or supported. The behavior of the option may change in future releases without notice.

`--column-inserts`
`--attribute-inserts`

Dump data as `INSERT` commands with explicit column names (`INSERT INTO` *table* `(`*column*`, ...) VALUES ...`). This will make restoration very slow; it is mainly useful for making dumps that can be loaded into non-Postgres Pro databases.

`--disable-dollar-quoting`

This option disables the use of dollar quoting for function bodies, and forces them to be quoted using SQL standard string syntax.

`--disable-triggers`

This option is relevant only when creating a data-only dump. It instructs pg_dumpall to include commands to temporarily disable triggers on the target tables while the data is restored. Use this if you have referential integrity checks or other triggers on the tables that you do not want to invoke during data restore.

Presently, the commands emitted for `--disable-triggers` must be done as superuser. So, you should also specify a superuser name with `-S`, or preferably be careful to start the resulting script as a superuser.

`--enable-large-mem-buffers`

Dump large `bytea` values exceeding 0.5 GB (up to 1 GB) and records with several `text` values exceeding 1 GB in total (up to 2 GB). This option cannot be used with `--inserts`, `--column-inserts`, or `--rows-per-insert`.

`--exclude-database=`*pattern*

Do not dump databases whose name matches *pattern*. Multiple patterns can be excluded by writing multiple `--exclude-database` switches. The *pattern* parameter is interpreted as a pattern according to the same rules used by psql's `\d` commands (see Patterns below), so multiple databases can also be excluded by writing wildcard characters in the pattern. When using wildcards, be careful to quote the pattern if needed to prevent shell wildcard expansion.

`--extra-float-digits=`*ndigits*

Use the specified value of extra_float_digits when dumping floating-point data, instead of the maximum available precision. Routine dumps made for backup purposes should not use this option.

`--if-exists`

Use `DROP ... IF EXISTS` commands to drop objects in `--clean` mode. This suppresses “does not exist” errors that might otherwise be reported. This option is not valid unless `--clean` is also specified.

`--inserts`

Dump data as `INSERT` commands (rather than `COPY`). This will make restoration very slow; it is mainly useful for making dumps that can be loaded into non-Postgres Pro databases. Note that the restore might fail altogether if you have rearranged column order. The `--column-inserts` option is safer, though even slower.

`--load-via-partition-root`

When dumping data for a table partition, make the `COPY` or `INSERT` statements target the root of the partitioning hierarchy that contains it, rather than the partition itself. This causes the appropriate partition to be re-determined for each row when the data is loaded. This may be useful when restoring data on a server where rows do not always fall into the same partitions as they did on the original server. That could happen, for example, if the partitioning column is of type text and the two systems have different definitions of the collation used to sort the partitioning column.

`--lock-wait-timeout=`*`timeout`*

Do not wait forever to acquire shared table locks at the beginning of the dump. Instead, fail if unable to lock a table within the specified *`timeout`*. The timeout may be specified in any of the formats accepted by `SET statement_timeout`.

`--no-comments`

Do not dump comments.

`--no-publications`

Do not dump publications.

`--no-role-passwords`

Do not dump passwords for roles. When restored, roles will have a null password, and password authentication will always fail until the password is set. Since password values aren't needed when this option is specified, the role information is read from the catalog view `pg_roles` instead of `pg_authid`. Therefore, this option also helps if access to `pg_authid` is restricted by some security policy.

`--no-security-labels`

Do not dump security labels.

`--no-subscriptions`

Do not dump subscriptions.

`--no-sync`

By default, `pg_dumpall` will wait for all files to be written safely to disk. This option causes `pg_dumpall` to return without waiting, which is faster, but means that a subsequent operating system crash can leave the dump corrupt. Generally, this option is useful for testing but should not be used when dumping data from production installation.

`--no-tablespaces`

Do not output commands to create tablespaces nor select tablespaces for objects. With this option, all objects will be created in whichever tablespace is the default during restore.

`--no-toast-compression`

Do not output commands to set TOAST compression methods. With this option, all columns will be restored with the default compression setting.

`--no-unlogged-table-data`

Do not dump the contents of unlogged tables. This option has no effect on whether or not the table definitions (schema) are dumped; it only suppresses dumping the table data.

`--on-conflict-do-nothing`

Add `ON CONFLICT DO NOTHING` to `INSERT` commands. This option is not valid unless `--inserts` or `--column-inserts` is also specified.

`--quote-all-identifiers`

Force quoting of all identifiers. This option is recommended when dumping a database from a server whose PostgreSQL major version is different from pg_dumpall's, or when the output is intended to be loaded into a server of a different major version. By default, pg_dumpall quotes only identifiers that are reserved words in its own major version. This sometimes results in compatibility issues when dealing with servers of other versions that may have slightly different sets of reserved words. Using `--quote-all-identifiers` prevents such issues, at the price of a harder-to-read dump script.

`--rows-per-insert=`*nrows*

Dump data as `INSERT` commands (rather than `COPY`). Controls the maximum number of rows per `INSERT` command. The value specified must be a number greater than zero. Any error during restoring will cause only rows that are part of the problematic `INSERT` to be lost, rather than the entire table contents.

`--use-set-session-authorization`

Output SQL-standard `SET SESSION AUTHORIZATION` commands instead of `ALTER OWNER` commands to determine object ownership. This makes the dump more standards compatible, but depending on the history of the objects in the dump, might not restore properly.

`-?`
`--help`

Show help about pg_dumpall command line arguments, and exit.

The following command-line options control the database connection parameters.

`-d` *connstr*
`--dbname=`*connstr*

Specifies parameters used to connect to the server, as a connection string; these will override any conflicting command line options.

The option is called `--dbname` for consistency with other client applications, but because pg_dumpall needs to connect to many databases, the database name in the connection string will be ignored. Use the `-l` option to specify the name of the database used for the initial connection, which will dump global objects and discover what other databases should be dumped.

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the database server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket. The default is taken from the `PGHOST` environment variable, if set, else a Unix domain socket connection is attempted.

`-l` *dbname*
`--database=`*dbname*

Specifies the name of the database to connect to for dumping global objects and discovering what other databases should be dumped. If not specified, the `postgres` database will be used, and if that does not exist, `template1` will be used.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections. Defaults to the `PGPORT` environment variable, if set, or a compiled-in default.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force pg_dumpall to prompt for a password before connecting to a database.

This option is never essential, since pg_dumpall will automatically prompt for a password if the server demands password authentication. However, pg_dumpall will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

Note that the password prompt will occur again for each database to be dumped. Usually, it's better to set up a `~/.pgpass` file than to rely on manual password entry.

`--role=`*`rolename`*

Specifies a role name to be used to create the dump. This option causes pg_dumpall to issue a `SET ROLE` *`rolename`* command after connecting to the database. It is useful when the authenticated user (specified by `-U`) lacks privileges needed by pg_dumpall, but can switch to a role with the required rights. Some installations have a policy against logging in directly as a superuser, and use of this option allows dumps to be made without violating the policy.

Environment

`PGHOST`
`PGOPTIONS`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Notes

Since pg_dumpall calls pg_dump internally, some diagnostic messages will refer to pg_dump.

The `--clean` option can be useful even when your intention is to restore the dump script into a fresh cluster. Use of `--clean` authorizes the script to drop and re-create the built-in `postgres` and `template1` databases, ensuring that those databases will retain the same properties (for instance, locale and encoding) that they had in the source cluster. Without the option, those databases will retain their existing database-level properties, as well as any pre-existing contents.

Once restored, it is wise to run `ANALYZE` on each database so the optimizer has useful statistics. You can also run `vacuumdb -a -z` to analyze all databases.

The dump script should not be expected to run completely without errors. In particular, because the script will issue `CREATE ROLE` for every role existing in the source cluster, it is certain to get a “role already exists” error for the bootstrap superuser, unless the destination cluster was initialized with a different bootstrap superuser name. This error is harmless and should be ignored. Use of the `--clean` option is likely to produce additional harmless error messages about non-existent objects, although you can minimize those by adding `--if-exists`.

pg_dumpall requires all needed tablespace directories to exist before the restore; otherwise, database creation will fail for databases in non-default locations.

It is generally recommended to use the `-X` (`--no-psqlrc`) option when restoring a database from a pg_dumpall script to ensure a clean restore process and prevent potential conflicts with non-default psql

configurations. Additionally, because the pg_dumpall script may include psql meta-commands, it may be incompatible with clients other than psql.

Examples

To dump all databases:

```
$ pg_dumpall > db.out
```

To restore database(s) from this file, you can use:

```
$ psql -X -f db.out -d postgres
```

It is not important which database you connect to here since the script file created by pg_dumpall will contain the appropriate commands to create and connect to the saved databases. An exception is that if you specified `--clean`, you must connect to the `postgres` database initially; the script will attempt to drop other databases immediately, and that will fail for the database you are connected to.

See Also

Check pg_dump for details on possible error conditions.

pg_isready

pg_isready — check the connection status of a Postgres Pro server

Synopsis

`pg_isready` [*connection-option*...] [*option*...]

Description

pg_isready is a utility for checking the connection status of a Postgres Pro database server. The exit status specifies the result of the connection check.

Options

`-d` *dbname*
`--dbname=`*dbname*

Specifies the name of the database to connect to. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options.

`-h` *hostname*
`--host=`*hostname*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix-domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or the local Unix-domain socket file extension on which the server is listening for connections. Defaults to the value of the `PGPORT` environment variable or, if not set, to the port specified at compile time, usually 5432.

`-q`
`--quiet`

Do not display status message. This is useful when scripting.

`-t` *seconds*
`--timeout=`*seconds*

The maximum number of seconds to wait when attempting connection before returning that the server is not responding. Setting to 0 disables. The default is 3 seconds.

`-U` *username*
`--username=`*username*

Connect to the database as the user *username* instead of the default.

`-V`
`--version`

Print the pg_isready version and exit.

`-?`
`--help`

Show help about pg_isready command line arguments, and exit.

Exit Status

pg_isready returns `0` to the shell if the server is accepting connections normally, `1` if the server is rejecting connections (for example during startup), `2` if there was no response to the connection attempt, and `3` if no attempt was made (for example due to invalid parameters).

Environment

`pg_isready`, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

It is not necessary to supply correct user name, password, or database name values to obtain the server status; however, if incorrect values are provided, the server will log a failed connection attempt.

Examples

Standard Usage:

```
$ pg_isready
/tmp:5432 - accepting connections
$ echo $?
0
```

Running with connection parameters to a Postgres Pro cluster in startup:

```
$ pg_isready -h localhost -p 5433
localhost:5433 - rejecting connections
$ echo $?
1
```

Running with connection parameters to a non-responsive Postgres Pro cluster:

```
$ pg_isready -h someremotehost
someremotehost:5432 - no response
$ echo $?
2
```

pg_receivewal

pg_receivewal — stream write-ahead logs from a Postgres Pro server

Synopsis

`pg_receivewal` [*option*...]

Description

pg_receivewal is used to stream the write-ahead log from a running Postgres Pro cluster. The write-ahead log is streamed using the streaming replication protocol, and is written to a local directory of files. This directory can be used as the archive location for doing a restore using point-in-time recovery (see Section 25.3).

pg_receivewal streams the write-ahead log in real time as it's being generated on the server, and does not wait for segments to complete like archive_command does. For this reason, it is not necessary to set archive_timeout when using pg_receivewal.

Unlike the WAL receiver of a Postgres Pro standby server, pg_receivewal by default flushes WAL data only when a WAL file is closed. The option `--synchronous` must be specified to flush WAL data in real time. Since pg_receivewal does not apply WAL, you should not allow it to become a synchronous standby when synchronous_commit equals `remote_apply`. If it does, it will appear to be a standby that never catches up, and will cause transaction commits to block. To avoid this, you should either configure an appropriate value for synchronous_standby_names, or specify `application_name` for pg_receivewal that does not match it, or change the value of `synchronous_commit` to something other than `remote_apply`.

The write-ahead log is streamed over a regular Postgres Pro connection and uses the replication protocol. The connection must be made with a user having `REPLICATION` permissions (see Section 21.2) or a superuser, and `pg_hba.conf` must permit the replication connection. The server must also be configured with max_wal_senders set high enough to leave at least one session available for the stream.

The starting point of the write-ahead log streaming is calculated when pg_receivewal starts:

1. First, scan the directory where the WAL segment files are written and find the newest completed segment file, using as the starting point the beginning of the next WAL segment file.
2. If a starting point cannot be calculated with the previous method, the latest WAL flush location is used as reported by the server from an `IDENTIFY_SYSTEM` command.

If the connection is lost, or if it cannot be initially established, with a non-fatal error, pg_receivewal will retry the connection indefinitely, and reestablish streaming as soon as possible. To avoid this behavior, use the `-n` parameter.

In the absence of fatal errors, pg_receivewal will run until terminated by the SIGINT signal (**Control+C**).

Options

`-D` *directory*
`--directory=`*directory*

Directory to write the output to.

This parameter is required.

`-E` *lsn*
`--endpos=`*lsn*

Automatically stop replication and exit with normal exit status 0 when receiving reaches the specified LSN.

If there is a record with LSN exactly equal to *lsn*, the record will be processed.

`--if-not-exists`

Do not error out when `--create-slot` is specified and a slot with the specified name already exists.

`-n`
`--no-loop`

Don't loop on connection errors. Instead, exit right away with an error.

`--no-sync`

This option causes `pg_receivewal` to not force WAL data to be flushed to disk. This is faster, but means that a subsequent operating system crash can leave the WAL segments corrupt. Generally, this option is useful for testing but should not be used when doing WAL archiving on a production deployment.

This option is incompatible with `--synchronous`.

`-s` *interval*
`--status-interval=`*interval*

Specifies the number of seconds between status packets sent back to the server. This allows for easier monitoring of the progress from server. A value of zero disables the periodic status updates completely, although an update will still be sent when requested by the server, to avoid timeout disconnect. The default value is 10 seconds.

`-S` *slotname*
`--slot=`*slotname*

Require pg_receivewal to use an existing replication slot (see Section 26.2.6). When this option is used, pg_receivewal will report a flush position to the server, indicating when each segment has been synchronized to disk so that the server can remove that segment if it is not otherwise needed.

When the replication client of pg_receivewal is configured on the server as a synchronous standby, then using a replication slot will report the flush position to the server, but only when a WAL file is closed. Therefore, that configuration will cause transactions on the primary to wait for a long time and effectively not work satisfactorily. The option `--synchronous` (see below) must be specified in addition to make this work correctly.

`--synchronous`

Flush the WAL data to disk immediately after it has been received. Also send a status packet back to the server immediately after flushing, regardless of `--status-interval`.

This option should be specified if the replication client of pg_receivewal is configured on the server as a synchronous standby, to ensure that timely feedback is sent to the server.

`-v`
`--verbose`

Enables verbose mode.

`-Z` *level*
`--compress=`*level*

Enables gzip compression of write-ahead logs, and specifies the compression level (0 through 9, 0 being no compression and 9 being best compression). The suffix `.gz` will automatically be added to all filenames.

The following command-line options control the database connection parameters.

`-d` *connstr*
`--dbname=`*connstr*

Specifies parameters used to connect to the server, as a connection string; these will override any conflicting command line options.

The option is called `--dbname` for consistency with other client applications, but because pg_receivewal doesn't connect to any particular database in the cluster, database name in the connection string will be ignored.

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket. The default is taken from the `PGHOST` environment variable, if set, else a Unix domain socket connection is attempted.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections. Defaults to the `PGPORT` environment variable, if set, or a compiled-in default.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force pg_receivewal to prompt for a password before connecting to a database.

This option is never essential, since pg_receivewal will automatically prompt for a password if the server demands password authentication. However, pg_receivewal will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

pg_receivewal can perform one of the two following actions in order to control physical replication slots:

`--create-slot`

Create a new physical replication slot with the name specified in `--slot`, then exit.

`--drop-slot`

Drop the replication slot with the name specified in `--slot`, then exit.

Other options are also available:

`-V`
`--version`

Print the pg_receivewal version and exit.

`-?`
`--help`

Show help about pg_receivewal command line arguments, and exit.

Exit Status

pg_receivewal will exit with status 0 when terminated by the SIGINT signal. (That is the normal way to end it. Hence it is not an error.) For fatal errors or other signals, the exit status will be nonzero.

Environment

This utility, like most other Postgres Pro utilities, uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

When using pg_receivewal instead of archive_command as the main WAL backup method, it is strongly recommended to use replication slots. Otherwise, the server is free to recycle or remove write-ahead log files before they are backed up, because it does not have any information, either from archive_command or the replication slots, about how far the WAL stream has been archived. Note, however, that a replication slot will fill up the server's disk space if the receiver does not keep up with fetching the WAL data.

pg_receivewal will preserve group permissions on the received WAL files if group permissions are enabled on the source cluster.

Examples

To stream the write-ahead log from the server at `mydbserver` and store it in the local directory `/usr/local/pgsql/archive`:

```
$ pg_receivewal -h mydbserver -D /usr/local/pgsql/archive
```

See Also

pg_basebackup

pg_recvlogical

pg_recvlogical — control Postgres Pro logical decoding streams

Synopsis

`pg_recvlogical` [*option*...]

Description

`pg_recvlogical` controls logical decoding replication slots and streams data from such replication slots.

It creates a replication-mode connection, so it is subject to the same constraints as pg_receivewal, plus those for logical replication (see Chapter 51).

`pg_recvlogical` has no equivalent to the logical decoding SQL interface's peek and get modes. It sends replay confirmations for data lazily as it receives it and on clean exit. To examine pending data on a slot without consuming it, use `pg_logical_slot_peek_changes`.

Options

At least one of the following options must be specified to select an action:

`--create-slot`

Create a new logical replication slot with the name specified by `--slot`, using the output plugin specified by `--plugin`, for the database specified by `--dbname`.

`--drop-slot`

Drop the replication slot with the name specified by `--slot`, then exit.

`--start`

Begin streaming changes from the logical replication slot specified by `--slot`, continuing until terminated by a signal. If the server side change stream ends with a server shutdown or disconnect, retry in a loop unless `--no-loop` is specified.

The stream format is determined by the output plugin specified when the slot was created.

The connection must be to the same database used to create the slot.

`--create-slot` and `--start` can be specified together. `--drop-slot` cannot be combined with another action.

The following command-line options control the location and format of the output and other replication behavior:

`-E` *lsn*
`--endpos=`*lsn*

In `--start` mode, automatically stop replication and exit with normal exit status 0 when receiving reaches the specified LSN. If specified when not in `--start` mode, an error is raised.

If there's a record with LSN exactly equal to *lsn*, the record will be output.

The `--endpos` option is not aware of transaction boundaries and may truncate output partway through a transaction. Any partially output transaction will not be consumed and will be replayed again when the slot is next read from. Individual messages are never truncated.

`-f` *filename*
`--file=`*filename*

Write received and decoded transaction data into this file. Use – for stdout.

`-F` *interval_seconds*
`--fsync-interval=`*interval_seconds*

Specifies how often pg_recvlogical should issue `fsync()` calls to ensure the output file is safely flushed to disk.

The server will occasionally request the client to perform a flush and report the flush position to the server. This setting is in addition to that, to perform flushes more frequently.

Specifying an interval of `0` disables issuing `fsync()` calls altogether, while still reporting progress to the server. In this case, data could be lost in the event of a crash.

`-I` *lsn*
`--startpos=`*lsn*

In `--start` mode, start replication from the given LSN. For details on the effect of this, see the documentation in Chapter 51 and Section 55.4. Ignored in other modes.

`--if-not-exists`

Do not error out when `--create-slot` is specified and a slot with the specified name already exists.

`-n`
`--no-loop`

When the connection to the server is lost, do not retry in a loop, just exit.

`-o` *name*`[=`*value*`]`
`--option=`*name*`[=`*value*`]`

Pass the option *name* to the output plugin with, if specified, the option value *value*. Which options exist and their effects depends on the used output plugin.

`-P` *plugin*
`--plugin=`*plugin*

When creating a slot, use the specified logical decoding output plugin. See Chapter 51. This option has no effect if the slot already exists.

`-s` *interval_seconds*
`--status-interval=`*interval_seconds*

This option has the same effect as the option of the same name in pg_receivewal. See the description there.

`-S` *slot_name*
`--slot=`*slot_name*

In `--start` mode, use the existing logical replication slot named *slot_name*. In `--create-slot` mode, create the slot with this name. In `--drop-slot` mode, delete the slot with this name.

`-v`
`--verbose`

Enables verbose mode.

The following command-line options control the database connection parameters.

`-d` *dbname*
`--dbname=`*dbname*

The database to connect to. See the description of the actions for what this means in detail. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options. Defaults to the user name.

`-h` *hostname-or-ip*
`--host=`*hostname-or-ip*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket. The default is taken from the `PGHOST` environment variable, if set, else a Unix domain socket connection is attempted.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections. Defaults to the `PGPORT` environment variable, if set, or a compiled-in default.

`-U` *user*
`--username=`*user*

User name to connect as. Defaults to current operating system user name.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force pg_recvlogical to prompt for a password before connecting to a database.

This option is never essential, since pg_recvlogical will automatically prompt for a password if the server demands password authentication. However, pg_recvlogical will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

The following additional options are available:

`-V`
`--version`

Print the pg_recvlogical version and exit.

`-?`
`--help`

Show help about pg_recvlogical command line arguments, and exit.

Environment

This utility, like most other Postgres Pro utilities, uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

pg_recvlogical will preserve group permissions on the received WAL files if group permissions are enabled on the source cluster.

Examples

See Section 51.1 for an example.

See Also

pg_receivewal

pg_restore

pg_restore — restore a Postgres Pro database from an archive file created by pg_dump

Synopsis

`pg_restore` [*connection-option*...] [*option*...] [*filename*]

Description

pg_restore is a utility for restoring a Postgres Pro database from an archive created by pg_dump in one of the non-plain-text formats. It will issue the commands necessary to reconstruct the database to the state it was in at the time it was saved. The archive files also allow pg_restore to be selective about what is restored, or even to reorder the items prior to being restored. The archive files are designed to be portable across architectures.

pg_restore can operate in two modes. If a database name is specified, pg_restore connects to that database and restores archive contents directly into the database. Otherwise, a script containing the SQL commands necessary to rebuild the database is created and written to a file or standard output. This script output is equivalent to the plain text output format of pg_dump. Some of the options controlling the output are therefore analogous to pg_dump options.

Obviously, pg_restore cannot restore information that is not present in the archive file. For instance, if the archive was made using the “dump data as `INSERT` commands” option, pg_restore will not be able to load the data using `COPY` statements.

Options

pg_restore accepts the following command line arguments.

filename

Specifies the location of the archive file (or directory, for a directory-format archive) to be restored. If not specified, the standard input is used.

`-a`
`--data-only`

Restore only the data, not the schema (data definitions). Table data, large objects, and sequence values are restored, if present in the archive.

This option is similar to, but for historical reasons not identical to, specifying `--section=data`.

`-c`
`--clean`

Before restoring database objects, issue commands to `DROP` all the objects that will be restored. This option is useful for overwriting an existing database. If any of the objects do not exist in the destination database, ignorable error messages will be reported, unless `--if-exists` is also specified.

`-C`
`--create`

Create the database before restoring into it. If `--clean` is also specified, drop and recreate the target database before connecting to it.

With `--create`, pg_restore also restores the database's comment if any, and any configuration variable settings that are specific to this database, that is, any `ALTER DATABASE ... SET ...` and `ALTER`

`ROLE ... IN DATABASE ... SET ...` commands that mention this database. Access privileges for the database itself are also restored, unless `--no-acl` is specified.

When this option is used, the database named with `-d` is used only to issue the initial `DROP DATABASE` and `CREATE DATABASE` commands. All data is restored into the database name that appears in the archive.

`-d` *dbname*
`--dbname=`*dbname*

Connect to database *dbname* and restore directly into the database. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options.

`-e`
`--exit-on-error`

Exit if an error is encountered while sending SQL commands to the database. The default is to continue and to display a count of errors at the end of the restoration.

`-f` *filename*
`--file=`*filename*

Specify output file for generated script, or for the listing when used with `-l`. Use `-` for stdout.

`-F` *format*
`--format=`*format*

Specify format of the archive. It is not necessary to specify the format, since pg_restore will determine the format automatically. If specified, it can be one of the following:

`c`
`custom`

The archive is in the custom format of pg_dump.

`d`
`directory`

The archive is a directory archive.

`t`
`tar`

The archive is a `tar` archive.

`-I` *index*
`--index=`*index*

Restore definition of named index only. Multiple indexes may be specified with multiple `-I` switches.

`-j` *number-of-jobs*
`--jobs=`*number-of-jobs*

Run the most time-consuming steps of pg_restore — those that load data, create indexes, or create constraints — concurrently, using up to *number-of-jobs* concurrent sessions. This option can dramatically reduce the time to restore a large database to a server running on a multiprocessor machine. This option is ignored when emitting a script rather than connecting directly to a database server.

Each job is one process or one thread, depending on the operating system, and uses a separate connection to the server.

The optimal value for this option depends on the hardware setup of the server, of the client, and of the network. Factors include the number of CPU cores and the disk setup. A good place to start is

the number of CPU cores on the server, but values larger than that can also lead to faster restore times in many cases. Of course, values that are too high will lead to decreased performance because of thrashing.

Only the custom and directory archive formats are supported with this option. The input must be a regular file or directory (not, for example, a pipe or standard input). Also, multiple jobs cannot be used together with the option `--single-transaction`.

`-l`
`--list`

List the table of contents of the archive. The output of this operation can be used as input to the `-L` option. Note that if filtering switches such as `-n` or `-t` are used with `-l`, they will restrict the items listed.

`-L` *`list-file`*
`--use-list=`*`list-file`*

Restore only those archive elements that are listed in *`list-file`*, and restore them in the order they appear in the file. Note that if filtering switches such as `-n` or `-t` are used with `-L`, they will further restrict the items restored.

`list-file` is normally created by editing the output of a previous `-l` operation. Lines can be moved or removed, and can also be commented out by placing a semicolon (`;`) at the start of the line. See below for examples.

`-n` *`schema`*
`--schema=`*`schema`*

Restore only objects that are in the named schema. Multiple schemas may be specified with multiple `-n` switches. This can be combined with the `-t` option to restore just a specific table.

`-N` *`schema`*
`--exclude-schema=`*`schema`*

Do not restore objects that are in the named schema. Multiple schemas to be excluded may be specified with multiple `-N` switches.

When both `-n` and `-N` are given for the same schema name, the `-N` switch wins and the schema is excluded.

`-O`
`--no-owner`

Do not output commands to set ownership of objects to match the original database. By default, pg_restore issues `ALTER OWNER` or `SET SESSION AUTHORIZATION` statements to set ownership of created schema elements. These statements will fail unless the initial connection to the database is made by a superuser (or the same user that owns all of the objects in the script). With `-O`, any user name can be used for the initial connection, and this user will own all the created objects.

`-P` *`function-name(argtype [, ...])`*
`--function=`*`function-name(argtype [, ...])`*

Restore the named function only. Be careful to spell the function name and arguments exactly as they appear in the dump file's table of contents. Multiple functions may be specified with multiple `-P` switches.

`-R`
`--no-reconnect`

This option is obsolete but still accepted for backwards compatibility.

`-s`
`--schema-only`

Restore only the schema (data definitions), not data, to the extent that schema entries are present in the archive.

This option is the inverse of `--data-only`. It is similar to, but for historical reasons not identical to, specifying `--section=pre-data --section=post-data`.

(Do not confuse this with the `--schema` option, which uses the word “schema” in a different meaning.)

`-S` *username*
`--superuser=`*username*

Specify the superuser user name to use when disabling triggers. This is relevant only if `--disable-triggers` is used.

`-t` *table*
`--table=`*table*

Restore definition and/or data of only the named table. For this purpose, “table” includes views, materialized views, sequences, and foreign tables. Multiple tables can be selected by writing multiple `-t` switches. This option can be combined with the `-n` option to specify table(s) in a particular schema.

> **Note**
>
> When `-t` is specified, pg_restore makes no attempt to restore any other database objects that the selected table(s) might depend upon. Therefore, there is no guarantee that a specific-table restore into a clean database will succeed.

> **Note**
>
> This flag does not behave identically to the `-t` flag of pg_dump. There is not currently any provision for wild-card matching in pg_restore, nor can you include a schema name within its `-t`. And, while pg_dump's `-t` flag will also dump subsidiary objects (such as indexes) of the selected table(s), pg_restore's `-t` flag does not include such subsidiary objects.

> **Note**
>
> In versions prior to Postgres Pro 9.6, this flag matched only tables, not any other type of relation.

`-T` *trigger*
`--trigger=`*trigger*

Restore named trigger only. Multiple triggers may be specified with multiple `-T` switches.

`-v`
`--verbose`

Specifies verbose mode. This will cause pg_restore to output detailed object comments and start/stop times to the output file, and progress messages to standard error. Repeating the option causes additional debug-level messages to appear on standard error.

`-V`
`--version`

Print the pg_restore version and exit.

`-x`
`--no-privileges`
`--no-acl`

Prevent restoration of access privileges (grant/revoke commands).

`-1`
`--single-transaction`

Execute the restore as a single transaction (that is, wrap the emitted commands in `BEGIN`/`COMMIT`). This ensures that either all the commands complete successfully, or no changes are applied. This option implies `--exit-on-error`.

`--disable-triggers`

This option is relevant only when performing a data-only restore. It instructs pg_restore to execute commands to temporarily disable triggers on the target tables while the data is restored. Use this if you have referential integrity checks or other triggers on the tables that you do not want to invoke during data restore.

Presently, the commands emitted for `--disable-triggers` must be done as superuser. So you should also specify a superuser name with `-S` or, preferably, run pg_restore as a Postgres Pro superuser.

`--enable-row-security`

This option is relevant only when restoring the contents of a table which has row security. By default, pg_restore will set row_security to off, to ensure that all data is restored in to the table. If the user does not have sufficient privileges to bypass row security, then an error is thrown. This parameter instructs pg_restore to set row_security to on instead, allowing the user to attempt to restore the contents of the table with row security enabled. This might still fail if the user does not have the right to insert the rows from the dump into the table.

Note that this option currently also requires the dump be in `INSERT` format, as `COPY FROM` does not support row security.

`--if-exists`

Use `DROP ... IF EXISTS` commands to drop objects in `--clean` mode. This suppresses “does not exist” errors that might otherwise be reported. This option is not valid unless `--clean` is also specified.

`--no-comments`

Do not output commands to restore comments, even if the archive contains them.

`--no-data-for-failed-tables`

By default, table data is restored even if the creation command for the table failed (e.g., because it already exists). With this option, data for such a table is skipped. This behavior is useful if the target database already contains the desired table contents. For example, auxiliary tables for Postgres Pro extensions such as PostGIS might already be loaded in the target database; specifying this option prevents duplicate or obsolete data from being loaded into them.

This option is effective only when restoring directly into a database, not when producing SQL script output.

`--no-publications`

Do not output commands to restore publications, even if the archive contains them.

`--no-security-labels`

Do not output commands to restore security labels, even if the archive contains them.

`--no-subscriptions`

Do not output commands to restore subscriptions, even if the archive contains them.

`--no-tablespaces`

Do not output commands to select tablespaces. With this option, all objects will be created in whichever tablespace is the default during restore.

`--section=`*sectionname*

Only restore the named section. The section name can be `pre-data`, `data`, or `post-data`. This option can be specified more than once to select multiple sections. The default is to restore all sections.

The data section contains actual table data as well as large-object definitions. Post-data items consist of definitions of indexes, triggers, rules and constraints other than validated check constraints. Pre-data items consist of all other data definition items.

`--strict-names`

Require that each schema (`-n`/`--schema`) and table (`-t`/`--table`) qualifier match at least one schema/table in the backup file.

`--use-set-session-authorization`

Output SQL-standard `SET SESSION AUTHORIZATION` commands instead of `ALTER OWNER` commands to determine object ownership. This makes the dump more standards-compatible, but depending on the history of the objects in the dump, might not restore properly.

`-?`
`--help`

Show help about pg_restore command line arguments, and exit.

The following command-line options control data transfer between databases when pg_transfer extension is used.

`--copy-mode-transfer`

Use this option to physically copy files, for example when database files and directory specified by `--transfer-dir` are located on different file systems.

`--generate-wal`

Generate WAL records for all transferred files. When restoring on primary server without this option, changes will not be replicated to standby server.

`--transfer-dir`

Directory to transfer data files from. Data files includes that of the table, its indexes and TOAST. By default files are moved instead of copying them.

pg_restore also accepts the following command line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket. The default is taken from the `PGHOST` environment variable, if set, else a Unix domain socket connection is attempted.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections. Defaults to the `PGPORT` environment variable, if set, or a compiled-in default.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force pg_restore to prompt for a password before connecting to a database.

This option is never essential, since pg_restore will automatically prompt for a password if the server demands password authentication. However, pg_restore will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--role=`*`rolename`*

Specifies a role name to be used to perform the restore. This option causes pg_restore to issue a `SET ROLE` *`rolename`* command after connecting to the database. It is useful when the authenticated user (specified by `-U`) lacks privileges needed by pg_restore, but can switch to a role with the required rights. Some installations have a policy against logging in directly as a superuser, and use of this option allows restores to be performed without violating the policy.

Environment

`PGHOST`
`PGOPTIONS`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15). However, it does not read `PGDATABASE` when a database name is not supplied.

Diagnostics

When a direct database connection is specified using the `-d` option, pg_restore internally executes SQL statements. If you have problems running pg_restore, make sure you are able to select information from the database using, for example, psql. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Notes

If your installation has any local additions to the `template1` database, be careful to load the output of pg_restore into a truly empty database; otherwise you are likely to get errors due to duplicate definitions of the added objects. To make an empty database without any local additions, copy from `template0` not `template1`, for example:

```
CREATE DATABASE foo WITH TEMPLATE template0;
```

The limitations of pg_restore are detailed below.

- When restoring data to a pre-existing table and the option `--disable-triggers` is used, pg_restore emits commands to disable triggers on user tables before inserting the data, then emits commands to re-enable them after the data has been inserted. If the restore is stopped in the middle, the system catalogs might be left in the wrong state.

- pg_restore cannot restore large objects selectively; for instance, only those for a specific table. If an archive contains large objects, then all large objects will be restored, or none of them if they are excluded via `-L`, `-t`, or other options.

See also the pg_dump documentation for details on limitations of pg_dump.

Once restored, it is wise to run `ANALYZE` on each restored table so the optimizer has useful statistics; see Section 24.1.3 and Section 24.1.6 for more information.

Examples

Assume we have dumped a database called `mydb` into a custom-format dump file:

```
$ pg_dump -Fc mydb > db.dump
```

To drop the database and recreate it from the dump:

```
$ dropdb mydb
$ pg_restore -C -d postgres db.dump
```

The database named in the `-d` switch can be any database existing in the cluster; pg_restore only uses it to issue the `CREATE DATABASE` command for `mydb`. With `-C`, data is always restored into the database name that appears in the dump file.

To restore the dump into a new database called `newdb`:

```
$ createdb -T template0 newdb
$ pg_restore -d newdb db.dump
```

Notice we don't use `-C`, and instead connect directly to the database to be restored into. Also note that we clone the new database from `template0` not `template1`, to ensure it is initially empty.

To reorder database items, it is first necessary to dump the table of contents of the archive:

```
$ pg_restore -l db.dump > db.list
```

The listing file consists of a header and one line for each item, e.g.:

```
;
; Archive created at Mon Sep 14 13:55:39 2009
;     dbname: DBDEMOS
;     TOC Entries: 81
;     Compression: 9
;     Dump Version: 1.10-0
;     Format: CUSTOM
;     Integer: 4 bytes
;     Offset: 8 bytes
;     Dumped from database version: 8.3.5
;     Dumped by pg_dump version: 8.3.8
;
;
; Selected TOC Entries:
;
3; 2615 2200 SCHEMA - public pasha
1861; 0 0 COMMENT - SCHEMA public pasha
1862; 0 0 ACL - public pasha
317; 1247 17715 TYPE public composite pasha
319; 1247 25899 DOMAIN public domain0 pasha
```

Semicolons start a comment, and the numbers at the start of lines refer to the internal archive ID assigned to each item.

Lines in the file can be commented out, deleted, and reordered. For example:

```
10; 145433 TABLE map_resolutions postgres
;2; 145344 TABLE species postgres
;4; 145359 TABLE nt_header postgres
6; 145402 TABLE species_records postgres
;8; 145416 TABLE ss_old postgres
```

could be used as input to pg_restore and would only restore items 10 and 6, in that order:

```
$ pg_restore -L db.list db.dump
```

See Also

pg_dump, pg_dumpall, psql

pg-wrapper

pg-wrapper — manage Postgres Pro symbolic links

Synopsis

`pg-wrapper links { update | remove }`

Description

pg-wrapper is a shell script provided in the Postgres Pro distribution to manage Postgres Pro symbolic links for the provided programs and adjust the handling of SQL man pages on Linux systems. Since Postgres Pro is installed into `/opt/pgpro/ent-14`, this is required to make client and server programs available in the standard system `PATH` and find the new SQL man pages. This setup is not performed automatically at installation time to avoid possible conflicts with other PostgreSQL-based products you may have installed, unless you have opted for using the `postgrespro-ent-14` quick-install package.

pg-wrapper is provided as part of the `postgrespro-ent-14-client` package. Once this package is installed, you can find pg-wrapper in the *`install-dir`*`/bin` directory, where *`install-dir`* is `/opt/pgpro/ent-14`.

pg-wrapper must be run as root.

Options

pg-wrapper accepts the following command-line arguments:

`links` {`update` | `remove`}

Manage Postgres Pro symbolic links and SQL man pages:

- `update` — create or replace symbolic links for server and client programs provided with Postgres Pro, as well as add SQL man pages to the man page configuration file.
- `remove` — remove symbolic links and SQL man page support for the current Postgres Pro version.

Notes

If you are installing Postgres Pro from the `postgrespro-ent-14` package, pg-wrapper is invoked automatically.

If you are installing individual Postgres Pro packages, you can run this script manually to create symbolic links to the provided client and server programs, as well as add SQL man pages to the man page configuration file.

For parallel installations with other `PostgreSQL`-based products, `pg-wrapper` behavior depends on whether the update-alternatives utility is supported by your system and the already installed `PostgreSQL`-based product:

- If update-alternatives is supported, `pg-wrapper` adds symbolic links to Postgres Pro programs into the alternative system, in accordance with their priority, as well as adds SQL man pages to the man page configuration file. For details on how to change the alternatives system priorities, see the man page for update-alternatives on your system.

  If SQL man pages are already installed from a different product, the pages unique for the new installation will be displayed, while the previous installation will keep its priority for all the coinciding man pages. For the new SQL documentation to be displayed for all pages, you have to modify the system configuration, for example, change the `MANPATH` value.
- If update-alternatives is not supported, `pg-wrapper` updates the system configuration only if there are no conflicts with any programs or man pages already installed. Otherwise, pg-wrapper does not

create or update any program links and skips SQL man page integration. In this case, you can either continue using the already available program versions and SQL man pages, or modify the `PATH` and `MANPATH` settings manually.

For details on binary installation specifics on Linux, see Section 17.1.

pg_verifybackup

pg_verifybackup — verify the integrity of a base backup of a PostgreSQL cluster

Synopsis

`pg_verifybackup` [*option*...]

Description

pg_verifybackup is used to check the integrity of a database cluster backup taken using `pg_basebackup` against a `backup_manifest` generated by the server at the time of the backup. The backup must be stored in the "plain" format; a "tar" format backup can be checked after extracting it.

It is important to note that the validation which is performed by pg_verifybackup does not and cannot include every check which will be performed by a running server when attempting to make use of the backup. Even if you use this tool, you should still perform test restores and verify that the resulting databases work as expected and that they appear to contain the correct data. However, pg_verifybackup can detect many problems that commonly occur due to storage problems or user error.

Backup verification proceeds in four stages. First, `pg_verifybackup` reads the `backup_manifest` file. If that file does not exist, cannot be read, is malformed, or fails verification against its own internal checksum, `pg_verifybackup` will terminate with a fatal error.

Second, `pg_verifybackup` will attempt to verify that the data files currently stored on disk are exactly the same as the data files which the server intended to send, with some exceptions that are described below. Extra and missing files will be detected, with a few exceptions. This step will ignore the presence or absence of, or any modifications to, `postgresql.auto.conf`, `standby.signal`, and `recovery.signal`, because it is expected that these files may have been created or modified as part of the process of taking the backup. It also won't complain about a `backup_manifest` file in the target directory or about anything inside `pg_wal`, even though these files won't be listed in the backup manifest. Only files are checked; the presence or absence of directories is not verified, except indirectly: if a directory is missing, any files it should have contained will necessarily also be missing.

Next, `pg_verifybackup` will checksum all the files, compare the checksums against the values in the manifest, and emit errors for any files for which the computed checksum does not match the checksum stored in the manifest. This step is not performed for any files which produced errors in the previous step, since they are already known to have problems. Files which were ignored in the previous step are also ignored in this step.

Finally, `pg_verifybackup` will use the manifest to verify that the write-ahead log records which will be needed to recover the backup are present and that they can be read and parsed. The `backup_manifest` contains information about which write-ahead log records will be needed, and `pg_verifybackup` will use that information to invoke `pg_waldump` to parse those write-ahead log records. The `--quiet` flag will be used, so that `pg_waldump` will only report errors, without producing any other output. While this level of verification is sufficient to detect obvious problems such as a missing file or one whose internal checksums do not match, they aren't extensive enough to detect every possible problem that might occur when attempting to recover. For instance, a server bug that produces write-ahead log records that have the correct checksums but specify nonsensical actions can't be detected by this method.

Note that if extra WAL files which are not required to recover the backup are present, they will not be checked by this tool, although a separate invocation of `pg_waldump` could be used for that purpose. Also note that WAL verification is version-specific: you must use the version of `pg_verifybackup`, and thus of `pg_waldump`, which pertains to the backup being checked. In contrast, the data file integrity checks should work with any version of the server that generates a `backup_manifest` file.

Options

pg_verifybackup accepts the following command-line arguments:

`-e`
`--exit-on-error`

Exit as soon as a problem with the backup is detected. If this option is not specified, `pg_verifybackup` will continue checking the backup even after a problem has been detected, and will report all problems detected as errors.

`-i` *path*
`--ignore=`*path*

Ignore the specified file or directory, which should be expressed as a relative path name, when comparing the list of data files actually present in the backup to those listed in the `backup_manifest` file. If a directory is specified, this option affects the entire subtree rooted at that location. Complaints about extra files, missing files, file size differences, or checksum mismatches will be suppressed if the relative path name matches the specified path name. This option can be specified multiple times.

`-m` *path*
`--manifest-path=`*path*

Use the manifest file at the specified path, rather than one located in the root of the backup directory.

`-n`
`--no-parse-wal`

Don't attempt to parse write-ahead log data that will be needed to recover from this backup.

`-q`
`--quiet`

Don't print anything when a backup is successfully verified.

`-s`
`--skip-checksums`

Do not verify data file checksums. The presence or absence of files and the sizes of those files will still be checked. This is much faster, because the files themselves do not need to be read.

`-w` *path*
`--wal-directory=`*path*

Try to parse WAL files stored in the specified directory, rather than in `pg_wal`. This may be useful if the backup is stored in a separate location from the WAL archive.

Other options are also available:

`-V`
`--version`

Print the pg_verifybackup version and exit.

`-?`
`--help`

Show help about pg_verifybackup command line arguments, and exit.

Examples

To create a base backup of the server at `mydbserver` and verify the integrity of the backup:

```
$ pg_basebackup -h mydbserver -D /usr/local/pgsql/data
$ pg_verifybackup /usr/local/pgsql/data
```

To create a base backup of the server at `mydbserver`, move the manifest somewhere outside the backup directory, and verify the backup:

```
$ pg_basebackup -h mydbserver -D /usr/local/pgsql/backup1234
$ mv /usr/local/pgsql/backup1234/backup_manifest /my/secure/location/
backup_manifest.1234
$ pg_verifybackup -m /my/secure/location/backup_manifest.1234 /usr/local/pgsql/
backup1234
```

To verify a backup while ignoring a file that was added manually to the backup directory, and also skipping checksum verification:

```
$ pg_basebackup -h mydbserver -D /usr/local/pgsql/data
$ edit /usr/local/pgsql/data/note.to.self
$ pg_verifybackup --ignore=note.to.self --skip-checksums /usr/local/pgsql/data
```

See Also

pg_basebackup

psql

psql — Postgres Pro interactive terminal

Synopsis

`psql` [*option*...] [*dbname* [*username*]]

Description

psql is a terminal-based front-end to Postgres Pro. It enables you to type in queries interactively, issue them to Postgres Pro, and see the query results. Alternatively, input can be from a file or from command line arguments. In addition, psql provides a number of meta-commands and various shell-like features to facilitate writing scripts and automating a wide variety of tasks.

Options

`-a`
`--echo-all`

Print all nonempty input lines to standard output as they are read. (This does not apply to lines read interactively.) This is equivalent to setting the variable `ECHO` to `all`.

`-A`
`--no-align`

Switches to unaligned output mode. (The default output mode is `aligned`.) This is equivalent to `\pset format unaligned`.

`-b`
`--echo-errors`

Print failed SQL commands to standard error output. This is equivalent to setting the variable `ECHO` to `errors`.

`-c` *command*
`--command=`*command*

Specifies that psql is to execute the given command string, *command*. This option can be repeated and combined in any order with the `-f` option. When either `-c` or `-f` is specified, psql does not read commands from standard input; instead it terminates after processing all the `-c` and `-f` options in sequence.

command must be either a command string that is completely parsable by the server (i.e., it contains no psql-specific features), or a single backslash command. Thus you cannot mix SQL and psql meta-commands within a `-c` option. To achieve that, you could use repeated `-c` options or pipe the string into psql, for example:

```
psql -c '\x' -c 'SELECT * FROM foo;'
```

or

```
echo '\x \\ SELECT * FROM foo;' | psql
```

(`\\` is the separator meta-command.)

Each SQL command string passed to `-c` is sent to the server as a single request. Because of this, the server executes it as a single transaction even if the string contains multiple SQL commands, unless there are explicit `BEGIN`/`COMMIT` commands included in the string to divide it into multiple transactions. (See Section 55.2.2.1 for more details about how the server handles multi-query strings.) Also, psql only prints the result of the last SQL command in the string. This is different from the behavior

when the same string is read from a file or fed to psql's standard input, because then psql sends each SQL command separately.

Because of this behavior, putting more than one SQL command in a single `-c` string often has unexpected results. It's better to use repeated `-c` commands or feed multiple commands to psql's standard input, either using echo as illustrated above, or via a shell here-document, for example:

```
psql <<EOF
\x
SELECT * FROM foo;
EOF
```

`--csv`

Switches to CSV (Comma-Separated Values) output mode. This is equivalent to `\pset format csv`.

`-d` *dbname*
`--dbname=`*dbname*

Specifies the name of the database to connect to. This is equivalent to specifying *dbname* as the first non-option argument on the command line. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options.

`-e`
`--echo-queries`

Copy all SQL commands sent to the server to standard output as well. This is equivalent to setting the variable `ECHO` to `queries`.

`-E`
`--echo-hidden`

Echo the actual queries generated by `\d` and other backslash commands. You can use this to study psql's internal operations. This is equivalent to setting the variable `ECHO_HIDDEN` to `on`.

`-f` *filename*
`--file=`*filename*

Read commands from the file *filename*, rather than standard input. This option can be repeated and combined in any order with the `-c` option. When either `-c` or `-f` is specified, psql does not read commands from standard input; instead it terminates after processing all the `-c` and `-f` options in sequence. Except for that, this option is largely equivalent to the meta-command `\i`.

If *filename* is `-` (hyphen), then standard input is read until an EOF indication or `\q` meta-command. This can be used to intersperse interactive input with input from files. Note however that Readline is not used in this case (much as if `-n` had been specified).

Using this option is subtly different from writing `psql < `*filename*. In general, both will do what you expect, but using `-f` enables some nice features such as error messages with line numbers. There is also a slight chance that using this option will reduce the start-up overhead. On the other hand, the variant using the shell's input redirection is (in theory) guaranteed to yield exactly the same output you would have received had you entered everything by hand.

`-F` *separator*
`--field-separator=`*separator*

Use *separator* as the field separator for unaligned output. This is equivalent to `\pset fieldsep` or `\f`.

`-h` *hostname*
`--host=`*hostname*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix-domain socket.

`-H`
`--html`

Switches to HTML output mode. This is equivalent to `\pset format html` or the `\H` command.

`-l`
`--list`

List all available databases, then exit. Other non-connection options are ignored. This is similar to the meta-command `\list`.

When this option is used, psql will connect to the database `postgres`, unless a different database is named on the command line (option `-d` or non-option argument, possibly via a service entry, but not via an environment variable).

`-L` *`filename`*
`--log-file=`*`filename`*

Write all query output into file *`filename`*, in addition to the normal output destination.

`-n`
`--no-readline`

Do not use Readline for line editing and do not use the command history. This can be useful to turn off tab expansion when cutting and pasting.

`-o` *`filename`*
`--output=`*`filename`*

Put all query output into file *`filename`*. This is equivalent to the command `\o`.

`-p` *`port`*
`--port=`*`port`*

Specifies the TCP port or the local Unix-domain socket file extension on which the server is listening for connections. Defaults to the value of the `PGPORT` environment variable or, if not set, to the port specified at compile time, usually 5432.

`-P` *`assignment`*
`--pset=`*`assignment`*

Specifies printing options, in the style of `\pset`. Note that here you have to separate name and value with an equal sign instead of a space. For example, to set the output format to LaTeX, you could write `-P format=latex`.

`-q`
`--quiet`

Specifies that psql should do its work quietly. By default, it prints welcome messages and various informational output. If this option is used, none of this happens. This is useful with the `-c` option. This is equivalent to setting the variable `QUIET` to `on`.

`-R` *`separator`*
`--record-separator=`*`separator`*

Use *`separator`* as the record separator for unaligned output. This is equivalent to `\pset recordsep`.

`-s`
`--single-step`

Run in single-step mode. That means the user is prompted before each command is sent to the server, with the option to cancel execution as well. Use this to debug scripts.

`-S`
`--single-line`

Runs in single-line mode where a newline terminates an SQL command, as a semicolon does.

> **Note**
>
> This mode is provided for those who insist on it, but you are not necessarily encouraged to use it. In particular, if you mix SQL and meta-commands on a line the order of execution might not always be clear to the inexperienced user.

`-t`
`--tuples-only`

Turn off printing of column names and result row count footers, etc. This is equivalent to `\t` or `\pset tuples_only`.

`-T` *table_options*
`--table-attr=`*table_options*

Specifies options to be placed within the HTML `table` tag. See `\pset tableattr` for details.

`-U` *username*
`--username=`*username*

Connect to the database as the user *username* instead of the default. (You must have permission to do so, of course.)

`-v` *assignment*
`--set=`*assignment*
`--variable=`*assignment*

Perform a variable assignment, like the `\set` meta-command. Note that you must separate name and value, if any, by an equal sign on the command line. To unset a variable, leave off the equal sign. To set a variable with an empty value, use the equal sign but leave off the value. These assignments are done during command line processing, so variables that reflect connection state will get overwritten later.

`-V`
`--version`

Print the psql version and exit.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available from other sources such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

Note that this option will remain set for the entire session, and so it affects uses of the meta-command `\connect` as well as the initial connection attempt.

`-W`
`--password`

Force psql to prompt for a password before connecting to a database, even if the password will not be used.

If the server requires password authentication and a password is not available from other sources such as a `.pgpass` file, psql will prompt for a password in any case. However, psql will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

Note that this option will remain set for the entire session, and so it affects uses of the meta-command `\connect` as well as the initial connection attempt.

`-x`
`--expanded`

Turn on the expanded table formatting mode. This is equivalent to `\x` or `\pset expanded`.

`-X`
`--no-psqlrc`

Do not read the start-up file (neither the system-wide `psqlrc` file nor the user's `~/.psqlrc` file).

`-z`
`--field-separator-zero`

Set the field separator for unaligned output to a zero byte. This is equivalent to `\pset fieldsep_zero`.

`-0`
`--record-separator-zero`

Set the record separator for unaligned output to a zero byte. This is useful for interfacing, for example, with `xargs -0`. This is equivalent to `\pset recordsep_zero`.

`-1`
`--single-transaction`

This option can only be used in combination with one or more `-c` and/or `-f` options. It causes psql to issue a `BEGIN` command before the first such option and a `COMMIT` command after the last one, thereby wrapping all the commands into a single transaction. This ensures that either all the commands complete successfully, or no changes are applied.

If the commands themselves contain `BEGIN`, `COMMIT`, or `ROLLBACK`, this option will not have the desired effects. Also, if an individual command cannot be executed inside a transaction block, specifying this option will cause the whole transaction to fail.

`-?`
`--help[=`*`topic`*`]`

Show help about psql and exit. The optional *`topic`* parameter (defaulting to `options`) selects which part of psql is explained: `commands` describes psql's backslash commands; `options` describes the command-line options that can be passed to psql; and `variables` shows help about psql configuration variables.

Exit Status

psql returns 0 to the shell if it finished normally, 1 if a fatal error of its own occurs (e.g., out of memory, file not found), 2 if the connection to the server went bad and the session was not interactive, and 3 if an error occurred in a script and the variable `ON_ERROR_STOP` was set.

Usage

Connecting to a Database

psql is a regular Postgres Pro client application. In order to connect to a database you need to know the name of your target database, the host name and port number of the server, and what user name you want to connect as. psql can be told about those parameters via command line options, namely `-d`, `-h`, `-p`, and `-U` respectively. If an argument is found that does not belong to any option it will be interpreted as the database name (or the user name, if the database name is already given). Not all of these options are required; there are useful defaults. If you omit the host name, psql will connect via a Unix-domain socket to a server on the local host, or via TCP/IP to `localhost` on machines that don't have Unix-domain sockets. The default port number is determined at compile time. Since the database server uses the same default, you will not have to specify the port in most cases. The default user name

is your operating-system user name, as is the default database name. Note that you cannot just connect to any database under any user name. Your database administrator should have informed you about your access rights.

When the defaults aren't quite right, you can save yourself some typing by setting the environment variables `PGDATABASE`, `PGHOST`, `PGPORT` and/or `PGUSER` to appropriate values. (For additional environment variables, see Section 36.15.) It is also convenient to have a `~/.pgpass` file to avoid regularly having to type in passwords. See Section 36.16 for more information.

An alternative way to specify connection parameters is in a *conninfo* string or a URI, which is used instead of a database name. This mechanism give you very wide control over the connection. For example:

```
$ psql "service=myservice sslmode=require"
$ psql postgresql://dbmaster:5433/mydb?sslmode=require
```

This way you can also use LDAP for connection parameter lookup as described in Section 36.18. See Section 36.1.2 for more information on all the available connection options.

If the connection could not be made for any reason (e.g., insufficient privileges, server is not running on the targeted host, etc.), psql will return an error and terminate.

If both standard input and standard output are a terminal, then psql sets the client encoding to “auto”, which will detect the appropriate client encoding from the locale settings (`LC_CTYPE` environment variable on Unix systems). If this doesn't work out as expected, the client encoding can be overridden using the environment variable `PGCLIENTENCODING`.

Entering SQL Commands

In normal operation, psql provides a prompt with the name of the database to which psql is currently connected, followed by the string `=>`. For example:

```
$ psql testdb
psql (14.18.1)
Type "help" for help.

testdb=>
```

At the prompt, the user can type in SQL commands. Ordinarily, input lines are sent to the server when a command-terminating semicolon is reached. An end of line does not terminate a command. Thus commands can be spread over several lines for clarity. If the command was sent and executed without error, the results of the command are displayed on the screen.

If untrusted users have access to a database that has not adopted a secure schema usage pattern, begin your session by removing publicly-writable schemas from `search_path`. One can add `options=-csearch_path=` to the connection string or issue `SELECT pg_catalog.set_config('search_path', '', false)` before other SQL commands. This consideration is not specific to psql; it applies to every interface for executing arbitrary SQL commands.

Whenever a command is executed, psql also polls for asynchronous notification events generated by `LISTEN` and `NOTIFY`.

While C-style block comments are passed to the server for processing and removal, SQL-standard comments are removed by psql.

Meta-Commands

Anything you enter in psql that begins with an unquoted backslash is a psql meta-command that is processed by psql itself. These commands make psql more useful for administration or scripting. Meta-commands are often called slash or backslash commands.

The format of a psql command is the backslash, followed immediately by a command verb, then any arguments. The arguments are separated from the command verb and each other by any number of whitespace characters.

To include whitespace in an argument you can quote it with single quotes. To include a single quote in an argument, write two single quotes within single-quoted text. Anything contained in single quotes is furthermore subject to C-like substitutions for `\n` (new line), `\t` (tab), `\b` (backspace), `\r` (carriage return), `\f` (form feed), `\`*`digits`* (octal), and `\x`*`digits`* (hexadecimal). A backslash preceding any other character within single-quoted text quotes that single character, whatever it is.

If an unquoted colon (`:`) followed by a psql variable name appears within an argument, it is replaced by the variable's value, as described in SQL Interpolation below. The forms `:'`*`variable_name`*`'` and `:"`*`variable_name`*`"` described there work as well. The `:{?`*`variable_name`*`}` syntax allows testing whether a variable is defined. It is substituted by TRUE or FALSE. Escaping the colon with a backslash protects it from substitution.

Within an argument, text that is enclosed in backquotes (`` ` ``) is taken as a command line that is passed to the shell. The output of the command (with any trailing newline removed) replaces the backquoted text. Within the text enclosed in backquotes, no special quoting or other processing occurs, except that appearances of `:`*`variable_name`* where *`variable_name`* is a psql variable name are replaced by the variable's value. Also, appearances of `:'`*`variable_name`*`'` are replaced by the variable's value suitably quoted to become a single shell command argument. (The latter form is almost always preferable, unless you are very sure of what is in the variable.) Because carriage return and line feed characters cannot be safely quoted on all platforms, the `:'`*`variable_name`*`'` form prints an error message and does not substitute the variable value when such characters appear in the value.

Some commands take an SQL identifier (such as a table name) as argument. These arguments follow the syntax rules of SQL: Unquoted letters are forced to lowercase, while double quotes (`"`) protect letters from case conversion and allow incorporation of whitespace into the identifier. Within double quotes, paired double quotes reduce to a single double quote in the resulting name. For example, `FOO"BAR"BAZ` is interpreted as `fooBARbaz`, and `"A weird"" name"` becomes `A weird" name`.

Parsing for arguments stops at the end of the line, or when another unquoted backslash is found. An unquoted backslash is taken as the beginning of a new meta-command. The special sequence `\\` (two backslashes) marks the end of arguments and continues parsing SQL commands, if any. That way SQL and psql commands can be freely mixed on a line. But in any case, the arguments of a meta-command cannot continue beyond the end of the line.

Many of the meta-commands act on the *current query buffer*. This is simply a buffer holding whatever SQL command text has been typed but not yet sent to the server for execution. This will include previous input lines as well as any text appearing before the meta-command on the same line.

The following meta-commands are defined:

`\a`

If the current table output format is unaligned, it is switched to aligned. If it is not unaligned, it is set to unaligned. This command is kept for backwards compatibility. See `\pset` for a more general solution.

`\c` or `\connect [ -reuse-previous=`*`on`*`|`*`off`*` ] [ `*`dbname`*` [ `*`username`*` ] [ `*`host`*` ] [ `*`port`*` ] | `*`conninfo`*` ]`

Establishes a new connection to a Postgres Pro server. The connection parameters to use can be specified either using a positional syntax (one or more of database name, user, host, and port), or using a *`conninfo`* connection string as detailed in Section 36.1.1. If no arguments are given, a new connection is made using the same parameters as before.

Specifying any of *`dbname`*, *`username`*, *`host`* or *`port`* as `-` is equivalent to omitting that parameter.

The new connection can re-use connection parameters from the previous connection; not only database name, user, host, and port, but other settings such as *`sslmode`*. By default, parameters are re-used in the positional syntax, but not when a *`conninfo`* string is given. Passing a first argument of `-reuse-previous=on` or `-reuse-previous=off` overrides that default. If parameters are re-used, then

any parameter not explicitly specified as a positional parameter or in the *conninfo* string is taken from the existing connection's parameters. An exception is that if the *host* setting is changed from its previous value using the positional syntax, any *hostaddr* setting present in the existing connection's parameters is dropped. Also, any password used for the existing connection will be re-used only if the user, host, and port settings are not changed. When the command neither specifies nor reuses a particular parameter, the libpq default is used.

If the new connection is successfully made, the previous connection is closed. If the connection attempt fails (wrong user name, access denied, etc.), the previous connection will be kept if psql is in interactive mode. But when executing a non-interactive script, the old connection is closed and an error is reported. That may or may not terminate the script; if it does not, all database-accessing commands will fail until another `\connect` command is successfully executed. This distinction was chosen as a user convenience against typos on the one hand, and a safety mechanism that scripts are not accidentally acting on the wrong database on the other hand. Note that whenever a `\connect` command attempts to re-use parameters, the values re-used are those of the last successful connection, not of any failed attempts made subsequently. However, in the case of a non-interactive `\connect` failure, no parameters are allowed to be re-used later, since the script would likely be expecting the values from the failed `\connect` to be re-used.

Examples:

```
=> \c mydb myuser host.dom 6432
=> \c service=foo
=> \c "host=localhost port=5432 dbname=mydb connect_timeout=10 sslmode=disable"
=> \c -reuse-previous=on sslmode=require    -- changes only sslmode
=> \c postgresql://tom@localhost/mydb?application_name=myapp
```

`\C [ title ]`

Sets the title of any tables being printed as the result of a query or unset any such title. This command is equivalent to `\pset title title`. (The name of this command derives from “caption”, as it was previously only used to set the caption in an HTML table.)

`\cd [ directory ]`

Changes the current working directory to *directory*. Without argument, changes to the current user's home directory.

> **Tip**
>
> To print your current working directory, use `\! pwd`.

`\conninfo`

Outputs information about the current database connection.

`\copy { table [ ( column_list ) ] } from { 'filename' | program 'command' | stdin | pstdin } [ [ with ] ( option [, ...] ) ] [ where condition ]`
`\copy { table [ ( column_list ) ] | ( query ) } to { 'filename' | program 'command' | stdout | pstdout } [ [ with ] ( option [, ...] ) ]`

Performs a frontend (client) copy. This is an operation that runs an SQL `COPY` command, but instead of the server reading or writing the specified file, psql reads or writes the file and routes the data between the server and the local file system. This means that file accessibility and privileges are those of the local user, not the server, and no SQL superuser privileges are required.

When `program` is specified, *command* is executed by psql and the data passed from or to *command* is routed between the server and the client. Again, the execution privileges are those of the local user, not the server, and no SQL superuser privileges are required.

For `\copy ... from stdin`, data rows are read from the same source that issued the command, continuing until `\.` is read or the stream reaches EOF. This option is useful for populating tables inline within an SQL script file. For `\copy ... to stdout`, output is sent to the same place as psql command output, and the `COPY count` command status is not printed (since it might be confused with a data row). To read/write psql's standard input or output regardless of the current command source or `\o` option, write `from pstdin` or `to pstdout`.

The syntax of this command is similar to that of the SQL `COPY` command. All options other than the data source/destination are as specified for `COPY`. Because of this, special parsing rules apply to the `\copy` meta-command. Unlike most other meta-commands, the entire remainder of the line is always taken to be the arguments of `\copy`, and neither variable interpolation nor backquote expansion are performed in the arguments.

> **Tip**
>
> Another way to obtain the same result as `\copy ... to` is to use the SQL `COPY ... TO STDOUT` command and terminate it with `\g filename` or `\g |program`. Unlike `\copy`, this method allows the command to span multiple lines; also, variable interpolation and backquote expansion can be used.

> **Tip**
>
> These operations are not as efficient as the SQL `COPY` command with a file or program data source or destination, because all data must pass through the client/server connection. For large amounts of data the SQL command might be preferable. Also, because of this pass-through method, `\copy ... from` in CSV mode will erroneously treat a `\.` data value alone on a line as an end-of-input marker.

`\copyright`

Shows the copyright and distribution terms of Postgres Pro.

`\crosstabview [ colV [ colH [ colD [ sortcolH ] ] ] ]`

Executes the current query buffer (like `\g`) and shows the results in a crosstab grid. The query must return at least three columns. The output column identified by *colV* becomes a vertical header and the output column identified by *colH* becomes a horizontal header. *colD* identifies the output column to display within the grid. *sortcolH* identifies an optional sort column for the horizontal header.

Each column specification can be a column number (starting at 1) or a column name. The usual SQL case folding and quoting rules apply to column names. If omitted, *colV* is taken as column 1 and *colH* as column 2. *colH* must differ from *colV*. If *colD* is not specified, then there must be exactly three columns in the query result, and the column that is neither *colV* nor *colH* is taken to be *colD*.

The vertical header, displayed as the leftmost column, contains the values found in column *colV*, in the same order as in the query results, but with duplicates removed.

The horizontal header, displayed as the first row, contains the values found in column *colH*, with duplicates removed. By default, these appear in the same order as in the query results. But if the optional *sortcolH* argument is given, it identifies a column whose values must be integer numbers, and the values from *colH* will appear in the horizontal header sorted according to the corresponding *sortcolH* values.

Inside the crosstab grid, for each distinct value `x` of *colH* and each distinct value `y` of *colV*, the cell located at the intersection `(x,y)` contains the value of the `colD` column in the query result row for which the value of *colH* is `x` and the value of *colV* is `y`. If there is no such row, the cell is empty. If there are multiple such rows, an error is reported.

`\d[S+] [ pattern ]`

For each relation (table, view, materialized view, index, sequence, or foreign table) or composite type matching the *pattern*, show all columns, their types, the tablespace (if not the default) and any special attributes such as `NOT NULL` or defaults. Associated indexes, constraints, rules, and triggers are also shown. For foreign tables, the associated foreign server is shown as well. ("Matching the pattern" is defined in Patterns below.)

For some types of relation, `\d` shows additional information for each column: column values for sequences, indexed expressions for indexes, and foreign data wrapper options for foreign tables.

The command form `\d+` is identical, except that more information is displayed: any comments associated with the columns of the table are shown, as is the presence of OIDs in the table, the view definition if the relation is a view, a non-default replica identity setting and the access method name if the relation has an access method.

By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects.

> **Note**
>
> If `\d` is used without a *pattern* argument, it is equivalent to `\dtvmsE` which will show a list of all visible tables, views, materialized views, sequences and foreign tables. This is purely a convenience measure.

`\da[S] [ pattern ]`

Lists aggregate functions, together with their return type and the data types they operate on. If *pattern* is specified, only aggregates whose names match the pattern are shown. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects.

`\dA[+] [ pattern ]`

Lists access methods. If *pattern* is specified, only access methods whose names match the pattern are shown. If `+` is appended to the command name, each access method is listed with its associated handler function and description.

`\dAc[+] [access-method-pattern [input-type-pattern]]`

Lists operator classes (see Section 40.16.1). If *access-method-pattern* is specified, only operator classes associated with access methods whose names match that pattern are listed. If *input-type-pattern* is specified, only operator classes associated with input types whose names match that pattern are listed. If `+` is appended to the command name, each operator class is listed with its associated operator family and owner.

`\dAf[+] [access-method-pattern [input-type-pattern]]`

Lists operator families (see Section 40.16.5). If *access-method-pattern* is specified, only operator families associated with access methods whose names match that pattern are listed. If *input-type-pattern* is specified, only operator families associated with input types whose names match that pattern are listed. If `+` is appended to the command name, each operator family is listed with its owner.

`\dAo[+] [access-method-pattern [operator-family-pattern]]`

Lists operators associated with operator families (see Section 40.16.2). If *access-method-pattern* is specified, only members of operator families associated with access methods whose names match that pattern are listed. If *operator-family-pattern* is specified, only members of operator families whose names match that pattern are listed. If `+` is appended to the command name, each operator is listed with its sort operator family (if it is an ordering operator).

`\dAp[+] [access-method-pattern [operator-family-pattern]]`

Lists support functions associated with operator families (see Section 40.16.3). If *access-method-pattern* is specified, only functions of operator families associated with access methods whose names match that pattern are listed. If *operator-family-pattern* is specified, only functions of operator families whose names match that pattern are listed. If + is appended to the command name, functions are displayed verbosely, with their actual parameter lists.

`\db[+] [ pattern ]`

Lists tablespaces. If *pattern* is specified, only tablespaces whose names match the pattern are shown. If + is appended to the command name, each tablespace is listed with its associated options, on-disk size, permissions and description.

`\dc[S+] [ pattern ]`

Lists conversions between character-set encodings. If *pattern* is specified, only conversions whose names match the pattern are listed. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects. If + is appended to the command name, each object is listed with its associated description.

`\dC[+] [ pattern ]`

Lists type casts. If *pattern* is specified, only casts whose source or target types match the pattern are listed. If + is appended to the command name, each object is listed with its associated description.

`\dd[S] [ pattern ]`

Shows the descriptions of objects of type `constraint`, `operator class`, `operator family`, `rule`, and `trigger`. All other comments may be viewed by the respective backslash commands for those object types.

`\dd` displays descriptions for objects matching the *pattern*, or of visible objects of the appropriate type if no argument is given. But in either case, only objects that have a description are listed. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects.

Descriptions for objects can be created with the `COMMENT` SQL command.

`\dD[S+] [ pattern ]`

Lists domains. If *pattern* is specified, only domains whose names match the pattern are shown. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects. If + is appended to the command name, each object is listed with its associated permissions and description.

`\ddp [ pattern ]`

Lists default access privilege settings. An entry is shown for each role (and schema, if applicable) for which the default privilege settings have been changed from the built-in defaults. If *pattern* is specified, only entries whose role name or schema name matches the pattern are listed.

The `ALTER DEFAULT PRIVILEGES` command is used to set default access privileges. The meaning of the privilege display is explained in Section 5.7.

`\dE[S+] [ pattern ]`
`\di[S+] [ pattern ]`
`\dm[S+] [ pattern ]`
`\ds[S+] [ pattern ]`
`\dt[S+] [ pattern ]`
`\dv[S+] [ pattern ]`

In this group of commands, the letters `E`, `i`, `m`, `s`, `t`, and `v` stand for foreign table, index, materialized view, sequence, table, and view, respectively. You can specify any or all of these letters, in any order,

to obtain a listing of objects of these types. For example, `\dti` lists tables and indexes. If `+` is appended to the command name, each object is listed with its persistence status (permanent, temporary, or unlogged), physical size on disk, and associated description if any. If *pattern* is specified, only objects whose names match the pattern are listed. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects.

`\des[+] [ pattern ]`

Lists foreign servers (mnemonic: "external servers"). If *pattern* is specified, only those servers whose name matches the pattern are listed. If the form `\des+` is used, a full description of each server is shown, including the server's access privileges, type, version, options, and description.

`\det[+] [ pattern ]`

Lists foreign tables (mnemonic: "external tables"). If *pattern* is specified, only entries whose table name or schema name matches the pattern are listed. If the form `\det+` is used, generic options and the foreign table description are also displayed.

`\deu[+] [ pattern ]`

Lists user mappings (mnemonic: "external users"). If *pattern* is specified, only those mappings whose user names match the pattern are listed. If the form `\deu+` is used, additional information about each mapping is shown.

> **Caution**
>
> `\deu+` might also display the user name and password of the remote user, so care should be taken not to disclose them.

`\dew[+] [ pattern ]`

Lists foreign-data wrappers (mnemonic: "external wrappers"). If *pattern* is specified, only those foreign-data wrappers whose name matches the pattern are listed. If the form `\dew+` is used, the access privileges, options, and description of the foreign-data wrapper are also shown.

`\df[anptwS+] [ pattern [ arg_pattern ... ] ]`

Lists functions, together with their result data types, argument data types, and function types, which are classified as "agg" (aggregate), "normal", "procedure", "trigger", or "window". To display only functions of specific type(s), add the corresponding letters `a`, `n`, `p`, `t`, or `w` to the command. If *pattern* is specified, only functions whose names match the pattern are shown. Any additional arguments are type-name patterns, which are matched to the type names of the first, second, and so on arguments of the function. (Matching functions can have more arguments than what you specify. To prevent that, write a dash – as the last *arg_pattern*.) By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects. If the form `\df+` is used, additional information about each function is shown, including volatility, parallel safety, owner, security classification, access privileges, language, source code and description.

`\dF[+] [ pattern ]`

Lists text search configurations. If *pattern* is specified, only configurations whose names match the pattern are shown. If the form `\dF+` is used, a full description of each configuration is shown, including the underlying text search parser and the dictionary list for each parser token type.

`\dFd[+] [ pattern ]`

Lists text search dictionaries. If *pattern* is specified, only dictionaries whose names match the pattern are shown. If the form `\dFd+` is used, additional information is shown about each selected dictionary, including the underlying text search template and the option values.

`\dFp[+] [ pattern ]`

Lists text search parsers. If *pattern* is specified, only parsers whose names match the pattern are shown. If the form `\dFp+` is used, a full description of each parser is shown, including the underlying functions and the list of recognized token types.

`\dFt[+] [ pattern ]`

Lists text search templates. If *pattern* is specified, only templates whose names match the pattern are shown. If the form `\dFt+` is used, additional information is shown about each template, including the underlying function names.

`\dg[S+] [ pattern ]`

Lists database roles. (Since the concepts of "users" and "groups" have been unified into "roles", this command is now equivalent to `\du`.) By default, only user-created roles are shown; supply the `S` modifier to include system roles. If *pattern* is specified, only those roles whose names match the pattern are listed. If the form `\dg+` is used, additional information is shown about each role; currently this adds the comment for each role.

`\dl`

This is an alias for `\lo_list`, which shows a list of large objects.

`\dL[S+] [ pattern ]`

Lists procedural languages. If *pattern* is specified, only languages whose names match the pattern are listed. By default, only user-created languages are shown; supply the `S` modifier to include system objects. If `+` is appended to the command name, each language is listed with its call handler, validator, access privileges, and whether it is a system object.

`\dn[S+] [ pattern ]`

Lists schemas (namespaces). If *pattern* is specified, only schemas whose names match the pattern are listed. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects. If `+` is appended to the command name, each object is listed with its associated permissions and description, if any.

`\do[S+] [ pattern [ arg_pattern [ arg_pattern ] ] ]`

Lists operators with their operand and result types. If *pattern* is specified, only operators whose names match the pattern are listed. If one *arg_pattern* is specified, only prefix operators whose right argument's type name matches that pattern are listed. If two *arg_pattern*s are specified, only binary operators whose argument type names match those patterns are listed. (Alternatively, write `-` for the unused argument of a unary operator.) By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects. If `+` is appended to the command name, additional information about each operator is shown, currently just the name of the underlying function.

`\dO[S+] [ pattern ]`

Lists collations. If *pattern* is specified, only collations whose names match the pattern are listed. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects. If `+` is appended to the command name, each collation is listed with its associated description, if any. Note that only collations usable with the current database's encoding are shown, so the results may vary in different databases of the same installation.

`\dp [ pattern ]`

Lists tables, views and sequences with their associated access privileges. If *pattern* is specified, only tables, views and sequences whose names match the pattern are listed.

The `GRANT` and `REVOKE` commands are used to set access privileges. The meaning of the privilege display is explained in Section 5.7.

`\dP[itn+] [ pattern ]`

Lists partitioned relations. If *pattern* is specified, only entries whose name matches the pattern are listed. The modifiers `t` (tables) and `i` (indexes) can be appended to the command, filtering the kind of relations to list. By default, partitioned tables and indexes are listed.

If the modifier `n` (“nested”) is used, or a pattern is specified, then non-root partitioned relations are included, and a column is shown displaying the parent of each partitioned relation.

If `+` is appended to the command name, the sum of the sizes of each relation's partitions is also displayed, along with the relation's description. If `n` is combined with `+`, two sizes are shown: one including the total size of directly-attached leaf partitions, and another showing the total size of all partitions, including indirectly attached sub-partitions.

`\drds [ role-pattern [ database-pattern ] ]`

Lists defined configuration settings. These settings can be role-specific, database-specific, or both. *role-pattern* and *database-pattern* are used to select specific roles and databases to list, respectively. If omitted, or if `*` is specified, all settings are listed, including those not role-specific or database-specific, respectively.

The `ALTER ROLE` and `ALTER DATABASE` commands are used to define per-role and per-database configuration settings.

`\dRp[+] [ pattern ]`

Lists replication publications. If *pattern* is specified, only those publications whose names match the pattern are listed. If `+` is appended to the command name, the tables associated with each publication are shown as well.

`\dRs[+] [ pattern ]`

Lists replication subscriptions. If *pattern* is specified, only those subscriptions whose names match the pattern are listed. If `+` is appended to the command name, additional properties of the subscriptions are shown.

`\dT[S+] [ pattern ]`

Lists data types. If *pattern* is specified, only types whose names match the pattern are listed. If `+` is appended to the command name, each type is listed with its internal name and size, its allowed values if it is an `enum` type, and its associated permissions. By default, only user-created objects are shown; supply a pattern or the `S` modifier to include system objects.

`\du[S+] [ pattern ]`

Lists database roles. (Since the concepts of “users” and “groups” have been unified into “roles”, this command is now equivalent to `\dg`.) By default, only user-created roles are shown; supply the `S` modifier to include system roles. If *pattern* is specified, only those roles whose names match the pattern are listed. If the form `\du+` is used, additional information is shown about each role; currently this adds the comment for each role.

`\duP [ pattern ]`

Lists profiles. If *pattern* is specified, only those profiles whose names match the pattern are listed. This command is only available for superusers.

`\dx[+] [ pattern ]`

Lists installed extensions. If *pattern* is specified, only those extensions whose names match the pattern are listed. If the form `\dx+` is used, all the objects belonging to each matching extension are listed.

`\dX [ pattern ]`

Lists extended statistics. If *pattern* is specified, only those extended statistics whose names match the pattern are listed.

The status of each kind of extended statistics is shown in a column named after its statistic kind (e.g. Ndistinct). `defined` means that it was requested when creating the statistics, and NULL means it wasn't requested. You can use `pg_stats_ext` if you'd like to know whether `ANALYZE` was run and statistics are available to the planner.

`\dy[+] [ pattern ]`

Lists event triggers. If *pattern* is specified, only those event triggers whose names match the pattern are listed. If + is appended to the command name, each object is listed with its associated description.

`\e` or `\edit [ filename ] [ line_number ]`

If *filename* is specified, the file is edited; after the editor exits, the file's content is copied into the current query buffer. If no *filename* is given, the current query buffer is copied to a temporary file which is then edited in the same fashion. Or, if the current query buffer is empty, the most recently executed query is copied to a temporary file and edited in the same fashion.

If you edit a file or the previous query, and you quit the editor without modifying the file, the query buffer is cleared. Otherwise, the new contents of the query buffer are re-parsed according to the normal rules of psql, treating the whole buffer as a single line. Any complete queries are immediately executed; that is, if the query buffer contains or ends with a semicolon, everything up to that point is executed and removed from the query buffer. Whatever remains in the query buffer is redisplayed. Type semicolon or `\g` to send it, or `\r` to cancel it by clearing the query buffer.

Treating the buffer as a single line primarily affects meta-commands: whatever is in the buffer after a meta-command will be taken as argument(s) to the meta-command, even if it spans multiple lines. (Thus you cannot make meta-command-using scripts this way. Use `\i` for that.)

If a line number is specified, psql will position the cursor on the specified line of the file or query buffer. Note that if a single all-digits argument is given, psql assumes it is a line number, not a file name.

> **Tip**
>
> See Environment, below, for how to configure and customize your editor.

`\echo text [ ... ]`

Prints the evaluated arguments to standard output, separated by spaces and followed by a newline. This can be useful to intersperse information in the output of scripts. For example:

```
=> \echo `date`
Tue Oct 26 21:40:57 CEST 1999
```

If the first argument is an unquoted `-n` the trailing newline is not written (nor is the first argument).

> **Tip**
>
> If you use the `\o` command to redirect your query output you might wish to use `\qecho` instead of this command. See also `\warn`.

`\ef [ function_description [ line_number ] ]`

This command fetches and edits the definition of the named function or procedure, in the form of a `CREATE OR REPLACE FUNCTION` or `CREATE OR REPLACE PROCEDURE` command. Editing is done in the

same way as for \edit. If you quit the editor without saving, the statement is discarded. If you save and exit the editor, the updated command is executed immediately if you added a semicolon to it. Otherwise it is redisplayed; type semicolon or \g to send it, or \r to cancel.

The target function can be specified by name alone, or by name and arguments, for example foo(integer, text). The argument types must be given if there is more than one function of the same name.

If no function is specified, a blank CREATE FUNCTION template is presented for editing.

If a line number is specified, psql will position the cursor on the specified line of the function body. (Note that the function body typically does not begin on the first line of the file.)

Unlike most other meta-commands, the entire remainder of the line is always taken to be the argument(s) of \ef, and neither variable interpolation nor backquote expansion are performed in the arguments.

> **Tip**
>
> See Environment, below, for how to configure and customize your editor.

\encoding [*encoding*]

Sets the client character set encoding. Without an argument, this command shows the current encoding.

\errverbose

Repeats the most recent server error message at maximum verbosity, as though VERBOSITY were set to verbose and SHOW_CONTEXT were set to always.

\ev [*view_name* [*line_number*]]

This command fetches and edits the definition of the named view, in the form of a CREATE OR REPLACE VIEW command. Editing is done in the same way as for \edit. If you quit the editor without saving, the statement is discarded. If you save and exit the editor, the updated command is executed immediately if you added a semicolon to it. Otherwise it is redisplayed; type semicolon or \g to send it, or \r to cancel.

If no view is specified, a blank CREATE VIEW template is presented for editing.

If a line number is specified, psql will position the cursor on the specified line of the view definition.

Unlike most other meta-commands, the entire remainder of the line is always taken to be the argument(s) of \ev, and neither variable interpolation nor backquote expansion are performed in the arguments.

\f [*string*]

Sets the field separator for unaligned query output. The default is the vertical bar (|). It is equivalent to \pset fieldsep.

\g [(*option*=*value* [...])] [*filename*]
\g [(*option*=*value* [...])] [|*command*]

Sends the current query buffer to the server for execution.

If parentheses appear after \g, they surround a space-separated list of *option*=*value* formatting-option clauses, which are interpreted in the same way as \pset *option value* commands, but take effect only for the duration of this query. In this list, spaces are not allowed around = signs, but are

required between option clauses. If =*value* is omitted, the named *option* is changed in the same way as for \pset *option* with no explicit *value*.

If a *filename* or |*command* argument is given, the query's output is written to the named file or piped to the given shell command, instead of displaying it as usual. The file or command is written to only if the query successfully returns zero or more tuples, not if the query fails or is a non-data-returning SQL command.

If the current query buffer is empty, the most recently sent query is re-executed instead. Except for that behavior, \g without any arguments is essentially equivalent to a semicolon. With arguments, \g provides a "one-shot" alternative to the \o command, and additionally allows one-shot adjustments of the output formatting options normally set by \pset.

When the last argument begins with |, the entire remainder of the line is taken to be the *command* to execute, and neither variable interpolation nor backquote expansion are performed in it. The rest of the line is simply passed literally to the shell.

\gdesc

Shows the description (that is, the column names and data types) of the result of the current query buffer. The query is not actually executed; however, if it contains some type of syntax error, that error will be reported in the normal way.

If the current query buffer is empty, the most recently sent query is described instead.

\gexec

Sends the current query buffer to the server, then treats each column of each row of the query's output (if any) as an SQL statement to be executed. For example, to create an index on each column of my_table:

```
=> SELECT format('create index on my_table(%I)', attname)
-> FROM pg_attribute
-> WHERE attrelid = 'my_table'::regclass AND attnum > 0
-> ORDER BY attnum
-> \gexec
CREATE INDEX
CREATE INDEX
CREATE INDEX
CREATE INDEX
```

The generated queries are executed in the order in which the rows are returned, and left-to-right within each row if there is more than one column. NULL fields are ignored. The generated queries are sent literally to the server for processing, so they cannot be psql meta-commands nor contain psql variable references. If any individual query fails, execution of the remaining queries continues unless ON_ERROR_STOP is set. Execution of each query is subject to ECHO processing. (Setting ECHO to all or queries is often advisable when using \gexec.) Query logging, single-step mode, timing, and other query execution features apply to each generated query as well.

If the current query buffer is empty, the most recently sent query is re-executed instead.

\gset [*prefix*]

Sends the current query buffer to the server and stores the query's output into psql variables (see Variables below). The query to be executed must return exactly one row. Each column of the row is stored into a separate variable, named the same as the column. For example:

```
=> SELECT 'hello' AS var1, 10 AS var2
-> \gset
=> \echo :var1 :var2
hello 10
```

If you specify a *prefix*, that string is prepended to the query's column names to create the variable names to use:

```
=> SELECT 'hello' AS var1, 10 AS var2
-> \gset result_
=> \echo :result_var1 :result_var2
hello 10
```

If a column result is NULL, the corresponding variable is unset rather than being set.

If the query fails or does not return one row, no variables are changed.

If the current query buffer is empty, the most recently sent query is re-executed instead.

```
\gx [ (option=value [...]) ] [ filename ]
\gx [ (option=value [...]) ] [ |command ]
```

`\gx` is equivalent to `\g`, except that it forces expanded output mode for this query, as if `expanded=on` were included in the list of `\pset` options. See also `\x`.

`\h` or `\help [ command ]`

Gives syntax help on the specified SQL command. If *command* is not specified, then psql will list all the commands for which syntax help is available. If *command* is an asterisk (`*`), then syntax help on all SQL commands is shown.

Unlike most other meta-commands, the entire remainder of the line is always taken to be the argument(s) of `\help`, and neither variable interpolation nor backquote expansion are performed in the arguments.

> **Note**
>
> To simplify typing, commands that consists of several words do not have to be quoted. Thus it is fine to type **`\help alter table`**.

`\H` or `\html`

Turns on HTML query output format. If the HTML format is already on, it is switched back to the default aligned text format. This command is for compatibility and convenience, but see `\pset` about setting other output options.

`\i` or `\include` *filename*

Reads input from the file *filename* and executes it as though it had been typed on the keyboard.

If *filename* is `-` (hyphen), then standard input is read until an EOF indication or `\q` meta-command. This can be used to intersperse interactive input with input from files. Note that Readline behavior will be used only if it is active at the outermost level.

> **Note**
>
> If you want to see the lines on the screen as they are read you must set the variable `ECHO` to `all`.

```
\if expression
\elif expression
\else
\endif
```

This group of commands implements nestable conditional blocks. A conditional block must begin with an `\if` and end with an `\endif`. In between there may be any number of `\elif` clauses, which

may optionally be followed by a single `\else` clause. Ordinary queries and other types of backslash commands may (and usually do) appear between the commands forming a conditional block.

The `\if` and `\elif` commands read their argument(s) and evaluate them as a Boolean expression. If the expression yields `true` then processing continues normally; otherwise, lines are skipped until a matching `\elif`, `\else`, or `\endif` is reached. Once an `\if` or `\elif` test has succeeded, the arguments of later `\elif` commands in the same block are not evaluated but are treated as false. Lines following an `\else` are processed only if no earlier matching `\if` or `\elif` succeeded.

The *`expression`* argument of an `\if` or `\elif` command is subject to variable interpolation and backquote expansion, just like any other backslash command argument. After that it is evaluated like the value of an on/off option variable. So a valid value is any unambiguous case-insensitive match for one of: `true`, `false`, `1`, `0`, `on`, `off`, `yes`, `no`. For example, `t`, `T`, and `tR` will all be considered to be `true`.

Expressions that do not properly evaluate to true or false will generate a warning and be treated as false.

Lines being skipped are parsed normally to identify queries and backslash commands, but queries are not sent to the server, and backslash commands other than conditionals (`\if`, `\elif`, `\else`, `\endif`) are ignored. Conditional commands are checked only for valid nesting. Variable references in skipped lines are not expanded, and backquote expansion is not performed either.

All the backslash commands of a given conditional block must appear in the same source file. If EOF is reached on the main input file or an `\include`-ed file before all local `\if`-blocks have been closed, then psql will raise an error.

Here is an example:

```
-- check for the existence of two separate records in the database and store
-- the results in separate psql variables
SELECT
    EXISTS(SELECT 1 FROM customer WHERE customer_id = 123) as is_customer,
    EXISTS(SELECT 1 FROM employee WHERE employee_id = 456) as is_employee
\gset
\if :is_customer
    SELECT * FROM customer WHERE customer_id = 123;
\elif :is_employee
    \echo 'is not a customer but is an employee'
    SELECT * FROM employee WHERE employee_id = 456;
\else
    \if yes
        \echo 'not a customer or employee'
    \else
        \echo 'this will never print'
    \endif
\endif
```

`\ir` or `\include_relative` *`filename`*

The `\ir` command is similar to `\i`, but resolves relative file names differently. When executing in interactive mode, the two commands behave identically. However, when invoked from a script, `\ir` interprets file names relative to the directory in which the script is located, rather than the current working directory.

`\l[+]` or `\list[+] [ pattern ]`

List the databases in the server and show their names, owners, character set encodings, and access privileges. If *`pattern`* is specified, only databases whose names match the pattern are listed. If `+` is appended to the command name, database sizes, default tablespaces, and descriptions are also displayed. (Size information is only available for databases that the current user can connect to.)

`\lo_export` *`loid filename`*

Reads the large object with OID *`loid`* from the database and writes it to *`filename`*. Note that this is subtly different from the server function `lo_export`, which acts with the permissions of the user that the database server runs as and on the server's file system.

> **Tip**
>
> Use `\lo_list` to find out the large object's OID.

`\lo_import` *`filename`* [*`comment`*]

Stores the file into a Postgres Pro large object. Optionally, it associates the given comment with the object. Example:

```
foo=> \lo_import '/home/peter/pictures/photo.xcf' 'a picture of me'
lo_import 152801
```

The response indicates that the large object received object ID 152801, which can be used to access the newly-created large object in the future. For the sake of readability, it is recommended to always associate a human-readable comment with every object. Both OIDs and comments can be viewed with the `\lo_list` command.

Note that this command is subtly different from the server-side `lo_import` because it acts as the local user on the local file system, rather than the server's user and file system.

`\lo_list`

Shows a list of all Postgres Pro large objects currently stored in the database, along with any comments provided for them.

`\lo_unlink` *`loid`*

Deletes the large object with OID *`loid`* from the database.

> **Tip**
>
> Use `\lo_list` to find out the large object's OID.

`\o` or `\out` [*`filename`*]
`\o` or `\out` [`|`*`command`*]

Arranges to save future query results to the file *`filename`* or pipe future results to the shell command *`command`*. If no argument is specified, the query output is reset to the standard output.

If the argument begins with `|`, then the entire remainder of the line is taken to be the *`command`* to execute, and neither variable interpolation nor backquote expansion are performed in it. The rest of the line is simply passed literally to the shell.

“Query results” includes all tables, command responses, and notices obtained from the database server, as well as output of various backslash commands that query the database (such as `\d`); but not error messages.

> **Tip**
>
> To intersperse text output in between query results, use `\qecho`.

\p or \print

Print the current query buffer to the standard output. If the current query buffer is empty, the most recently executed query is printed instead.

\password [*username*]

Changes the password of the specified user (by default, the current user). This command prompts for the new password, encrypts it, and sends it to the server as an ALTER ROLE command. This makes sure that the new password does not appear in cleartext in the command history, the server log, or elsewhere.

\prompt [*text*] *name*

Prompts the user to supply text, which is assigned to the variable *name*. An optional prompt string, *text*, can be specified. (For multiword prompts, surround the text with single quotes.)

By default, \prompt uses the terminal for input and output. However, if the -f command line switch was used, \prompt uses standard input and standard output.

\pset [*option* [*value*]]

This command sets options affecting the output of query result tables. *option* indicates which option is to be set. The semantics of *value* vary depending on the selected option. For some options, omitting *value* causes the option to be toggled or unset, as described under the particular option. If no such behavior is mentioned, then omitting *value* just results in the current setting being displayed.

\pset without any arguments displays the current status of all printing options.

Adjustable printing options are:

border

The *value* must be a number. In general, the higher the number the more borders and lines the tables will have, but details depend on the particular format. In HTML format, this will translate directly into the border=... attribute. In most other formats only values 0 (no border), 1 (internal dividing lines), and 2 (table frame) make sense, and values above 2 will be treated the same as border = 2. The latex and latex-longtable formats additionally allow a value of 3 to add dividing lines between data rows.

columns

Sets the target width for the wrapped format, and also the width limit for determining whether output is wide enough to require the pager or switch to the vertical display in expanded auto mode. Zero (the default) causes the target width to be controlled by the environment variable COLUMNS, or the detected screen width if COLUMNS is not set. In addition, if columns is zero then the wrapped format only affects screen output. If columns is nonzero then file and pipe output is wrapped to that width as well.

csv_fieldsep

Specifies the field separator to be used in CSV output format. If the separator character appears in a field's value, that field is output within double quotes, following standard CSV rules. The default is a comma.

expanded (or x)

If *value* is specified it must be either on or off, which will enable or disable expanded mode, or auto. If *value* is omitted the command toggles between the on and off settings. When expanded mode is enabled, query results are displayed in two columns, with the column name on the left and the data on the right. This mode is useful if the data wouldn't fit on the screen in the normal “horizontal” mode. In the auto setting, the expanded mode is used whenever the query output has more than one column and is wider than the screen; otherwise, the regular mode is used. The auto setting is only effective in the aligned and wrapped formats. In other formats, it always behaves as if the expanded mode is off.

`fieldsep`

Specifies the field separator to be used in unaligned output format. That way one can create, for example, tab-separated output, which other programs might prefer. To set a tab as field separator, type `\pset fieldsep '\t'`. The default field separator is `'|'` (a vertical bar).

`fieldsep_zero`

Sets the field separator to use in unaligned output format to a zero byte.

`footer`

If *`value`* is specified it must be either `on` or `off` which will enable or disable display of the table footer (the `(`*`n`*` rows)` count). If *`value`* is omitted the command toggles footer display on or off.

`format`

Sets the output format to one of `aligned`, `asciidoc`, `csv`, `html`, `latex`, `latex-longtable`, `troff-ms`, `unaligned`, or `wrapped`. Unique abbreviations are allowed.

`aligned` format is the standard, human-readable, nicely formatted text output; this is the default.

`unaligned` format writes all columns of a row on one line, separated by the currently active field separator. This is useful for creating output that might be intended to be read in by other programs, for example, tab-separated or comma-separated format. However, the field separator character is not treated specially if it appears in a column's value; so CSV format may be better suited for such purposes.

`csv` format writes column values separated by commas, applying the quoting rules described in *RFC 4180*. This output is compatible with the CSV format of the server's `COPY` command. A header line with column names is generated unless the `tuples_only` parameter is `on`. Titles and footers are not printed. Each row is terminated by the system-dependent end-of-line character, which is typically a single newline (`\n`) for Unix-like systems or a carriage return and newline sequence (`\r\n`) for Microsoft Windows. Field separator characters other than comma can be selected with `\pset csv_fieldsep`.

`wrapped` format is like `aligned` but wraps wide data values across lines to make the output fit in the target column width. The target width is determined as described under the `columns` option. Note that psql will not attempt to wrap column header titles; therefore, `wrapped` format behaves the same as `aligned` if the total width needed for column headers exceeds the target.

The `asciidoc`, `html`, `latex`, `latex-longtable`, and `troff-ms` formats put out tables that are intended to be included in documents using the respective mark-up language. They are not complete documents! This might not be necessary in HTML, but in LaTeX you must have a complete document wrapper. The `latex` format uses LaTeX's `tabular` environment. The `latex-longtable` format requires the LaTeX `longtable` and `booktabs` packages.

`linestyle`

Sets the border line drawing style to one of `ascii`, `old-ascii`, or `unicode`. Unique abbreviations are allowed. (That would mean one letter is enough.) The default setting is `ascii`. This option only affects the `aligned` and `wrapped` output formats.

`ascii` style uses plain ASCII characters. Newlines in data are shown using a `+` symbol in the right-hand margin. When the `wrapped` format wraps data from one line to the next without a newline character, a dot (`.`) is shown in the right-hand margin of the first line, and again in the left-hand margin of the following line.

`old-ascii` style uses plain ASCII characters, using the formatting style used in PostgreSQL 8.4 and earlier. Newlines in data are shown using a `:` symbol in place of the left-hand column separator. When the data is wrapped from one line to the next without a newline character, a `;` symbol is used in place of the left-hand column separator.

`unicode` style uses Unicode box-drawing characters. Newlines in data are shown using a carriage return symbol in the right-hand margin. When the data is wrapped from one line to the next without a newline character, an ellipsis symbol is shown in the right-hand margin of the first line, and again in the left-hand margin of the following line.

When the `border` setting is greater than zero, the `linestyle` option also determines the characters with which the border lines are drawn. Plain ASCII characters work everywhere, but Unicode characters look nicer on displays that recognize them.

`null`

Sets the string to be printed in place of a null value. The default is to print nothing, which can easily be mistaken for an empty string. For example, one might prefer `\pset null '(null)'`.

`numericlocale`

If *`value`* is specified it must be either `on` or `off` which will enable or disable display of a locale-specific character to separate groups of digits to the left of the decimal marker. If *`value`* is omitted the command toggles between regular and locale-specific numeric output.

`pager`

Controls use of a pager program for query and psql help output. If the environment variable `PSQL_PAGER` or `PAGER` is set, the output is piped to the specified program. Otherwise a platform-dependent default program (such as `more`) is used.

When the `pager` option is `off`, the pager program is not used. When the `pager` option is `on`, the pager is used when appropriate, i.e., when the output is to a terminal and will not fit on the screen. The `pager` option can also be set to `always`, which causes the pager to be used for all terminal output regardless of whether it fits on the screen. `\pset pager` without a *`value`* toggles pager use on and off.

`pager_min_lines`

If `pager_min_lines` is set to a number greater than the page height, the pager program will not be called unless there are at least this many lines of output to show. The default setting is 0.

`recordsep`

Specifies the record (line) separator to use in unaligned output format. The default is a newline character.

`recordsep_zero`

Sets the record separator to use in unaligned output format to a zero byte.

`tableattr` (or `T`)

In HTML format, this specifies attributes to be placed inside the `table` tag. This could for example be `cellpadding` or `bgcolor`. Note that you probably don't want to specify `border` here, as that is already taken care of by `\pset border`. If no *`value`* is given, the table attributes are unset.

In `latex-longtable` format, this controls the proportional width of each column containing a left-aligned data type. It is specified as a whitespace-separated list of values, e.g., `'0.2 0.2 0.6'`. Unspecified output columns use the last specified value.

`title` (or `C`)

Sets the table title for any subsequently printed tables. This can be used to give your output descriptive tags. If no *`value`* is given, the title is unset.

`tuples_only` (or `t`)

If *`value`* is specified it must be either `on` or `off` which will enable or disable tuples-only mode. If *`value`* is omitted the command toggles between regular and tuples-only output. Regular output

includes extra information such as column headers, titles, and various footers. In tuples-only mode, only actual table data is shown.

`unicode_border_linestyle`

Sets the border drawing style for the `unicode` line style to one of `single` or `double`.

`unicode_column_linestyle`

Sets the column drawing style for the `unicode` line style to one of `single` or `double`.

`unicode_header_linestyle`

Sets the header drawing style for the `unicode` line style to one of `single` or `double`.

Illustrations of how these different formats look can be seen in Examples, below.

> **Tip**
>
> There are various shortcut commands for `\pset`. See `\a`, `\C`, `\f`, `\H`, `\t`, `\T`, and `\x`.

`\q` or `\quit`

Quits the psql program. In a script file, only execution of that script is terminated.

`\qecho` *text* `[ ... ]`

This command is identical to `\echo` except that the output will be written to the query output channel, as set by `\o`.

`\r` or `\reset`

Resets (clears) the query buffer.

`\s [` *filename* `]`

Print psql's command line history to *filename*. If *filename* is omitted, the history is written to the standard output (using the pager if appropriate). This command is not available if psql was built without Readline support.

`\set [` *name* `[` *value* `[ ... ] ] ]`

Sets the psql variable *name* to *value*, or if more than one value is given, to the concatenation of all of them. If only one argument is given, the variable is set to an empty-string value. To unset a variable, use the `\unset` command.

`\set` without any arguments displays the names and values of all currently-set psql variables.

Valid variable names can contain letters, digits, and underscores. See Variables below for details. Variable names are case-sensitive.

Certain variables are special, in that they control psql's behavior or are automatically set to reflect connection state. These variables are documented in Variables, below.

> **Note**
>
> This command is unrelated to the SQL command `SET`.

`\setenv` *name* `[` *value* `]`

Sets the environment variable *name* to *value*, or if the *value* is not supplied, unsets the environment variable. Example:

```
testdb=> \setenv PAGER less
testdb=> \setenv LESS -imx4F
```

`\sf[+] function_description`

This command fetches and shows the definition of the named function or procedure, in the form of a `CREATE OR REPLACE FUNCTION` or `CREATE OR REPLACE PROCEDURE` command. The definition is printed to the current query output channel, as set by `\o`.

The target function can be specified by name alone, or by name and arguments, for example `foo(integer, text)`. The argument types must be given if there is more than one function of the same name.

If `+` is appended to the command name, then the output lines are numbered, with the first line of the function body being line 1.

Unlike most other meta-commands, the entire remainder of the line is always taken to be the argument(s) of `\sf`, and neither variable interpolation nor backquote expansion are performed in the arguments.

`\sv[+] view_name`

This command fetches and shows the definition of the named view, in the form of a `CREATE OR REPLACE VIEW` command. The definition is printed to the current query output channel, as set by `\o`.

If `+` is appended to the command name, then the output lines are numbered from 1.

Unlike most other meta-commands, the entire remainder of the line is always taken to be the argument(s) of `\sv`, and neither variable interpolation nor backquote expansion are performed in the arguments.

`\t`

Toggles the display of output column name headings and row count footer. This command is equivalent to `\pset tuples_only` and is provided for convenience.

`\T table_options`

Specifies attributes to be placed within the `table` tag in HTML output format. This command is equivalent to `\pset tableattr table_options`.

`\timing [ on | off ]`

With a parameter, turns displaying of how long each SQL statement takes on or off. Without a parameter, toggles the display between on and off. The display is in milliseconds; intervals longer than 1 second are also shown in minutes:seconds format, with hours and days fields added if needed.

`\unset name`

Unsets (deletes) the psql variable *name*.

Most variables that control psql's behavior cannot be unset; instead, an `\unset` command is interpreted as setting them to their default values. See Variables below.

`\w` or `\write filename`
`\w` or `\write |command`

Writes the current query buffer to the file *filename* or pipes it to the shell command *command*. If the current query buffer is empty, the most recently executed query is written instead.

If the argument begins with `|`, then the entire remainder of the line is taken to be the *command* to execute, and neither variable interpolation nor backquote expansion are performed in it. The rest of the line is simply passed literally to the shell.

`\warn` *text* [...]

This command is identical to `\echo` except that the output will be written to psql's standard error channel, rather than standard output.

`\watch` [*seconds*]

Repeatedly execute the current query buffer (as `\g` does) until interrupted or the query fails. Wait the specified number of seconds (default 2) between executions. Each query result is displayed with a header that includes the `\pset title` string (if any), the time as of query start, and the delay interval.

If the current query buffer is empty, the most recently sent query is re-executed instead.

`\x` [*on* | *off* | *auto*]

Sets or toggles expanded table formatting mode. As such it is equivalent to `\pset expanded`.

`\z` [*pattern*]

Lists tables, views and sequences with their associated access privileges. If a *pattern* is specified, only tables, views and sequences whose names match the pattern are listed.

This is an alias for `\dp` ("display privileges").

`\!` [*command*]

With no argument, escapes to a sub-shell; psql resumes when the sub-shell exits. With an argument, executes the shell command *command*.

Unlike most other meta-commands, the entire remainder of the line is always taken to be the argument(s) of `\!`, and neither variable interpolation nor backquote expansion are performed in the arguments. The rest of the line is simply passed literally to the shell.

`\?` [*topic*]

Shows help information. The optional *topic* parameter (defaulting to `commands`) selects which part of psql is explained: `commands` describes psql's backslash commands; `options` describes the command-line options that can be passed to psql; and `variables` shows help about psql configuration variables.

`\;`

Backslash-semicolon is not a meta-command in the same way as the preceding commands; rather, it simply causes a semicolon to be added to the query buffer without any further processing.

Normally, psql will dispatch an SQL command to the server as soon as it reaches the command-ending semicolon, even if more input remains on the current line. Thus for example entering

```
select 1; select 2; select 3;
```

will result in the three SQL commands being individually sent to the server, with each one's results being displayed before continuing to the next command. However, a semicolon entered as `\;` will not trigger command processing, so that the command before it and the one after are effectively combined and sent to the server in one request. So for example

```
select 1\; select 2\; select 3;
```

results in sending the three SQL commands to the server in a single request, when the non-backslashed semicolon is reached. The server executes such a request as a single transaction, unless there are explicit `BEGIN`/`COMMIT` commands included in the string to divide it into multiple transactions. (See Section 55.2.2.1 for more details about how the server handles multi-query strings.) psql prints only the last query result it receives for each request; in this example, although all three `SELECT`s are indeed executed, psql only prints the `3`.

Patterns

The various `\d` commands accept a *pattern* parameter to specify the object name(s) to be displayed. In the simplest case, a pattern is just the exact name of the object. The characters within a pattern are normally folded to lower case, just as in SQL names; for example, `\dt FOO` will display the table named `foo`. As in SQL names, placing double quotes around a pattern stops folding to lower case. Should you need to include an actual double quote character in a pattern, write it as a pair of double quotes within a double-quote sequence; again this is in accord with the rules for SQL quoted identifiers. For example, `\dt "FOO""BAR"` will display the table named `FOO"BAR` (not `foo"bar`). Unlike the normal rules for SQL names, you can put double quotes around just part of a pattern, for instance `\dt FOO"FOO"BAR` will display the table named `fooFOObar`.

Whenever the *pattern* parameter is omitted completely, the `\d` commands display all objects that are visible in the current schema search path — this is equivalent to using `*` as the pattern. (An object is said to be *visible* if its containing schema is in the search path and no object of the same kind and name appears earlier in the search path. This is equivalent to the statement that the object can be referenced by name without explicit schema qualification.) To see all objects in the database regardless of visibility, use `*.*` as the pattern.

Within a pattern, `*` matches any sequence of characters (including no characters) and `?` matches any single character. (This notation is comparable to Unix shell file name patterns.) For example, `\dt int*` displays tables whose names begin with `int`. But within double quotes, `*` and `?` lose these special meanings and are just matched literally.

A relation pattern that contains a dot (`.`) is interpreted as a schema name pattern followed by an object name pattern. For example, `\dt foo*.*bar*` displays all tables whose table name includes `bar` that are in schemas whose schema name starts with `foo`. When no dot appears, then the pattern matches only objects that are visible in the current schema search path. Again, a dot within double quotes loses its special meaning and is matched literally. A relation pattern that contains two dots (`.`) is interpreted as a database name followed by a schema name pattern followed by an object name pattern. The database name portion will not be treated as a pattern and must match the name of the currently connected database, else an error will be raised.

A schema pattern that contains a dot (`.`) is interpreted as a database name followed by a schema name pattern. For example, `\dn mydb.*foo*` displays all schemas whose schema name includes `foo`. The database name portion will not be treated as a pattern and must match the name of the currently connected database, else an error will be raised.

Advanced users can use regular-expression notations such as character classes, for example `[0-9]` to match any digit. All regular expression special characters work as specified in Section 9.7.3, except for `.` which is taken as a separator as mentioned above, `*` which is translated to the regular-expression notation `.*`, `?` which is translated to `.`, and `$` which is matched literally. You can emulate these pattern characters at need by writing `?` for `.`, `(R+|)` for *R*`*`, or `(R|)` for *R*`?`. `$` is not needed as a regular-expression character since the pattern must match the whole name, unlike the usual interpretation of regular expressions (in other words, `$` is automatically appended to your pattern). Write `*` at the beginning and/or end if you don't wish the pattern to be anchored. Note that within double quotes, all regular expression special characters lose their special meanings and are matched literally. Also, the regular expression special characters are matched literally in operator name patterns (i.e., the argument of `\do`).

Advanced Features

Variables

psql provides variable substitution features similar to common Unix command shells. Variables are simply name/value pairs, where the value can be any string of any length. The name must consist of letters (including non-Latin letters), digits, and underscores.

To set a variable, use the psql meta-command `\set`. For example,

```
testdb=> \set foo bar
```

sets the variable `foo` to the value `bar`. To retrieve the content of the variable, precede the name with a colon, for example:

```
testdb=> \echo :foo
bar
```

This works in both regular SQL commands and meta-commands; there is more detail in SQL Interpolation, below.

If you call `\set` without a second argument, the variable is set to an empty-string value. To unset (i.e., delete) a variable, use the command `\unset`. To show the values of all variables, call `\set` without any argument.

> **Note**
>
> The arguments of `\set` are subject to the same substitution rules as with other commands. Thus you can construct interesting references such as `\set :foo 'something'` and get "soft links" or "variable variables" of Perl or PHP fame, respectively. Unfortunately (or fortunately?), there is no way to do anything useful with these constructs. On the other hand, `\set bar :foo` is a perfectly valid way to copy a variable.

A number of these variables are treated specially by psql. They represent certain option settings that can be changed at run time by altering the value of the variable, or in some cases represent changeable state of psql. By convention, all specially treated variables' names consist of all upper-case ASCII letters (and possibly digits and underscores). To ensure maximum compatibility in the future, avoid using such variable names for your own purposes.

Variables that control psql's behavior generally cannot be unset or set to invalid values. An `\unset` command is allowed but is interpreted as setting the variable to its default value. A `\set` command without a second argument is interpreted as setting the variable to `on`, for control variables that accept that value, and is rejected for others. Also, control variables that accept the values `on` and `off` will also accept other common spellings of Boolean values, such as `true` and `false`.

The specially treated variables are:

`AUTOCOMMIT`

When `on` (the default), each SQL command is automatically committed upon successful completion. To postpone commit in this mode, you must enter a `BEGIN` or `START TRANSACTION` SQL command. When `off` or unset, SQL commands are not committed until you explicitly issue `COMMIT` or `END`. The autocommit-off mode works by issuing an implicit `BEGIN` for you, just before any command that is not already in a transaction block and is not itself a `BEGIN` or other transaction-control command, nor a command that cannot be executed inside a transaction block (such as `VACUUM`).

> **Note**
>
> In autocommit-off mode, you must explicitly abandon any failed transaction by entering `ABORT` or `ROLLBACK`. Also keep in mind that if you exit the session without committing, your work will be lost.

> **Note**
>
> The autocommit-on mode is Postgres Pro's traditional behavior, but autocommit-off is closer to the SQL spec. If you prefer autocommit-off, you might wish to set it in the system-wide `psqlrc` file or your `~/.psqlrc` file.

COMP_KEYWORD_CASE

Determines which letter case to use when completing an SQL key word. If set to `lower` or `upper`, the completed word will be in lower or upper case, respectively. If set to `preserve-lower` or `preserve-upper` (the default), the completed word will be in the case of the word already entered, but words being completed without anything entered will be in lower or upper case, respectively.

DBNAME

The name of the database you are currently connected to. This is set every time you connect to a database (including program start-up), but can be changed or unset.

ECHO

If set to `all`, all nonempty input lines are printed to standard output as they are read. (This does not apply to lines read interactively.) To select this behavior on program start-up, use the switch `-a`. If set to `queries`, psql prints each query to standard output as it is sent to the server. The switch to select this behavior is `-e`. If set to `errors`, then only failed queries are displayed on standard error output. The switch for this behavior is `-b`. If set to `none` (the default), then no queries are displayed.

ECHO_HIDDEN

When this variable is set to `on` and a backslash command queries the database, the query is first shown. This feature helps you to study Postgres Pro internals and provide similar functionality in your own programs. (To select this behavior on program start-up, use the switch `-E`.) If you set this variable to the value `noexec`, the queries are just shown but are not actually sent to the server and executed. The default value is `off`.

ENCODING

The current client character set encoding. This is set every time you connect to a database (including program start-up), and when you change the encoding with `\encoding`, but it can be changed or unset.

ERROR

`true` if the last SQL query failed, `false` if it succeeded. See also `SQLSTATE`.

FETCH_COUNT

If this variable is set to an integer value greater than zero, the results of `SELECT` queries are fetched and displayed in groups of that many rows, rather than the default behavior of collecting the entire result set before display. Therefore only a limited amount of memory is used, regardless of the size of the result set. Settings of 100 to 1000 are commonly used when enabling this feature. Keep in mind that when using this feature, a query might fail after having already displayed some rows.

> **Tip**
>
> Although you can use any output format with this feature, the default `aligned` format tends to look bad because each group of `FETCH_COUNT` rows will be formatted separately, leading to varying column widths across the row groups. The other output formats work better.

HIDE_TABLEAM

If this variable is set to `true`, a table's access method details are not displayed. This is mainly useful for regression tests.

HIDE_TOAST_COMPRESSION

If this variable is set to `true`, column compression method details are not displayed. This is mainly useful for regression tests.

HISTCONTROL

If this variable is set to ignorespace, lines which begin with a space are not entered into the history list. If set to a value of ignoredups, lines matching the previous history line are not entered. A value of ignoreboth combines the two options. If set to none (the default), all lines read in interactive mode are saved on the history list.

> **Note**
>
> This feature was shamelessly plagiarized from Bash.

HISTFILE

The file name that will be used to store the history list. If unset, the file name is taken from the PSQL_HISTORY environment variable. If that is not set either, the default is ~/.psql_history, or %APPDATA%\postgresql\psql_history on Windows. For example, putting:

```
\set HISTFILE ~/.psql_history-:DBNAME
```

in ~/.psqlrc will cause psql to maintain a separate history for each database.

> **Note**
>
> This feature was shamelessly plagiarized from Bash.

HISTSIZE

The maximum number of commands to store in the command history (default 500). If set to a negative value, no limit is applied.

> **Note**
>
> This feature was shamelessly plagiarized from Bash.

HOST

The database server host you are currently connected to. This is set every time you connect to a database (including program start-up), but can be changed or unset.

IGNOREEOF

If set to 1 or less, sending an EOF character (usually **Control+D**) to an interactive session of psql will terminate the application. If set to a larger numeric value, that many consecutive EOF characters must be typed to make an interactive session terminate. If the variable is set to a non-numeric value, it is interpreted as 10. The default is 0.

> **Note**
>
> This feature was shamelessly plagiarized from Bash.

LASTOID

The value of the last affected OID, as returned from an INSERT or \lo_import command. This variable is only guaranteed to be valid until after the result of the next SQL command has been displayed. Postgres Pro servers since version 12 do not support OID system columns anymore, thus LASTOID will always be 0 following INSERT when targeting such servers.

LAST_ERROR_MESSAGE
LAST_ERROR_SQLSTATE

The primary error message and associated SQLSTATE code for the most recent failed query in the current psql session, or an empty string and 00000 if no error has occurred in the current session.

ON_ERROR_ROLLBACK

When set to on, if a statement in a transaction block generates an error, the error is ignored and the transaction continues. When set to interactive, such errors are only ignored in interactive sessions, and not when reading script files. When set to off (the default), a statement in a transaction block that generates an error aborts the entire transaction. The error rollback mode works by issuing an implicit SAVEPOINT for you, just before each command that is in a transaction block, and then rolling back to the savepoint if the command fails.

ON_ERROR_STOP

By default, command processing continues after an error. When this variable is set to on, processing will instead stop immediately. In interactive mode, psql will return to the command prompt; otherwise, psql will exit, returning error code 3 to distinguish this case from fatal error conditions, which are reported using error code 1. In either case, any currently running scripts (the top-level script, if any, and any other scripts which it may have in invoked) will be terminated immediately. If the top-level command string contained multiple SQL commands, processing will stop with the current command.

PORT

The database server port to which you are currently connected. This is set every time you connect to a database (including program start-up), but can be changed or unset.

PROMPT1
PROMPT2
PROMPT3

These specify what the prompts psql issues should look like. See Prompting below.

QUIET

Setting this variable to on is equivalent to the command line option -q. It is probably not too useful in interactive mode.

ROW_COUNT

The number of rows returned or affected by the last SQL query, or 0 if the query failed or did not report a row count.

SERVER_VERSION_NAME
SERVER_VERSION_NUM

The server's version number as a string, for example 9.6.2, 10.1 or 11beta1, and in numeric form, for example 90602 or 100001. These are set every time you connect to a database (including program start-up), but can be changed or unset.

SHOW_CONTEXT

This variable can be set to the values never, errors, or always to control whether CONTEXT fields are displayed in messages from the server. The default is errors (meaning that context will be shown in error messages, but not in notice or warning messages). This setting has no effect when VERBOSITY is set to terse or sqlstate. (See also \errverbose, for use when you want a verbose version of the error you just got.)

SINGLELINE

Setting this variable to on is equivalent to the command line option -S.

SINGLESTEP

Setting this variable to on is equivalent to the command line option -s.

SQLSTATE

The error code (see Appendix A) associated with the last SQL query's failure, or 00000 if it succeeded.

USER

The database user you are currently connected as. This is set every time you connect to a database (including program start-up), but can be changed or unset.

VERBOSITY

This variable can be set to the values default, verbose, terse, or sqlstate to control the verbosity of error reports. (See also \errverbose, for use when you want a verbose version of the error you just got.)

VERSION
VERSION_NAME
VERSION_NUM

These variables are set at program start-up to reflect psql's version, respectively as a verbose string, a short string (e.g., 9.6.2, 10.1, or 11beta1), and a number (e.g., 90602 or 100001). They can be changed or unset.

SQL Interpolation

A key feature of psql variables is that you can substitute ("interpolate") them into regular SQL statements, as well as the arguments of meta-commands. Furthermore, psql provides facilities for ensuring that variable values used as SQL literals and identifiers are properly quoted. The syntax for interpolating a value without any quoting is to prepend the variable name with a colon (:). For example,

```
testdb=> \set foo 'my_table'
testdb=> SELECT * FROM :foo;
```

would query the table my_table. Note that this may be unsafe: the value of the variable is copied literally, so it can contain unbalanced quotes, or even backslash commands. You must make sure that it makes sense where you put it.

When a value is to be used as an SQL literal or identifier, it is safest to arrange for it to be quoted. To quote the value of a variable as an SQL literal, write a colon followed by the variable name in single quotes. To quote the value as an SQL identifier, write a colon followed by the variable name in double quotes. These constructs deal correctly with quotes and other special characters embedded within the variable value. The previous example would be more safely written this way:

```
testdb=> \set foo 'my_table'
testdb=> SELECT * FROM :"foo";
```

Variable interpolation will not be performed within quoted SQL literals and identifiers. Therefore, a construction such as ':foo' doesn't work to produce a quoted literal from a variable's value (and it would be unsafe if it did work, since it wouldn't correctly handle quotes embedded in the value).

One example use of this mechanism is to copy the contents of a file into a table column. First load the file into a variable and then interpolate the variable's value as a quoted string:

```
testdb=> \set content `cat my_file.txt`
testdb=> INSERT INTO my_table VALUES (:'content');
```

(Note that this still won't work if my_file.txt contains NUL bytes. psql does not support embedded NUL bytes in variable values.)

Since colons can legally appear in SQL commands, an apparent attempt at interpolation (that is, :name, :'name', or :"name") is not replaced unless the named variable is currently set. In any case, you can escape a colon with a backslash to protect it from substitution.

The `:{?name}` special syntax returns TRUE or FALSE depending on whether the variable exists or not, and is thus always substituted, unless the colon is backslash-escaped.

The colon syntax for variables is standard SQL for embedded query languages, such as ECPG. The colon syntaxes for array slices and type casts are Postgres Pro extensions, which can sometimes conflict with the standard usage. The colon-quote syntax for escaping a variable's value as an SQL literal or identifier is a psql extension.

Prompting

The prompts psql issues can be customized to your preference. The three variables `PROMPT1`, `PROMPT2`, and `PROMPT3` contain strings and special escape sequences that describe the appearance of the prompt. Prompt 1 is the normal prompt that is issued when psql requests a new command. Prompt 2 is issued when more input is expected during command entry, for example because the command was not terminated with a semicolon or a quote was not closed. Prompt 3 is issued when you are running an SQL `COPY FROM STDIN` command and you need to type in a row value on the terminal.

The value of the selected prompt variable is printed literally, except where a percent sign (`%`) is encountered. Depending on the next character, certain other text is substituted instead. Defined substitutions are:

`%M`

The full host name (with domain name) of the database server, or `[local]` if the connection is over a Unix domain socket, or `[local:/dir/name]`, if the Unix domain socket is not at the compiled in default location.

`%m`

The host name of the database server, truncated at the first dot, or `[local]` if the connection is over a Unix domain socket.

`%>`

The port number at which the database server is listening.

`%n`

The database session user name. (The expansion of this value might change during a database session as the result of the command `SET SESSION AUTHORIZATION`.)

`%/`

The name of the current database.

`%~`

Like `%/`, but the output is `~` (tilde) if the database is your default database.

`%#`

If the session user is a database superuser, then a `#`, otherwise a `>`. (The expansion of this value might change during a database session as the result of the command `SET SESSION AUTHORIZATION`.)

`%p`

The process ID of the backend currently connected to.

`%R`

In prompt 1 normally `=`, but `@` if the session is in an inactive branch of a conditional block, or `^` if in single-line mode, or `!` if the session is disconnected from the database (which can happen if `\connect` fails). In prompt 2 `%R` is replaced by a character that depends on why psql expects more input: `-` if the command simply wasn't terminated yet, but `*` if there is an unfinished `/* ... */` comment, a single quote if there is an unfinished quoted string, a double quote if there is an unfinished quoted

identifier, a dollar sign if there is an unfinished dollar-quoted string, or `(` if there is an unmatched left parenthesis. In prompt 3 `%R` doesn't produce anything.

`%x`

Transaction status: an empty string when not in a transaction block, or `*` when in a transaction block, or `!` when in a failed transaction block, or `?` when the transaction state is indeterminate (for example, because there is no connection).

`%l`

The line number inside the current statement, starting from `1`.

`%`*`digits`*

The character with the indicated octal code is substituted.

`%:`*`name`*`:`

The value of the psql variable *`name`*. See Variables, above, for details.

`` %``command` ``

The output of *`command`*, similar to ordinary "back-tick" substitution.

`%[ ... %]`

Prompts can contain terminal control characters which, for example, change the color, background, or style of the prompt text, or change the title of the terminal window. In order for the line editing features of Readline to work properly, these non-printing control characters must be designated as invisible by surrounding them with `%[` and `%]`. Multiple pairs of these can occur within the prompt. For example:

```
testdb=> \set PROMPT1 '%[%033[1;33;40m%]%n@%/%R%[%033[0m%]%# '
```

results in a boldfaced (`1;`) yellow-on-black (`33;40`) prompt on VT100-compatible, color-capable terminals.

`%w`

Whitespace of the same width as the most recent output of `PROMPT1`. This can be used as a `PROMPT2` setting, so that multi-line statements are aligned with the first line, but there is no visible secondary prompt.

To insert a percent sign into your prompt, write `%%`. The default prompts are `'%/%R%x%# '` for prompts 1 and 2, and `'>> '` for prompt 3.

> **Note**
>
> This feature was shamelessly plagiarized from tcsh.

Command-Line Editing

psql supports the Readline library for convenient line editing and retrieval. The command history is automatically saved when psql exits and is reloaded when psql starts up. Tab-completion is also supported, although the completion logic makes no claim to be an SQL parser. The queries generated by tab-completion can also interfere with other SQL commands, e.g., `SET TRANSACTION ISOLATION LEVEL`. If for some reason you do not like the tab completion, you can turn it off by putting this in a file named `.inputrc` in your home directory:

```
$if psql
set disable-completion on
$endif
```

(This is not a psql but a Readline feature. Read its documentation for further details.)

Environment

`COLUMNS`

If `\pset columns` is zero, controls the width for the `wrapped` format and width for determining if wide output requires the pager or should be switched to the vertical format in expanded auto mode.

`PGDATABASE`
`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters (see Section 36.15).

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

`PSQL_EDITOR`
`EDITOR`
`VISUAL`

Editor used by the `\e`, `\ef`, and `\ev` commands. These variables are examined in the order listed; the first that is set is used. If none of them is set, the default is to use `vi` on Unix systems or `notepad.exe` on Windows systems.

`PSQL_EDITOR_LINENUMBER_ARG`

When `\e`, `\ef`, or `\ev` is used with a line number argument, this variable specifies the command-line argument used to pass the starting line number to the user's editor. For editors such as Emacs or vi, this is a plus sign. Include a trailing space in the value of the variable if there needs to be space between the option name and the line number. Examples:

```
PSQL_EDITOR_LINENUMBER_ARG='+'
PSQL_EDITOR_LINENUMBER_ARG='--line '
```

The default is `+` on Unix systems (corresponding to the default editor `vi`, and useful for many other common editors); but there is no default on Windows systems.

`PSQL_HISTORY`

Alternative location for the command history file. Tilde (`~`) expansion is performed.

`PSQL_PAGER`
`PAGER`

If a query's results do not fit on the screen, they are piped through this command. Typical values are `more` or `less`. Use of the pager can be disabled by setting `PSQL_PAGER` or `PAGER` to an empty string, or by adjusting the pager-related options of the `\pset` command. These variables are examined in the order listed; the first that is set is used. If none of them is set, the default is to use `more` on most platforms, but `less` on Cygwin.

`PSQLRC`

Alternative location of the user's `.psqlrc` file. Tilde (`~`) expansion is performed.

`SHELL`

Command executed by the `\!` command.

`TMPDIR`

Directory for storing temporary files. The default is `/tmp`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Files

`psqlrc` and `~/.psqlrc`

Unless it is passed an `-X` option, psql attempts to read and execute commands from the system-wide startup file (`psqlrc`) and then the user's personal startup file (`~/.psqlrc`), after connecting to the database but before accepting normal commands. These files can be used to set up the client and/or the server to taste, typically with `\set` and `SET` commands.

The system-wide startup file is named `psqlrc` and is sought in the installation's "system configuration" directory, which is most reliably identified by running `pg_config --sysconfdir`. By default this directory will be `../etc/` relative to the directory containing the Postgres Pro executables. The name of this directory can be set explicitly via the `PGSYSCONFDIR` environment variable.

The user's personal startup file is named `.psqlrc` and is sought in the invoking user's home directory. On Windows, which lacks such a concept, the personal startup file is named `%APPDATA%\postgresql\psqlrc.conf`. The location of the user's startup file can be set explicitly via the `PSQLRC` environment variable.

Both the system-wide startup file and the user's personal startup file can be made psql-version-specific by appending a dash and the Postgres Pro major or minor release number to the file name, for example `~/.psqlrc-9.2` or `~/.psqlrc-9.2.5`. The most specific version-matching file will be read in preference to a non-version-specific file.

`.psql_history`

The command-line history is stored in the file `~/.psql_history`, or `%APPDATA%\postgresql\psql_history` on Windows.

The location of the history file can be set explicitly via the `HISTFILE` psql variable or the `PSQL_HISTORY` environment variable.

Notes

- psql works best with servers of the same or an older major version. Backslash commands are particularly likely to fail if the server is of a newer version than psql itself. However, backslash commands of the `\d` family should work with servers of versions back to 7.4, though not necessarily with servers newer than psql itself. The general functionality of running SQL commands and displaying query results should also work with servers of a newer major version, but this cannot be guaranteed in all cases.

  If you want to use psql to connect to several servers of different major versions, it is recommended that you use the newest version of psql. Alternatively, you can keep around a copy of psql from each major version and be sure to use the version that matches the respective server. But in practice, this additional complication should not be necessary.

- Before Postgres Pro 9.6, the `-c` option implied `-X` (`--no-psqlrc`); this is no longer the case.

- Before PostgreSQL 8.4, psql allowed the first argument of a single-letter backslash command to start directly after the command, without intervening whitespace. Now, some whitespace is required.

Notes for Windows Users

psql is built as a "console application". Since the Windows console windows use a different encoding than the rest of the system, you must take special care when using 8-bit characters within psql. If psql detects a problematic console code page, it will warn you at startup. To change the console code page, two things are necessary:

- Set the code page by entering **cmd.exe /c chcp 1252**. (1252 is a code page that is appropriate for German; replace it with your value.) If you are using Cygwin, you can put this command in `/etc/profile`.
- Set the console font to `Lucida Console`, because the raster font does not work with the ANSI code page.

By default, psql works in the UTF-8 encoding and uses Windows Unicode API for console output. The console code page must be set to 65001 to ensure the correct display of all characters supported by your Windows console font.

Postgres Pro Windows installer ships the `less.exe` pager with UTF-8 support and provides a shortcut that opens the console window with `Lucida Console` font and codepage 65001 settings. If you use a different pager, make sure it also supports UTF-8.

You can override the default psql encoding by setting the `PGCLIENTENCODING` environment variable.

Examples

The first example shows how to spread a command over several lines of input. Notice the changing prompt:

```
testdb=> CREATE TABLE my_table (
testdb(>  first integer not null default 0,
testdb(>  second text)
testdb-> ;
CREATE TABLE
```

Now look at the table definition again:

```
testdb=> \d my_table
              Table "public.my_table"
 Column |  Type   | Collation | Nullable | Default
--------+---------+-----------+----------+---------
 first  | integer |           | not null | 0
 second | text    |           |          |
```

Now we change the prompt to something more interesting:

```
testdb=> \set PROMPT1 '%n@%m %~%R%# '
peter@localhost testdb=>
```

Let's assume you have filled the table with data and want to take a look at it:

```
peter@localhost testdb=> SELECT * FROM my_table;
 first | second
-------+--------
     1 | one
     2 | two
     3 | three
     4 | four
(4 rows)
```

You can display tables in different ways by using the `\pset` command:

```
peter@localhost testdb=> \pset border 2
Border style is 2.
peter@localhost testdb=> SELECT * FROM my_table;
+-------+--------+
| first | second |
+-------+--------+
|     1 | one    |
|     2 | two    |
|     3 | three  |
```

```
|     4 | four   |
+-------+--------+
(4 rows)

peter@localhost testdb=> \pset border 0
Border style is 0.
peter@localhost testdb=> SELECT * FROM my_table;
first second
----- ------
    1 one
    2 two
    3 three
    4 four
(4 rows)

peter@localhost testdb=> \pset border 1
Border style is 1.
peter@localhost testdb=> \pset format csv
Output format is csv.
peter@localhost testdb=> \pset tuples_only
Tuples only is on.
peter@localhost testdb=> SELECT second, first FROM my_table;
one,1
two,2
three,3
four,4
peter@localhost testdb=> \pset format unaligned
Output format is unaligned.
peter@localhost testdb=> \pset fieldsep '\t'
Field separator is "    ".
peter@localhost testdb=> SELECT second, first FROM my_table;
one     1
two     2
three   3
four    4
```

Alternatively, use the short commands:

```
peter@localhost testdb=> \a \t \x
Output format is aligned.
Tuples only is off.
Expanded display is on.
peter@localhost testdb=> SELECT * FROM my_table;
-[ RECORD 1 ]-
first  | 1
second | one
-[ RECORD 2 ]-
first  | 2
second | two
-[ RECORD 3 ]-
first  | 3
second | three
-[ RECORD 4 ]-
first  | 4
second | four
```

Also, these output format options can be set for just one query by using `\g`:

```
peter@localhost testdb=> SELECT * FROM my_table
peter@localhost testdb-> \g (format=aligned tuples_only=off expanded=on)
```

```
-[ RECORD 1 ]-
first  | 1
second | one
-[ RECORD 2 ]-
first  | 2
second | two
-[ RECORD 3 ]-
first  | 3
second | three
-[ RECORD 4 ]-
first  | 4
second | four
```

Here is an example of using the `\df` command to find only functions with names matching `int*pl` and whose second argument is of type `bigint`:

```
testdb=> \df int*pl * bigint
                            List of functions
   Schema   |  Name   | Result data type | Argument data types | Type
------------+---------+------------------+---------------------+------
 pg_catalog | int28pl | bigint           | smallint, bigint    | func
 pg_catalog | int48pl | bigint           | integer, bigint     | func
 pg_catalog | int8pl  | bigint           | bigint, bigint      | func
(3 rows)
```

When suitable, query results can be shown in a crosstab representation with the `\crosstabview` command:

```
testdb=> SELECT first, second, first > 2 AS gt2 FROM my_table;
 first | second | gt2
-------+--------+-----
     1 | one    | f
     2 | two    | f
     3 | three  | t
     4 | four   | t
(4 rows)

testdb=> \crosstabview first second
 first | one | two | three | four
-------+-----+-----+-------+------
     1 | f   |     |       |
     2 |     | f   |       |
     3 |     |     | t     |
     4 |     |     |       | t
(4 rows)
```

This second example shows a multiplication table with rows sorted in reverse numerical order and columns with an independent, ascending numerical order.

```
testdb=> SELECT t1.first as "A", t2.first+100 AS "B", t1.first*(t2.first+100) as "AxB",
testdb(> row_number() over(order by t2.first) AS ord
testdb(> FROM my_table t1 CROSS JOIN my_table t2 ORDER BY 1 DESC
testdb(> \crosstabview "A" "B" "AxB" ord
 A | 101 | 102 | 103 | 104
---+-----+-----+-----+-----
 4 | 404 | 408 | 412 | 416
 3 | 303 | 306 | 309 | 312
 2 | 202 | 204 | 206 | 208
 1 | 101 | 102 | 103 | 104
(4 rows)
```

reindexdb

reindexdb — reindex a Postgres Pro database

Synopsis

`reindexdb` [*connection-option*...] [*option*...] [`-S` | `--schema` *schema*] ... [`-t` | `--table` *table*] ... [`-i` | `--index` *index*] ... [*dbname*]

`reindexdb` [*connection-option*...] [*option*...] `-a` | `--all`

`reindexdb` [*connection-option*...] [*option*...] `-s` | `--system` [*dbname*]

Description

reindexdb is a utility for rebuilding indexes in a Postgres Pro database.

reindexdb is a wrapper around the SQL command `REINDEX`. There is no effective difference between reindexing databases via this utility and via other methods for accessing the server.

Options

reindexdb accepts the following command-line arguments:

`-a`
`--all`

Reindex all databases.

`--concurrently`

Use the `CONCURRENTLY` option. See REINDEX, where all the caveats of this option are explained in detail.

`[-d]` *dbname*
`[--dbname=]`*dbname*

Specifies the name of the database to be reindexed, when `-a`/`--all` is not used. If this is not specified, the database name is read from the environment variable `PGDATABASE`. If that is not set, the user name specified for the connection is used. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options.

`-e`
`--echo`

Echo the commands that reindexdb generates and sends to the server.

`-i` *index*
`--index=`*index*

Recreate *index* only. Multiple indexes can be recreated by writing multiple `-i` switches.

`-j` *njobs*
`--jobs=`*njobs*

Execute the reindex commands in parallel by running *njobs* commands simultaneously. This option may reduce the processing time but it also increases the load on the database server.

reindexdb will open *njobs* connections to the database, so make sure your max_connections setting is high enough to accommodate all connections.

Note that this option is incompatible with the `--index` and `--system` options.

`-q`
`--quiet`

Do not display progress messages.

`-s`
`--system`

Reindex database's system catalogs only.

`-S` *schema*
`--schema=`*schema*

Reindex *schema* only. Multiple schemas can be reindexed by writing multiple `-S` switches.

`-t` *table*
`--table=`*table*

Reindex *table* only. Multiple tables can be reindexed by writing multiple `-t` switches.

`--tablespace=`*tablespace*

Specifies the tablespace where indexes are rebuilt. (This name is processed as a double-quoted identifier.)

`-v`
`--verbose`

Print detailed information during processing.

`-V`
`--version`

Print the reindexdb version and exit.

`-?`
`--help`

Show help about reindexdb command line arguments, and exit.

reindexdb also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force reindexdb to prompt for a password before connecting to a database.

This option is never essential, since reindexdb will automatically prompt for a password if the server demands password authentication. However, reindexdb will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--maintenance-db=`*dbname*

When the `-a`/`--all` is used, connect to this database to gather the list of databases to reindex. If not specified, the `postgres` database will be used, or if that does not exist, `template1` will be used. This can be a connection string. If so, connection string parameters will override any conflicting command line options. Also, connection string parameters other than the database name itself will be re-used when connecting to other databases.

Environment

`PGDATABASE`
`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

In case of difficulty, see REINDEX and psql for discussions of potential problems and error messages. The database server must be running at the targeted host. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Notes

reindexdb might need to connect several times to the Postgres Pro server, asking for a password each time. It is convenient to have a `~/.pgpass` file in such cases. See Section 36.16 for more information.

Examples

To reindex the database `test`:

```
$ reindexdb test
```

To reindex the table `foo` and the index `bar` in a database named `abcd`:

```
$ reindexdb --table=foo --index=bar abcd
```

See Also

REINDEX

vacuumdb

vacuumdb — garbage-collect and analyze a Postgres Pro database

Synopsis

`vacuumdb` [*connection-option*...] [*option*...] [`-t` | `--table` *table* [(*column* [,...])]] ... [*dbname*]

`vacuumdb` [*connection-option*...] [*option*...] `-a` | `--all`

Description

vacuumdb is a utility for cleaning a Postgres Pro database. vacuumdb will also generate internal statistics used by the Postgres Pro query optimizer.

vacuumdb is a wrapper around the SQL command `VACUUM`. There is no effective difference between vacuuming and analyzing databases via this utility and via other methods for accessing the server.

Options

vacuumdb accepts the following command-line arguments:

`-a`
`--all`

Vacuum all databases.

`[-d]` *dbname*
`[--dbname=]`*dbname*

Specifies the name of the database to be cleaned or analyzed, when `-a`/`--all` is not used. If this is not specified, the database name is read from the environment variable `PGDATABASE`. If that is not set, the user name specified for the connection is used. The *dbname* can be a connection string. If so, connection string parameters will override any conflicting command line options.

`--disable-page-skipping`

Disable skipping pages based on the contents of the visibility map.

> **Note**
>
> This option is only available for servers running Postgres Pro 9.6 and later.

`-e`
`--echo`

Echo the commands that vacuumdb generates and sends to the server.

`-f`
`--full`

Perform “full” vacuuming.

`-F`
`--freeze`

Aggressively “freeze” tuples.

`--force-index-cleanup`

Always remove index entries pointing to dead tuples.

> **Note**
>
> This option is only available for servers running PostgreSQL 12 and later.

`-j` *njobs*
`--jobs=`*njobs*

Execute the vacuum or analyze commands in parallel by running *njobs* commands simultaneously. This option may reduce the processing time but it also increases the load on the database server.

vacuumdb will open *njobs* connections to the database, so make sure your max_connections setting is high enough to accommodate all connections.

Note that using this mode together with the `-f` (`FULL`) option might cause deadlock failures if certain system catalogs are processed in parallel.

`--min-mxid-age` *mxid_age*

Only execute the vacuum or analyze commands on tables with a multixact ID age of at least *mxid_age*. This setting is useful for prioritizing tables to process to prevent multixact ID wraparound (see Section 24.1.5.1).

For the purposes of this option, the multixact ID age of a relation is the greatest of the ages of the main relation and its associated TOAST table, if one exists. Since the commands issued by vacuumdb will also process the TOAST table for the relation if necessary, it does not need to be considered separately.

> **Note**
>
> This option is only available for servers running Postgres Pro 9.6 and later.

`--min-xid-age` *xid_age*

Only execute the vacuum or analyze commands on tables with a transaction ID age of at least *xid_age*. This setting is useful for prioritizing tables to process to prevent transaction ID wraparound (see Section 24.1.5).

For the purposes of this option, the transaction ID age of a relation is the greatest of the ages of the main relation and its associated TOAST table, if one exists. Since the commands issued by vacuumdb will also process the TOAST table for the relation if necessary, it does not need to be considered separately.

> **Note**
>
> This option is only available for servers running Postgres Pro 9.6 and later.

`--no-index-cleanup`

Do not remove index entries pointing to dead tuples.

> **Note**
>
> This option is only available for servers running Postgres Pro 12 and later.

`--no-process-toast`

Skip the TOAST table associated with the table to vacuum, if any.

> **Note**
>
> This option is only available for servers running PostgreSQL 14 and later.

`--no-truncate`

Do not truncate empty pages at the end of the table.

> **Note**
>
> This option is only available for servers running PostgreSQL 12 and later.

`-P` *parallel_workers*
`--parallel=`*parallel_workers*

Specify the number of parallel workers for *parallel vacuum*. This allows the vacuum to leverage multiple CPUs to process indexes. See VACUUM.

> **Note**
>
> This option is only available for servers running PostgreSQL 13 and later.

`-q`
`--quiet`

Do not display progress messages.

`--skip-locked`

Skip relations that cannot be immediately locked for processing.

> **Note**
>
> This option is only available for servers running PostgreSQL 12 and later.

`-t` *table* `[ (`*column* `[,...]) ]`
`--table=`*table* `[ (`*column* `[,...]) ]`

Clean or analyze *table* only. Column names can be specified only in conjunction with the `--analyze` or `--analyze-only` options. Multiple tables can be vacuumed by writing multiple `-t` switches.

> **Tip**
>
> If you specify columns, you probably have to escape the parentheses from the shell. (See examples below.)

`-v`
`--verbose`

Print detailed information during processing.

`-V`
`--version`

Print the vacuumdb version and exit.

`-z`
`--analyze`

Also calculate statistics for use by the optimizer.

`-Z`
`--analyze-only`

Only calculate statistics for use by the optimizer (no vacuum).

`--analyze-in-stages`

Only calculate statistics for use by the optimizer (no vacuum), like `--analyze-only`. Run several (currently three) stages of analyze with different configuration settings, to produce usable statistics faster.

This option is useful to analyze a database that was newly populated from a restored dump or by `pg_upgrade`. This option will try to create some statistics as fast as possible, to make the database usable, and then produce full statistics in the subsequent stages.

`-?`
`--help`

Show help about vacuumdb command line arguments, and exit.

vacuumdb also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force vacuumdb to prompt for a password before connecting to a database.

This option is never essential, since vacuumdb will automatically prompt for a password if the server demands password authentication. However, vacuumdb will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

`--maintenance-db=`*dbname*

When the `-a`/`--all` is used, connect to this database to gather the list of databases to vacuum. If not specified, the `postgres` database will be used, or if that does not exist, `template1` will be used.

This can be a connection string. If so, connection string parameters will override any conflicting command line options. Also, connection string parameters other than the database name itself will be re-used when connecting to other databases.

Environment

`PGDATABASE`
`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Diagnostics

In case of difficulty, see VACUUM and psql for discussions of potential problems and error messages. The database server must be running at the targeted host. Also, any default connection settings and environment variables used by the libpq front-end library will apply.

Notes

vacuumdb might need to connect several times to the Postgres Pro server, asking for a password each time. It is convenient to have a `~/.pgpass` file in such cases. See Section 36.16 for more information.

Examples

To clean the database `test`:

```
$ vacuumdb test
```

To clean and analyze for the optimizer a database named `bigdb`:

```
$ vacuumdb --analyze bigdb
```

To clean a single table `foo` in a database named `xyzzy`, and analyze a single column `bar` of the table for the optimizer:

```
$ vacuumdb --analyze --verbose --table='foo(bar)' xyzzy
```

See Also

VACUUM

Postgres Pro Server Applications

This part contains reference information for Postgres Pro server applications and support utilities. These commands can only be run usefully on the host where the database server resides. Other utility programs are listed in Postgres Pro Client Applications.

initdb

initdb — create a new Postgres Pro database cluster

Synopsis

`initdb` [*option*...] [`--pgdata` | `-D`] *directory*

Description

`initdb` creates a new Postgres Pro database cluster. A database cluster is a collection of databases that are managed by a single server instance.

Creating a database cluster consists of creating the directories in which the database data will live, generating the shared catalog tables (tables that belong to the whole cluster rather than to any particular database), and creating the `template1` and `postgres` databases. When you later create a new database, everything in the `template1` database is copied. (Therefore, anything installed in `template1` is automatically copied into each database created later.) The `postgres` database is a default database meant for use by users, utilities and third party applications.

Although `initdb` will attempt to create the specified data directory, it might not have permission if the parent directory of the desired data directory is root-owned. To initialize in such a setup, create an empty data directory as root, then use `chown` to assign ownership of that directory to the database user account, then `su` to become the database user to run `initdb`.

`initdb` must be run as the user that will own the server process, because the server needs to have access to the files and directories that `initdb` creates. Since the server cannot be run as root, you must not run `initdb` as root either. (It will in fact refuse to do so.)

For security reasons the new cluster created by `initdb` will only be accessible by the cluster owner by default. The `--allow-group-access` option allows any user in the same group as the cluster owner to read files in the cluster. This is useful for performing backups as a non-privileged user.

`initdb` initializes the database cluster's default locale and character set encoding. The character set encoding, collation order (`LC_COLLATE`) and character set classes (`LC_CTYPE`, e.g., upper, lower, digit) can be set separately for a database when it is created. `initdb` determines those settings for the `template1` database, which will serve as the default for all other databases.

To alter the default collation order or character set classes, use the `--lc-collate` and `--lc-ctype` options. Collation orders other than `C` or `POSIX` also have a performance penalty. For these reasons it is important to choose the right locale when running `initdb`.

The remaining locale categories can be changed later when the server is started. You can also use `--locale` to set the default for all locale categories, including collation order and character set classes. All server locale values (`lc_*`) can be displayed via `SHOW ALL`. More details can be found in Section 23.1.

To alter the default encoding, use the `--encoding`. More details can be found in Section 23.3.

Options

`-A` *authmethod*
`--auth=`*authmethod*

This option specifies the default authentication method for local users used in `pg_hba.conf` (`host` and `local` lines). `initdb` will prepopulate `pg_hba.conf` entries using the specified authentication method for non-replication as well as replication connections.

Do not use `trust` unless you trust all local users on your system. `trust` is the default for ease of installation.

`--auth-host=`*authmethod*

This option specifies the authentication method for local users via TCP/IP connections used in `pg_hba.conf` (`host` lines).

`--auth-local=`*authmethod*

This option specifies the authentication method for local users via Unix-domain socket connections used in `pg_hba.conf` (`local` lines).

`-D` *directory*
`--pgdata=`*directory*

This option specifies the directory where the database cluster should be stored. This is the only information required by `initdb`, but you can avoid writing it by setting the `PGDATA` environment variable, which can be convenient since the database server (`postgres`) can find the database directory later by the same variable.

`-E` *encoding*
`--encoding=`*encoding*

Selects the encoding of the template database. This will also be the default encoding of any database you create later, unless you override it there. The default is derived from the locale, or `SQL_ASCII` if that does not work. The character sets supported by the Postgres Pro server are described in Section 23.3.1.

`-g`
`--allow-group-access`

Allows users in the same group as the cluster owner to read all cluster files created by `initdb`. This option is ignored on Windows as it does not support POSIX-style group permissions.

`-k`
`--data-checksums`

Use checksums on data pages to help detect corruption by the I/O system that would otherwise be silent. Enabling checksums may incur a noticeable performance penalty. If set, checksums are calculated for all objects, in all databases. All checksum failures will be reported in the `pg_stat_database` view. See Section 29.2 for details.

By default, Postgres Pro clusters are initialized with checksums enabled. To change this behavior, provide the `--no-data-checksums` option.

`--no-data-checksums`

Disable checksums on data pages.

By default, Postgres Pro clusters are initialized with checksums enabled.

`--locale=`*locale*`[@`*provider*`]`

Sets the default locale for the database cluster. If this option is not specified, the locale is inherited from the environment that `initdb` runs in. Locale support is described in Section 23.1.

Optionally, you can specify the provider of the default collation after the `@` symbol. Supported values are `icu` and `libc`. For details, see Section 23.2.2.

`--lc-collate=`*locale*`[@`*provider*`]`
`--lc-ctype=`*locale*
`--lc-messages=`*locale*
`--lc-monetary=`*locale*
`--lc-numeric=`*locale*
`--lc-time=`*locale*

Like `--locale`, but only sets the locale in the specified category.

`--no-locale`

Equivalent to `--locale=C`.

`-N`
`--no-sync`

By default, `initdb` will wait for all files to be written safely to disk. This option causes `initdb` to return without waiting, which is faster, but means that a subsequent operating system crash can leave the data directory corrupt. Generally, this option is useful for testing, but should not be used when creating a production installation.

`--no-instructions`

By default, `initdb` will write instructions for how to start the cluster at the end of its output. This option causes those instructions to be left out. This is primarily intended for use by tools that wrap `initdb` in platform-specific behavior, where those instructions are likely to be incorrect.

`--pwfile=`*`filename`*

Makes `initdb` read the database superuser's password from a file. The first line of the file is taken as the password.

`-S`
`--sync-only`

Safely write all database files to disk and exit. This does not perform any of the normal initdb operations.

`--no-tune`

By default, the use of pgpro_tune is enabled in `initdb`. Use this option to disable it.

`--tune=`*`options`*

Sets parameters for pgpro_tune. See their description for further information.

`-T` *`config`*
`--text-search-config=`*`config`*

Sets the default text search configuration. See default_text_search_config for further information.

`-U` *`username`*
`--username=`*`username`*

Selects the user name of the database superuser. This defaults to the name of the effective user running `initdb`. It is really not important what the superuser's name is, but one might choose to keep the customary name postgres, even if the operating system user's name is different.

`-W`
`--pwprompt`

Makes `initdb` prompt for a password to give the database superuser. If you don't plan on using password authentication, this is not important. Otherwise you won't be able to use password authentication until you have a password set up.

`-X` *`directory`*
`--waldir=`*`directory`*

This option specifies the directory where the write-ahead log should be stored.

`--wal-segsize=`*`size`*

Set the *WAL segment size*, in megabytes. This is the size of each individual file in the WAL log. The default size is 16 megabytes. The value must be a power of 2 between 1 and 1024 (megabytes). This option can only be set during initialization, and cannot be changed later.

It may be useful to adjust this size to control the granularity of WAL log shipping or archiving. Also, in databases with a high volume of WAL, the sheer number of WAL files per directory can become a performance and management problem. Increasing the WAL file size will reduce the number of WAL files.

Other, less commonly used, options are also available:

`-d`
`--debug`

Print debugging output from the bootstrap backend and a few other messages of lesser interest for the general public. The bootstrap backend is the program `initdb` uses to create the catalog tables. This option generates a tremendous amount of extremely boring output.

`--discard-caches`

Run the bootstrap backend with the `debug_discard_caches=1` option. This takes a very long time and is only of use for deep debugging.

`-L` *directory*

Specifies where `initdb` should find its input files to initialize the database cluster. This is normally not necessary. You will be told if you need to specify their location explicitly.

`-n`
`--no-clean`

By default, when `initdb` determines that an error prevented it from completely creating the database cluster, it removes any files it might have created before discovering that it cannot finish the job. This option inhibits tidying-up and is thus useful for debugging.

Other options for testing 64-bit XIDs:

`-m` *START_MX_ID*
`--multixact-id=`*START_MX_ID*

Specifies the initial multixact ID value in the decimal format for a new database instance to test database upgrades, default value is `0`.

`-o` *START_MX_OFFSET*
`--multixact-offset=`*START_MX_OFFSET*

Specifies the initial multixact offset value in the decimal format for a new database instance to test database upgrades, default value is `0`.

`-x` *START_XID*
`--xid=`*START_XID*

Specifies the initial XID value in the decimal format for a new database instance to test database upgrades, default value is `0`.

Other options:

`-V`
`--version`

Print the initdb version and exit.

`-?`
`--help`

Show help about initdb command line arguments, and exit.

Environment

`PGDATA`

Specifies the directory where the database cluster is to be stored; can be overridden using the `-D` option.

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

`PGPRO_TUNE`

Specifies whether to use pgpro_tune without modifying command-line options directly. If set to `disable`, this environment variable has the same effect as passing `--no-tune`, disabling the use of pgpro_tune. If set to any other value, and neither `--tune` nor `--no-tune` is explicitly specified on the command line, the behavior is the same as if `--tune` is specified with the value of `PGPRO_TUNE`.

`TZ`

Specifies the default time zone of the created database cluster. The value should be a full time zone name (see Section 8.5.3).

Notes

`initdb` can also be invoked via `pg_ctl initdb`.

See Also

pg_ctl, postgres

pg_archivecleanup

pg_archivecleanup — clean up Postgres Pro WAL archive files

Synopsis

`pg_archivecleanup` [*option*...] *archivelocation* *oldestkeptwalfile*

Description

pg_archivecleanup is designed to be used as an `archive_cleanup_command` to clean up WAL file archives when running as a standby server (see Section 26.2). pg_archivecleanup can also be used as a standalone program to clean WAL file archives.

To configure a standby server to use pg_archivecleanup, put this into its `postgresql.conf` configuration file:

```
archive_cleanup_command = 'pg_archivecleanup archivelocation %r'
```

where *archivelocation* is the directory from which WAL segment files should be removed.

When used within archive_cleanup_command, all WAL files logically preceding the value of the `%r` argument will be removed from *archivelocation*. This minimizes the number of files that need to be retained, while preserving crash-restart capability. Use of this parameter is appropriate if the *archivelocation* is a transient staging area for this particular standby server, but *not* when the *archivelocation* is intended as a long-term WAL archive area, or when multiple standby servers are recovering from the same archive location.

When used as a standalone program all WAL files logically preceding the *oldestkeptwalfile* will be removed from *archivelocation*. In this mode, if you specify a `.partial` or `.backup` file name, then only the file prefix will be used as the *oldestkeptwalfile*. This treatment of `.backup` file name allows you to remove all WAL files archived prior to a specific base backup without error. For example, the following example will remove all files older than WAL file name `000000010000003700000010`:

```
pg_archivecleanup -d archive 000000010000003700000010.00000020.backup

pg_archivecleanup:  keep WAL file "archive/000000010000003700000010" and later
pg_archivecleanup:  removing file "archive/00000001000000370000000F"
pg_archivecleanup:  removing file "archive/00000001000000370000000E"
```

pg_archivecleanup assumes that *archivelocation* is a directory readable and writable by the server-owning user.

Options

pg_archivecleanup accepts the following command-line arguments:

`-d`

Print lots of debug logging output on `stderr`.

`-n`

Print the names of the files that would have been removed on `stdout` (performs a dry run).

`-V`
`--version`

Print the pg_archivecleanup version and exit.

`-x` *extension*

Provide an extension that will be stripped from all file names before deciding if they should be deleted. This is typically useful for cleaning up archives that have been compressed during storage, and therefore have had an extension added by the compression program. For example: `-x .gz`.

`-?`
`--help`

Show help about pg_archivecleanup command line arguments, and exit.

Environment

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

pg_archivecleanup is designed to work with PostgreSQL 8.0 and later when used as a standalone utility, or with PostgreSQL 9.0 and later when used as an archive cleanup command.

pg_archivecleanup is written in C and has an easy-to-modify source code, with specifically designated sections to modify for your own needs

Examples

On Linux or Unix systems, you might use:

```
archive_cleanup_command = 'pg_archivecleanup -d /mnt/standby/archive %r 2>>cleanup.log'
```

where the archive directory is physically located on the standby server, so that the `archive_command` is accessing it across NFS, but the files are local to the standby. This will:

- produce debugging output in `cleanup.log`
- remove no-longer-needed files from the archive directory

pg_checksums

pg_checksums — enable, disable or check data checksums in a Postgres Pro database cluster

Synopsis

`pg_checksums` [*option*...] [[`-D` | `--pgdata`]*datadir*]

Description

pg_checksums checks, enables or disables data checksums in a Postgres Pro cluster. The server must be shut down cleanly before running pg_checksums. When verifying checksums, the exit status is zero if there are no checksum errors, and nonzero if at least one checksum failure is detected. When enabling or disabling checksums, the exit status is nonzero if the operation failed.

When verifying checksums, every file in the cluster is scanned. When enabling checksums, every file in the cluster is rewritten in-place. Disabling checksums only updates the file `pg_control`.

Options

The following command-line options are available:

`-D` *directory*
`--pgdata=`*directory*

Specifies the directory where the database cluster is stored.

`-c`
`--check`

Checks checksums. This is the default mode if nothing else is specified.

`-d`
`--disable`

Disables checksums.

`-e`
`--enable`

Enables checksums.

`-f` *filenode*
`--filenode=`*filenode*

Only validate checksums in the relation with filenode *filenode*.

`-N`
`--no-sync`

By default, `pg_checksums` will wait for all files to be written safely to disk. This option causes `pg_checksums` to return without waiting, which is faster, but means that a subsequent operating system crash can leave the updated data directory corrupt. Generally, this option is useful for testing but should not be used on a production installation. This option has no effect when using `--check`.

`-P`
`--progress`

Enable progress reporting. Turning this on will deliver a progress report while checking or enabling checksums.

`-v`
`--verbose`

Enable verbose output. Lists all checked files.

`-V`
`--version`

Print the pg_checksums version and exit.

`-?`
`--help`

Show help about pg_checksums command line arguments, and exit.

Environment

`PGDATA`

Specifies the directory where the database cluster is stored; can be overridden using the `-D` option.

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

Enabling checksums in a large cluster can potentially take a long time. During this operation, the cluster or other programs that write to the data directory must not be started or else data loss may occur.

When using a replication setup with tools which perform direct copies of relation file blocks (for example pg_rewind), enabling or disabling checksums can lead to page corruptions in the shape of incorrect checksums if the operation is not done consistently across all nodes. When enabling or disabling checksums in a replication setup, it is thus recommended to stop all the clusters before switching them all consistently. Destroying all standbys, performing the operation on the primary and finally recreating the standbys from scratch is also safe.

If pg_checksums is aborted or killed while enabling or disabling checksums, the cluster's data checksum configuration remains unchanged, and pg_checksums can be re-run to perform the same operation.

pg_controldata

pg_controldata — display control information of a Postgres Pro database cluster

Synopsis

`pg_controldata` [*option*] [[`-D` | `--pgdata`]*datadir*]

Description

`pg_controldata` prints information initialized during `initdb`, such as the catalog version. It also shows information about write-ahead logging and checkpoint processing. This information is cluster-wide, and not specific to any one database.

This utility can only be run by the user who initialized the cluster because it requires read access to the data directory. You can specify the data directory on the command line, or use the environment variable `PGDATA`. This utility supports the options `-V` and `--version`, which print the pg_controldata version and exit. It also supports options `-?` and `--help`, which output the supported arguments.

> **Note**
>
> It is recommended that you use pgpro_controldata instead since it can read control information of different versions of PostgreSQL or Postgres Pro database clusters, including newer versions.

Environment

`PGDATA`

Default data directory location

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

See Also

pgpro_controldata

pg_ctl

pg_ctl — initialize, start, stop, or control a Postgres Pro server

Synopsis

`pg_ctl init[db]` [`-D` *`datadir`*] [`-s`] [`-o` *`initdb-options`*]

`pg_ctl start` [`-D` *`datadir`*] [`-l` *`filename`*] [`-W`] [`-t` *`seconds`*] [`-s`] [`-o` *`options`*] [`-p` *`path`*] [`-c`]

`pg_ctl stop` [`-D` *`datadir`*] [`-m s[mart]` | `f[ast]` | `i[mmediate]`] [`-W`] [`-t` *`seconds`*] [`-s`]

`pg_ctl restart` [`-D` *`datadir`*] [`-m s[mart]` | `f[ast]` | `i[mmediate]`] [`-W`] [`-t` *`seconds`*] [`-s`] [`-o` *`options`*] [`-c`]

`pg_ctl reload` [`-D` *`datadir`*] [`-s`]

`pg_ctl status` [`-D` *`datadir`*]

`pg_ctl promote` [`-D` *`datadir`*] [`-W`] [`-t` *`seconds`*] [`-s`]

`pg_ctl logrotate` [`-D` *`datadir`*] [`-s`]

`pg_ctl kill` *`signal_name process_id`*

On Microsoft Windows, also:

`pg_ctl register` [`-D` *`datadir`*] [`-N` *`servicename`*] [`-U` *`username`*] [`-P` *`password`*] [`-S a[uto]` | `d[emand]`] [`-e` *`source`*] [`-W`] [`-t` *`seconds`*] [`-s`] [`-o` *`options`*]

`pg_ctl unregister` [`-N` *`servicename`*]

Description

pg_ctl is a utility for initializing a Postgres Pro database cluster, starting, stopping, or restarting the Postgres Pro database server (postgres), or displaying the status of a running server. Although the server can be started manually, pg_ctl encapsulates tasks such as redirecting log output and properly detaching from the terminal and process group. It also provides convenient options for controlled shutdown.

The `init` or `initdb` mode creates a new Postgres Pro database cluster, that is, a collection of databases that will be managed by a single server instance. This mode invokes the `initdb` command. See initdb for details.

`start` mode launches a new server. The server is started in the background, and its standard input is attached to `/dev/null` (or `nul` on Windows). On Unix-like systems, by default, the server's standard output and standard error are sent to pg_ctl's standard output (not standard error). The standard output of pg_ctl should then be redirected to a file or piped to another process such as a log rotating program like rotatelogs; otherwise `postgres` will write its output to the controlling terminal (from the background) and will not leave the shell's process group. On Windows, by default the server's standard output and standard error are sent to the terminal. These default behaviors can be changed by using `-l` to append the server's output to a log file. Use of either `-l` or output redirection is recommended.

`stop` mode shuts down the server that is running in the specified data directory. Three different shutdown methods can be selected with the `-m` option. “Smart” mode disallows new connections, then waits for all existing clients to disconnect and any online backup to finish. If the server is in hot standby, recovery and streaming replication will be terminated once all clients have disconnected. “Fast” mode (the default) does not wait for clients to disconnect and will terminate an online backup in progress. All

active transactions are rolled back and clients are forcibly disconnected, then the server is shut down. “Immediate” mode will abort all server processes immediately, without a clean shutdown. This choice will lead to a crash-recovery cycle during the next server start.

> **Note**
>
> When the built-in connection pooler is enabled and serves client sessions, the “Smart” shutdown is performed as “Fast”.

`restart` mode effectively executes a stop followed by a start. This allows changing the `postgres` command-line options, or changing configuration-file options that cannot be changed without restarting the server. If relative paths were used on the command line during server start, `restart` might fail unless pg_ctl is executed in the same current directory as it was during server start.

`reload` mode simply sends the `postgres` server process a SIGHUP signal, causing it to reread its configuration files (`postgresql.conf`, `pg_hba.conf`, etc.). This allows changing configuration-file options that do not require a full server restart to take effect.

`status` mode checks whether a server is running in the specified data directory. If it is, the server's PID and the command line options that were used to invoke it are displayed. If the server is not running, pg_ctl returns an exit status of 3. If an accessible data directory is not specified, pg_ctl returns an exit status of 4.

`promote` mode commands the standby server that is running in the specified data directory to end standby mode and begin read-write operations.

`logrotate` mode rotates the server log file. For details on how to use this mode with external log rotation tools, see Section 24.3.

`kill` mode sends a signal to a specified process. This is primarily valuable on Microsoft Windows which does not have a built-in kill command. Use `--help` to see a list of supported signal names.

`register` mode registers the Postgres Pro server as a system service on Microsoft Windows. The `-S` option allows selection of service start type, either “auto” (start service automatically on system startup) or “demand” (start service on demand).

`unregister` mode unregisters a system service on Microsoft Windows. This undoes the effects of the `register` command.

Options

`-c`
`--core-files`

Attempt to allow server crashes to produce core files, on platforms where this is possible, by lifting any soft resource limit placed on core files. This is useful in debugging or diagnosing problems by allowing a stack trace to be obtained from a failed server process.

`-D` *`datadir`*
`--pgdata=`*`datadir`*

Specifies the file system location of the database configuration files. If this option is omitted, the environment variable `PGDATA` is used.

`-l` *`filename`*
`--log=`*`filename`*

Append the server log output to *`filename`*. If the file does not exist, it is created. The umask is set to 077, so access to the log file is disallowed to other users by default.

`-m` *mode*
`--mode=`*mode*

Specifies the shutdown mode. *mode* can be `smart`, `fast`, or `immediate`, or the first letter of one of these three. If this option is omitted, `fast` is the default.

`-o` *options*
`--options=`*options*

Specifies options to be passed directly to the `postgres` command. `-o` can be specified multiple times, with all the given options being passed through.

The *options* should usually be surrounded by single or double quotes to ensure that they are passed through as a group.

`-o` *initdb-options*
`--options=`*initdb-options*

Specifies options to be passed directly to the `initdb` command. `-o` can be specified multiple times, with all the given options being passed through.

The *initdb-options* should usually be surrounded by single or double quotes to ensure that they are passed through as a group.

`-p` *path*

Specifies the location of the `postgres` executable. By default the `postgres` executable is taken from the same directory as `pg_ctl`, or failing that, the hard-wired installation directory. It is not necessary to use this option unless you are doing something unusual and get errors that the `postgres` executable was not found.

In `init` mode, this option analogously specifies the location of the `initdb` executable.

`-s`
`--silent`

Print only errors, no informational messages.

`-t` *seconds*
`--timeout=`*seconds*

Specifies the maximum number of seconds to wait when waiting for an operation to complete (see option `-w`). Defaults to the value of the `PGCTLTIMEOUT` environment variable or, if not set, to 60 seconds.

`-V`
`--version`

Print the pg_ctl version and exit.

`-w`
`--wait`

Wait for the operation to complete. This is supported for the modes `start`, `stop`, `restart`, `promote`, and `register`, and is the default for those modes.

When waiting, `pg_ctl` repeatedly checks the server's PID file, sleeping for a short amount of time between checks. Startup is considered complete when the PID file indicates that the server is ready to accept connections. Shutdown is considered complete when the server removes the PID file. `pg_ctl` returns an exit code based on the success of the startup or shutdown.

If the operation does not complete within the timeout (see option `-t`), then `pg_ctl` exits with a nonzero exit status. But note that the operation might continue in the background and eventually succeed.

`-W`
`--no-wait`

Do not wait for the operation to complete. This is the opposite of the option `-w`.

If waiting is disabled, the requested action is triggered, but there is no feedback about its success. In that case, the server log file or an external monitoring system would have to be used to check the progress and success of the operation.

In prior releases of Postgres Pro, this was the default except for the `stop` mode.

`-?`
`--help`

Show help about pg_ctl command line arguments, and exit.

If an option is specified that is valid, but not relevant to the selected operating mode, pg_ctl ignores it.

Options for Windows

`-e` *source*

Name of the event source for pg_ctl to use for logging to the event log when running as a Windows service. The default is `Postgres Pro`. Note that this only controls messages sent from pg_ctl itself; once started, the server will use the event source specified by its event_source parameter. Should the server fail very early in startup, before that parameter has been set, it might also log using the default event source name `Postgres Pro`.

`-N` *servicename*

Name of the system service to register. This name will be used as both the service name and the display name. The default is `Postgres Pro`.

`-P` *password*

Password for the user to run the service as.

`-S` *start-type*

Start type of the system service. *start-type* can be `auto`, or `demand`, or the first letter of one of these two. If this option is omitted, `auto` is the default.

`-U` *username*

User name for the user to run the service as. For domain users, use the format `DOMAIN\username`.

Environment

`PGCTLTIMEOUT`

Default limit on the number of seconds to wait when waiting for startup or shutdown to complete. If not set, the default is 60 seconds.

`PGDATA`

Default data directory location.

Most `pg_ctl` modes require knowing the data directory location; therefore, the `-D` option is required unless `PGDATA` is set.

For additional variables that affect the server, see postgres.

Files

`postmaster.pid`

pg_ctl examines this file in the data directory to determine whether the server is currently running.

`postmaster.opts`

If this file exists in the data directory, pg_ctl (in `restart` mode) will pass the contents of the file as options to postgres, unless overridden by the `-o` option. The contents of this file are also displayed in `status` mode.

Examples

Starting the Server

To start the server, waiting until the server is accepting connections:

```
$ pg_ctl start
```

To start the server using port 5433, and running without `fsync`, use:

```
$ pg_ctl -o "-F -p 5433" start
```

Stopping the Server

To stop the server, use:

```
$ pg_ctl stop
```

The `-m` option allows control over *how* the server shuts down:

```
$ pg_ctl stop -m smart
```

Restarting the Server

Restarting the server is almost equivalent to stopping the server and starting it again, except that by default, `pg_ctl` saves and reuses the command line options that were passed to the previously-running instance. To restart the server using the same options as before, use:

```
$ pg_ctl restart
```

But if `-o` is specified, that replaces any previous options. To restart using port 5433, disabling `fsync` upon restart:

```
$ pg_ctl -o "-F -p 5433" restart
```

Showing the Server Status

Here is sample status output from pg_ctl:

```
$ pg_ctl status

pg_ctl: server is running (PID: 13718)
/usr/local/pgsql/bin/postgres "-D" "/usr/local/pgsql/data" "-p" "5433" "-B" "128"
```

The second line is the command that would be invoked in restart mode.

See Also

initdb, postgres

pgpro_tune

pgpro_tune — a command-line tool for automatic tuning

Synopsis

`pgpro_tune` [*option*...] [`-D` | `--pgdata`] *directory preset_name*

Description

The pgpro_tune utility is a command-line tool for automatic tuning. Optimal values for different configuration parameters of Postgres Pro depend on the hardware configuration. The pgpro_tune utility collects information about the system and transforms it into a set of parameters written into the configuration file.

Usage

The use of pgpro_tune is enabled in `initdb` by default. There are two `initdb` options for this tool: `--no-tune` disables its usage, `--tune=OPTIONS` allows passing additional options for the pgpro_tune run.

First pgpro_tune runs the default preset. Additional presets may be provided by using `-P` or `--preset=NAME` option, or specifying the preset name as the last command-line argument. To disable the default preset, use the `--no-default` option.

Additional options may be passed via `-O` or `--options=OPTIONS` parameter for any preset, but for the default preset `--default-options=OPTIONS` should be used.

Additional environment variables can be set for presets with the `--set NAME=VALUE` parameter. These values will be the same both for the default preset and all custom presets.

By default, the presets are placed in the `share` directory, but you can specify their location manually in the `--preset-dir=NAME` parameter.

By default, pgpro_tune works with the `postgresql.conf` configuration file located in the data directory. The data directory can be specified with `-D` or `--pgdata=DATADIR`, or provided with environment variable `PGDATA`. When runing pgpro_tune from `initdb`, the tool will use the data directory of `initdb`.

Configuration file can also be specified with `--config-file=FILENAME`.

The pgpro_tune tool writes its changes into a separate block at the end of the configuration file, which is commented as added by pgpro_tune. For details, see the example of the preset.

Options

`--config-file=`*filename*

Specifies the main configuration file name.

`-D` *datadir*
`--pgdata=`*datadir*

Specifies the directory where the database cluster should be stored.

`--default-options=`*options*

Specifies parameters for the default preset.

`--no-default`

Disables the default preset. Note that in this case another preset must be specified anyway either with the `-P` option or as the last parameter with the preset name.

`-O` *preset-options*
`--options=`*preset-options*

Specifies options to be passed directly to the preset that was previously specified in the `-P` parameter or to the preset indicated as the last command-line parameter, if `-P` was not used.

`-P` *name*
`--preset=`*name*

Specifies the preset name. If several names are indicated, presets are executed in turn, taking into account the output of the previous preset.

> **Note**
>
> The preset name may be specified either with this option or as the last parameter. Using both will cause an error.

`--preset-dir=`*name*

Specifies the directory containing presets. By default, presets are located in the `share` directory.

`--set` *name*=*value*

Sets the environment variable for presets.

`--show`

Shows all available presets from the directory specified in the `--preset-dir` option, if it is set, or from the default directory otherwise.

`-V`
`--version`

Print the pgpro_tune version and exit.

`-?`
`--help`

Show help about pgpro_tune command line arguments, and exit.

Environment variables

pgpro_tune sets the following environment variables before running presets.

- `EDITION` — the Postgres Pro edition.
- `ENABLE_CRASH_INFO` — if set, Postgres Pro was built with the `--enable-crash-info` option.
- `ENABLE_NLS` — if set, Postgres Pro was built with the `--enable-nls` option.
- `ENABLE_PGPRO_TUNE` — if set, Postgres Pro was built with the `--enable-pgpro-tune` option.
- `MEMMB` — the RAM size in megabytes.
- `MVER` — Postgres Pro major version.
- `NCPU` — the number of CPUs.
- `USE_BONJOUR` — if set, Postgres Pro was built with the `--with-bonjour` option.
- `USE_BSD_AUTH` — if set, Postgres Pro was built with the `--with-bsd-auth` option.
- `USE_ICU` — if set, Postgres Pro was built the `--with-icu` option.
- `USE_LDAP` — if set, Postgres Pro was built with the `--with-ldap` option.
- `USE_LIBUNWIND` — if set, Postgres Pro was built with the `--with-libunwind` option.

- USE_LIBXML — if set, Postgres Pro was built with the --with-libxml option.
- USE_LIBXSLT — if set, Postgres Pro was built with the --with-libxslt option.
- USE_LLVM — if set, Postgres Pro was built with the --with-llvm option.
- USE_LZ4 — if set, Postgres Pro was built with the --with-lz4 option.
- USE_OPENSSL — if set, Postgres Pro was built with the --with-openssl option.
- USE_PAM — if set, Postgres Pro was built with the --with-pam option.
- USE_SYSTEMD — if set, Postgres Pro was built with the --with-systemd option.
- USE_ZSTD — if set, Postgres Pro was built with the --with-zstd option.

Writing presets

A preset is an executable, usually a shell script, that transforms the information passed through environment variables into the set of configuration parameters.

The expected output of the preset is the set of specifically formatted lines. The first non-whitespace character is the indicator of the line content interpretation for pgpro_tune. The indicator should be one of the following:

- # for the comment action, the rest of the output line will be written into the configuration file after '#'.
- = for the replace action, the rest of the output line should contain a pair of parameters NAME and VALUE (both NAME=VALUE and NAME VALUE are acceptable). Line NAME = VALUE will be written into the configuration file. The text after VALUE will be added as a comment.
- =+ or += for the add action, the rest of the output line should contain a pair of parameters NAME and VALUE. VALUE will be added to the previous effective value of the parameter NAME at the back (=+) or at the front (+=). If there is no effective value, the ADD action works like the replace action. The text after VALUE will be added as a comment.
- -= for the withdraw action, the rest of the output line should contain a pair of parameters NAME and VALUE. If the NAME parameter has the effective value containing VALUE, it will be removed and the rest of the effective value will remain the same. The text after VALUE will be added as a comment. If there is no effective value, nothing happens.

Example of the preset

Suppose you have the following configuration file called test.conf:

```
work_mem = 4MB # Default value
shared_preload_libraries = 'plantuner'
search_path = '"$user",wrong_schema,public'
```

And the following preset called test.tune:

```
echo "# Adding new configuration parameters."
#Replace configuration parameter value by a new one
echo "work_mem = 8MB"
#Append to the start of existing value
echo "shared_preload_libraries += pg_stat_statements"
#Append to the end of existing value
echo "shared_preload_libraries =+ pg_prewarm"
#Withdraw from existing value
echo "search_path -= 'wrong_schema'"
```

Run the following command to use this preset:

```
pgpro_tune --config-file=/path/to/test.conf -P/path/to/test.tune --no-default
```

This command will result in the following changes of the configuration file:

```
#------------------------------------------------------------------------------
# The following settings were added by pgpro_tune.
# pgpro_tune was run with the following options:
# --no-default --config-file=/path/to/test/conf -P/path/to/test/tune --no-default
# At YYYY-MM-DD HH:MM:SS
#------------------------------------------------------------------------------
# Adding new configuration parameters.
work_mem = 8MB
shared_preload_libraries = 'pg_stat_statements, plantuner'
shared_preload_libraries = 'pg_stat_statements, plantuner, pg_prewarm'
search_path = '"$user", public'
#------------------------------------------------------------------------------
# End of settings added by pgpro_tune at YYYY-MM-DD HH-MM-SS
#------------------------------------------------------------------------------
```

pg_resetwal

pg_resetwal — reset the write-ahead log and other control information of a Postgres Pro database cluster

Synopsis

`pg_resetwal` [`-f` | `--force`] [`-n` | `--dry-run`] [*option*...] [`-D` | `--pgdata`]*datadir*

Description

`pg_resetwal` clears the write-ahead log (WAL) and optionally resets some other control information stored in the `pg_control` file. This function is sometimes needed if these files have become corrupted. It should be used only as a last resort, when the server will not start due to such corruption.

After running this command, it should be possible to start the server, but bear in mind that the database might contain inconsistent data due to partially-committed transactions. You should immediately dump your data, run `initdb`, and restore. After restore, check for inconsistencies and repair as needed.

This utility can only be run by the user who installed the server, because it requires read/write access to the data directory. For safety reasons, you must specify the data directory on the command line. `pg_resetwal` does not use the environment variable `PGDATA`.

If `pg_resetwal` complains that it cannot determine valid data for `pg_control`, you can force it to proceed anyway by specifying the `-f` (force) option. In this case plausible values will be substituted for the missing data. Most of the fields can be expected to match, but manual assistance might be needed for the next OID, next transaction ID, next multitransaction ID and offset, and WAL starting location fields. These fields can be set using the options discussed below. If you are not able to determine correct values for all these fields, `-f` can still be used, but the recovered database must be treated with even more suspicion than usual: an immediate dump and restore is imperative. *Do not* execute any data-modifying operations in the database before you dump, as any such action is likely to make the corruption worse.

Options

`-f`
`--force`

Force `pg_resetwal` to proceed even if it cannot determine valid data for `pg_control`, as explained above.

`-n`
`--dry-run`

The `-n`/`--dry-run` option instructs `pg_resetwal` to print the values reconstructed from `pg_control` and values about to be changed, and then exit without modifying anything. This is mainly a debugging tool, but can be useful as a sanity check before allowing `pg_resetwal` to proceed for real.

`-V`
`--version`

Display version information, then exit.

`-?`
`--help`

Show help, then exit.

The following options are only needed when `pg_resetwal` is unable to determine appropriate values by reading `pg_control`. Safe values can be determined as described below. For values that take numeric arguments, hexadecimal values can be specified by using the prefix `0x`.

`-c` *xid*,*xid*
`--commit-timestamp-ids=`*xid*,*xid*

Manually set the oldest and newest transaction IDs for which the commit time can be retrieved.

A safe value for the oldest transaction ID for which the commit time can be retrieved (first part) can be determined by looking for the numerically smallest file name in the directory `pg_commit_ts` under the data directory. Conversely, a safe value for the newest transaction ID for which the commit time can be retrieved (second part) can be determined by looking for the numerically greatest file name in the same directory. The file names are in hexadecimal.

`-l` *walfile*
`--next-wal-file=`*walfile*

Manually set the WAL starting location by specifying the name of the next WAL segment file.

The name of next WAL segment file should be larger than any WAL segment file name currently existing in the directory `pg_wal` under the data directory. These names are also in hexadecimal and have three parts. The first part is the "timeline ID" and should usually be kept the same. For example, if `000000010000000320000004A` is the largest entry in `pg_wal`, use `-l 000000010000000320000004B` or higher.

Note that when using nondefault WAL segment sizes, the numbers in the WAL file names are different from the LSNs that are reported by system functions and system views. This option takes a WAL file name, not an LSN.

> **Note**
>
> `pg_resetwal` itself looks at the files in `pg_wal` and chooses a default `-l` setting beyond the last existing file name. Therefore, manual adjustment of `-l` should only be needed if you are aware of WAL segment files that are not currently present in `pg_wal`, such as entries in an offline archive; or if the contents of `pg_wal` have been lost entirely.

`-m` *mxid*,*mxid*
`--multixact-ids=`*mxid*,*mxid*

Manually set the next and oldest multitransaction ID.

A safe value for the next multitransaction ID (first part) can be determined by looking for the numerically largest file name in the directory `pg_multixact/offsets` under the data directory, adding one, and then multiplying by 65536 (0x10000). Conversely, a safe value for the oldest multitransaction ID (second part of `-m`) can be determined by looking for the numerically smallest file name in the same directory and multiplying by 65536. The file names are in hexadecimal, so the easiest way to do this is to specify the option value in hexadecimal and append four zeroes.

`-o` *oid*
`--next-oid=`*oid*

Manually set the next OID.

There is no comparably easy way to determine a next OID that's beyond the largest one in the database, but fortunately it is not critical to get the next-OID setting right.

`-O` *mxoff*
`--multixact-offset=`*mxoff*

Manually set the next multitransaction offset.

A safe value can be determined by looking for the numerically largest file name in the directory `pg_multixact/members` under the data directory, adding one, and then multiplying by 52352

(0xCC80). The file names are in hexadecimal. There is no simple recipe such as the ones for other options of appending zeroes.

`--wal-segsize=`*wal_segment_size*

Set the new WAL segment size, in megabytes. The value must be set to a power of 2 between 1 and 1024 (megabytes). See the same option of initdb for more information.

> **Note**
>
> While `pg_resetwal` will set the WAL starting address beyond the latest existing WAL segment file, some segment size changes can cause previous WAL file names to be reused. It is recommended to use `-l` together with this option to manually set the WAL starting address if WAL file name overlap will cause problems with your archiving strategy.

`-u` *xid*
`--oldest-transaction-id=`*xid*

Manually set the oldest unfrozen transaction ID.

A safe value can be determined by looking for the numerically smallest file name in the directory `pg_xact` under the data directory and then multiplying by 1048576 (0x100000). Note that the file names are in hexadecimal. It is usually easiest to specify the option value in hexadecimal too. For example, if `0007` is the smallest entry in `pg_xact`, `-u 0x700000` will work (five trailing zeroes provide the proper multiplier).

`-x` *xid*
`--next-transaction-id=`*xid*

Manually set the next transaction ID.

A safe value can be determined by looking for the numerically largest file name in the directory `pg_xact` under the data directory, adding one, and then multiplying by 1048576 (0x100000). Note that the file names are in hexadecimal. It is usually easiest to specify the option value in hexadecimal too. For example, if `0011` is the largest entry in `pg_xact`, `-x 0x1200000` will work (five trailing zeroes provide the proper multiplier).

Environment

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

This command must not be used when the server is running. `pg_resetwal` will refuse to start up if it finds a server lock file in the data directory. If the server crashed then a lock file might have been left behind; in that case you can remove the lock file to allow `pg_resetwal` to run. But before you do so, make doubly certain that there is no server process still alive.

`pg_resetwal` works only with servers of the same major version.

See Also

pg_controldata

pg_rewind

pg_rewind — synchronize a Postgres Pro data directory with another data directory that was forked from it

Synopsis

`pg_rewind` [*option*...] { `-D` | `--target-pgdata` } *directory* { `--source-pgdata=`*directory* | `--source-server=`*connstr* }

Description

pg_rewind is a tool for synchronizing a Postgres Pro cluster with another copy of the same cluster, after the clusters' timelines have diverged. A typical scenario is to bring an old primary server back online after failover as a standby that follows the new primary.

After a successful rewind, the state of the target data directory is analogous to a base backup of the source data directory. Unlike taking a new base backup or using a tool like rsync, pg_rewind does not require comparing or copying unchanged relation blocks in the cluster. Only changed blocks from existing relation files are copied; all other files, including new relation files, configuration files, and WAL segments, are copied in full. As such the rewind operation is significantly faster than other approaches when the database is large and only a small fraction of blocks differ between the clusters.

pg_rewind examines the timeline histories of the source and target clusters to determine the point where they diverged, and expects to find WAL in the target cluster's `pg_wal` directory reaching all the way back to the point of divergence. The point of divergence can be found either on the target timeline, the source timeline, or their common ancestor. In the typical failover scenario where the target cluster was shut down soon after the divergence, this is not a problem, but if the target cluster ran for a long time after the divergence, its old WAL files might no longer be present. In this case, you can manually copy them from the WAL archive to the `pg_wal` directory, or run pg_rewind with the `-c` option to automatically retrieve them from the WAL archive. The use of pg_rewind is not limited to failover, e.g., a standby server can be promoted, run some write transactions, and then rewound to become a standby again.

After running pg_rewind, WAL replay needs to complete for the data directory to be in a consistent state. When the target server is started again it will enter archive recovery and replay all WAL generated in the source server from the last checkpoint before the point of divergence. If some of the WAL was no longer available in the source server when pg_rewind was run, and therefore could not be copied by the pg_rewind session, it must be made available when the target server is started. This can be done by creating a `recovery.signal` file in the target data directory and by configuring a suitable restore_command in `postgresql.conf`.

pg_rewind requires that the target server either has the wal_log_hints option enabled in `postgresql.conf` or data checksums enabled when the cluster was initialized with initdb. While `wal_log_hints` is currently off by default, the checksums are enabled. full_page_writes must also be set to `on`, and it is enabled by default.

Warning

If pg_rewind fails while processing, then the data folder of the target is likely not in a state that can be recovered. In such a case, taking a new fresh backup is recommended.

As pg_rewind copies configuration files entirely from the source, it may be required to correct the configuration used for recovery before restarting the target server, especially if the target is reintroduced as a standby of the source. If you restart the server after the rewind operation has finished but without configuring recovery, the target may again diverge from the primary.

pg_rewind will fail immediately if it finds files it cannot write directly to. This can happen for example when the source and the target server use the same file mapping for read-only SSL keys

and certificates. If such files are present on the target server it is recommended to remove them before running pg_rewind. After doing the rewind, some of those files may have been copied from the source, in which case it may be necessary to remove the data copied and restore back the set of links used before the rewind.

Options

pg_rewind accepts the following command-line arguments:

`-D` *directory*
`--target-pgdata=`*directory*

This option specifies the target data directory that is synchronized with the source. The target server must be shut down cleanly before running pg_rewind

`--source-pgdata=`*directory*

Specifies the file system path to the data directory of the source server to synchronize the target with. This option requires the source server to be cleanly shut down.

`--source-server=`*connstr*

Specifies a libpq connection string to connect to the source Postgres Pro server to synchronize the target with. The connection must be a normal (non-replication) connection with a role having sufficient permissions to execute the functions used by pg_rewind on the source server (see Notes section for details) or a superuser role. This option requires the source server to be running and accepting connections.

`-R`
`--write-recovery-conf`

Create `standby.signal` and append connection settings to `postgresql.auto.conf` in the output directory. `--source-server` is mandatory with this option.

`-n`
`--dry-run`

Do everything except actually modifying the target directory.

`-N`
`--no-sync`

By default, `pg_rewind` will wait for all files to be written safely to disk. This option causes `pg_rewind` to return without waiting, which is faster, but means that a subsequent operating system crash can leave the data directory corrupt. Generally, this option is useful for testing but should not be used on a production installation.

`-P`
`--progress`

Enables progress reporting. Turning this on will deliver an approximate progress report while copying data from the source cluster.

`-c`
`--restore-target-wal`

Use `restore_command` defined in the target cluster configuration to retrieve WAL files from the WAL archive if these files are no longer available in the `pg_wal` directory.

`--debug`

Print verbose debugging output that is mostly useful for developers debugging pg_rewind.

`--no-ensure-shutdown`

pg_rewind requires that the target server is cleanly shut down before rewinding. By default, if the target server is not shut down cleanly, pg_rewind starts the target server in single-user mode to complete crash recovery first, and stops it. By passing this option, pg_rewind skips this and errors out immediately if the server is not cleanly shut down. Users are expected to handle the situation themselves in that case.

`-V`
`--version`

Display version information, then exit.

`-?`
`--help`

Show help, then exit.

Environment

When `--source-server` option is used, pg_rewind also uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

When executing pg_rewind using an online cluster as source, a role having sufficient permissions to execute the functions used by pg_rewind on the source cluster can be used instead of a superuser. Here is how to create such a role, named `rewind_user` here:

```
CREATE USER rewind_user LOGIN;
GRANT EXECUTE ON function pg_catalog.pg_ls_dir(text, boolean, boolean) TO rewind_user;
GRANT EXECUTE ON function pg_catalog.pg_stat_file(text, boolean) TO rewind_user;
GRANT EXECUTE ON function pg_catalog.pg_read_binary_file(text) TO rewind_user;
GRANT EXECUTE ON function pg_catalog.pg_read_binary_file(text, bigint, bigint, boolean)
 TO rewind_user;
```

When executing pg_rewind using an online cluster as source which has been recently promoted, it is necessary to execute a `CHECKPOINT` after promotion such that its control file reflects up-to-date timeline information, which is used by pg_rewind to check if the target cluster can be rewound using the designated source cluster.

How It Works

The basic idea is to copy all file system-level changes from the source cluster to the target cluster:

1. Scan the WAL log of the target cluster, starting from the last checkpoint before the point where the source cluster's timeline history forked off from the target cluster. For each WAL record, record each data block that was touched. This yields a list of all the data blocks that were changed in the target cluster, after the source cluster forked off. If some of the WAL files are no longer available, try re-running pg_rewind with the `-c` option to search for the missing files in the WAL archive.
2. Copy all those changed blocks from the source cluster to the target cluster, either using direct file system access (`--source-pgdata`) or SQL (`--source-server`). Relation files are now in a state equivalent to the moment of the last completed checkpoint prior to the point at which the WAL timelines of the source and target diverged plus the current state on the source of any blocks changed on the target after that divergence.
3. Copy all other files, including new relation files, WAL segments, `pg_xact`, and configuration files from the source cluster to the target cluster. Similarly to base backups, the contents of the directories `pg_dynshmem/`, `pg_notify/`, `pg_replslot/`, `pg_serial/`, `pg_snapshots/`, `pg_stat_tmp/`, and

pg_subtrans/ are omitted from the data copied from the source cluster. The files backup_label, tablespace_map, pg_internal.init, postmaster.opts, and postmaster.pid, as well as any file or directory beginning with pgsql_tmp, are omitted.

4. Create a backup_label file to begin WAL replay at the checkpoint created at failover and configure the pg_control file with a minimum consistency LSN defined as the result of pg_current_wal_insert_lsn() when rewinding from a live source or the last checkpoint LSN when rewinding from a stopped source.
5. When starting the target, Postgres Pro replays all the required WAL, resulting in a data directory in a consistent state.

pg-setup

pg-setup — set up a new Postgres Pro database cluster and manage the corresponding service

Synopsis

`pg-setup initdb [`*`initdb_options`*`]`

`pg-setup find-free-port`

`pg-setup set-server-port` *`port`*

`pg-setup set` *`parameter value`*

`pg-setup service` *`service_option`*

Description

pg-setup is a shell script provided in the Postgres Pro distribution to automate database cluster setup on Linux systems. This script is provided as part of the `postgrespro-ent-14-server` package. Once Postgres Pro is installed, you can find pg-setup in the *`install-dir`*`/bin` directory, where *`install-dir`* is `/opt/pgpro/ent-14`.

pg-setup must be run as root, but performs database administration operations as user `postgres`. You can run this script with different options to:

- initialize the database cluster
- configure the database cluster for a specific Postgres Pro product
- check for available ports and change the port used by Postgres Pro server
- enable/disable automatic startup of Postgres Pro service
- start, stop, or restart Postgres Pro service

Options

pg-setup accepts the following command-line arguments:

`initdb [`*`initdb_options`*`]`

Initialize the database cluster on behalf of the `postgres` user.

By default, the database cluster, configured for your Postgres Pro distribution, is initialized in the `/var/lib/pgpro/ent-14/data` directory, with checksums enabled, `auth-local` parameter set to `peer`, and `auth-host` parameter set to `md5`. Localization settings are inherited from the `LANG` environment variable for the current session. All the `LC_*` environment variables are ignored. Optionally, you can provide initdb options to customize the installation.

If the default database is created using pg-setup, the path to its data directory is stored in the `/etc/default/postgrespro-enterprise-14` file, so all the subsequent pg-setup commands, as well as any commands that manage Postgres Pro service, affect this database only. You cannot manage several databases using pg-setup.

For systems where more than one database server and/or application will run, you may need to adjust the configuration since pg-setup chooses the configuration settings depending on hardware characteristics, assuming that the system will use only one database server.

`find-free-port`

Search for a free port on your system. This option is useful if you are going to install more than one server instance, or the default 5432 port is used by another program.

`set-server-port` *port*

Specify the port number on which the server will listen for connections. Use this option to avoid conflicts if you are installing more than one server instance on the same system.

Default: 5432

`set` *name value*

Set the specified configuration parameter to the provided *value* in the `postgresql.conf` file. If this parameter has been already defined by the `ALTER SYSTEM` command, its previous value is removed from the `postgresql.auto.conf` file.

`service` *service_option*

Manage Postgres Pro service using one of the following options:

- `enable` — enable automatic service startup upon system restart.
- `disable` — disable automatic service startup upon system restart.
- `start` — start the service.
- `stop` — stop the service.
- `condrestart` — restart the service if it is running when pg-setup is invoked.
- `status` — return the Postgres Pro service status.

Notes

If you are installing Postgres Pro from the `postgrespro-ent-14` package, pg-setup is invoked automatically with the default settings. As a result, the database cluster is initialized and the default database is created in the `/var/lib/pgpro/ent-14/data` directory, Postgres Pro service autostart is enabled, and the service is started.

If you are installing Postgres Pro server directly from the `postgrespro-ent-14-server` package, you can run this script manually to initialize the database cluster or manage the Postgres Pro service.

For details on binary installation specifics on Linux, see Section 17.1.

pg_test_fsync

pg_test_fsync — determine fastest `wal_sync_method` for Postgres Pro

Synopsis

`pg_test_fsync` [*option*...]

Description

pg_test_fsync is intended to give you a reasonable idea of what the fastest wal_sync_method is on your specific system, as well as supplying diagnostic information in the event of an identified I/O problem. However, differences shown by pg_test_fsync might not make any significant difference in real database throughput, especially since many database servers are not speed-limited by their write-ahead logs. pg_test_fsync reports average file sync operation time in microseconds for each `wal_sync_method`, which can also be used to inform efforts to optimize the value of commit_delay.

Options

pg_test_fsync accepts the following command-line options:

`-f`
`--filename`

Specifies the file name to write test data in. This file should be in the same file system that the `pg_wal` directory is or will be placed in. (`pg_wal` contains the WAL files.) The default is `pg_test_fsync.out` in the current directory.

`-s`
`--secs-per-test`

Specifies the number of seconds for each test. The more time per test, the greater the test's accuracy, but the longer it takes to run. The default is 5 seconds, which allows the program to complete in under 2 minutes.

`-V`
`--version`

Print the pg_test_fsync version and exit.

`-?`
`--help`

Show help about pg_test_fsync command line arguments, and exit.

Environment

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

See Also

postgres

pg_test_timing

pg_test_timing — measure timing overhead

Synopsis

`pg_test_timing` [*option*...]

Description

pg_test_timing is a tool to measure the timing overhead on your system and confirm that the system time never moves backwards. Systems that are slow to collect timing data can give less accurate `EXPLAIN ANALYZE` results.

Options

pg_test_timing accepts the following command-line options:

`-d` *duration*
`--duration=`*duration*

Specifies the test duration, in seconds. Longer durations give slightly better accuracy, and are more likely to discover problems with the system clock moving backwards. The default test duration is 3 seconds.

`-V`
`--version`

Print the pg_test_timing version and exit.

`-?`
`--help`

Show help about pg_test_timing command line arguments, and exit.

Usage

Interpreting Results

Good results will show most (>90%) individual timing calls take less than one microsecond. Average per loop overhead will be even lower, below 100 nanoseconds. This example from an Intel i7-860 system using a TSC clock source shows excellent performance:

```
Testing timing overhead for 3 seconds.
Per loop time including overhead: 35.96 ns
Histogram of timing durations:
  < us   % of total      count
     1     96.40465   80435604
     2      3.59518    2999652
     4      0.00015        126
     8      0.00002         13
    16      0.00000          2
```

Note that different units are used for the per loop time than the histogram. The loop can have resolution within a few nanoseconds (ns), while the individual timing calls can only resolve down to one microsecond (us).

Measuring Executor Timing Overhead

When the query executor is running a statement using `EXPLAIN ANALYZE`, individual operations are timed as well as showing a summary. The overhead of your system can be checked by counting rows with the psql program:

```
CREATE TABLE t AS SELECT * FROM generate_series(1,100000);
\timing
SELECT COUNT(*) FROM t;
EXPLAIN ANALYZE SELECT COUNT(*) FROM t;
```

The i7-860 system measured runs the count query in 9.8 ms while the `EXPLAIN ANALYZE` version takes 16.6 ms, each processing just over 100,000 rows. That 6.8 ms difference means the timing overhead per row is 68 ns, about twice what pg_test_timing estimated it would be. Even that relatively small amount of overhead is making the fully timed count statement take almost 70% longer. On more substantial queries, the timing overhead would be less problematic.

Changing Time Sources

On some newer Linux systems, it's possible to change the clock source used to collect timing data at any time. A second example shows the slowdown possible from switching to the slower acpi_pm time source, on the same system used for the fast results above:

```
# cat /sys/devices/system/clocksource/clocksource0/available_clocksource
tsc hpet acpi_pm
# echo acpi_pm > /sys/devices/system/clocksource/clocksource0/current_clocksource
# pg_test_timing
Per loop time including overhead: 722.92 ns
Histogram of timing durations:
  < us   % of total      count
     1     27.84870    1155682
     2     72.05956    2990371
     4      0.07810       3241
     8      0.01357        563
    16      0.00007          3
```

In this configuration, the sample `EXPLAIN ANALYZE` above takes 115.9 ms. That's 1061 ns of timing overhead, again a small multiple of what's measured directly by this utility. That much timing overhead means the actual query itself is only taking a tiny fraction of the accounted for time, most of it is being consumed in overhead instead. In this configuration, any `EXPLAIN ANALYZE` totals involving many timed operations would be inflated significantly by timing overhead.

FreeBSD also allows changing the time source on the fly, and it logs information about the timer selected during boot:

```
# dmesg | grep "Timecounter"
Timecounter "ACPI-fast" frequency 3579545 Hz quality 900
Timecounter "i8254" frequency 1193182 Hz quality 0
Timecounters tick every 10.000 msec
Timecounter "TSC" frequency 2531787134 Hz quality 800
# sysctl kern.timecounter.hardware=TSC
kern.timecounter.hardware: ACPI-fast -> TSC
```

Other systems may only allow setting the time source on boot. On older Linux systems the "clock" kernel setting is the only way to make this sort of change. And even on some more recent ones, the only option you'll see for a clock source is "jiffies". Jiffies are the older Linux software clock implementation, which can have good resolution when it's backed by fast enough timing hardware, as in this example:

```
$ cat /sys/devices/system/clocksource/clocksource0/available_clocksource
jiffies
$ dmesg | grep time.c
time.c: Using 3.579545 MHz WALL PM GTOD PIT/TSC timer.
time.c: Detected 2400.153 MHz processor.
$ pg_test_timing
Testing timing overhead for 3 seconds.
Per timing duration including loop overhead: 97.75 ns
Histogram of timing durations:
```

```
    < us   % of total      count
       1     90.23734   27694571
       2      9.75277    2993204
       4      0.00981       3010
       8      0.00007         22
      16      0.00000          1
      32      0.00000          1
```

Clock Hardware and Timing Accuracy

Collecting accurate timing information is normally done on computers using hardware clocks with various levels of accuracy. With some hardware the operating systems can pass the system clock time almost directly to programs. A system clock can also be derived from a chip that simply provides timing interrupts, periodic ticks at some known time interval. In either case, operating system kernels provide a clock source that hides these details. But the accuracy of that clock source and how quickly it can return results varies based on the underlying hardware.

Inaccurate time keeping can result in system instability. Test any change to the clock source very carefully. Operating system defaults are sometimes made to favor reliability over best accuracy. And if you are using a virtual machine, look into the recommended time sources compatible with it. Virtual hardware faces additional difficulties when emulating timers, and there are often per operating system settings suggested by vendors.

The Time Stamp Counter (TSC) clock source is the most accurate one available on current generation CPUs. It's the preferred way to track the system time when it's supported by the operating system and the TSC clock is reliable. There are several ways that TSC can fail to provide an accurate timing source, making it unreliable. Older systems can have a TSC clock that varies based on the CPU temperature, making it unusable for timing. Trying to use TSC on some older multicore CPUs can give a reported time that's inconsistent among multiple cores. This can result in the time going backwards, a problem this program checks for. And even the newest systems can fail to provide accurate TSC timing with very aggressive power saving configurations.

Newer operating systems may check for the known TSC problems and switch to a slower, more stable clock source when they are seen. If your system supports TSC time but doesn't default to that, it may be disabled for a good reason. And some operating systems may not detect all the possible problems correctly, or will allow using TSC even in situations where it's known to be inaccurate.

The High Precision Event Timer (HPET) is the preferred timer on systems where it's available and TSC is not accurate. The timer chip itself is programmable to allow up to 100 nanosecond resolution, but you may not see that much accuracy in your system clock.

Advanced Configuration and Power Interface (ACPI) provides a Power Management (PM) Timer, which Linux refers to as the acpi_pm. The clock derived from acpi_pm will at best provide 300 nanosecond resolution.

Timers used on older PC hardware include the 8254 Programmable Interval Timer (PIT), the real-time clock (RTC), the Advanced Programmable Interrupt Controller (APIC) timer, and the Cyclone timer. These timers aim for millisecond resolution.

See Also

EXPLAIN

pg_upgrade

pg_upgrade — upgrade a Postgres Pro server instance

Synopsis

`pg_upgrade -b` *oldbindir* [`-B` *newbindir*] `-d` *oldconfigdir* `-D` *newconfigdir* [*option*...]

Description

pg_upgrade (formerly called pg_migrator) allows data stored in PostgreSQL or Postgres Pro data files to be upgraded to a later Postgres Pro major version without the data dump/restore typically required for major version upgrades, e.g., from 9.5.8 to 9.6.4 or from 10.7 to 11.2. It is not required for minor version upgrades, e.g., from 9.6.2 to 9.6.3 or from 10.1 to 10.2.

Major Postgres Pro releases regularly add new features that often change the layout of the system tables, but the internal data storage format rarely changes. pg_upgrade uses this fact to perform rapid upgrades by creating new system tables and simply reusing the old user data files. If a future major release ever changes the data storage format in a way that makes the old data format unreadable, pg_upgrade will not be usable for such upgrades. (The community will attempt to avoid such situations.)

pg_upgrade does its best to make sure the old and new clusters are binary-compatible, e.g., by checking for compatible compile-time settings, including 32/64-bit binaries. It is important that any external modules are also binary compatible, though this cannot be checked by pg_upgrade.

pg_upgrade supports upgrades from 9.0.X and later to the current major release of Postgres Pro, including snapshot and beta releases.

Options

pg_upgrade accepts the following command-line arguments:

`-b` *bindir*
`--old-bindir=`*bindir*

the old Postgres Pro executable directory; environment variable `PGBINOLD`

`-B` *bindir*
`--new-bindir=`*bindir*

the new Postgres Pro executable directory; default is the directory where pg_upgrade resides; environment variable `PGBINNEW`

`-c`
`--check`

check clusters only, don't change any data

`-d` *configdir*
`--old-datadir=`*configdir*

the old database cluster configuration directory; environment variable `PGDATAOLD`

`-D` *configdir*
`--new-datadir=`*configdir*

the new database cluster configuration directory; environment variable `PGDATANEW`

`-j` *njobs*
`--jobs=`*njobs*

number of simultaneous processes or threads to use

`-k`
`--link`

use hard links instead of copying files to the new cluster

`-o` *options*
`--old-options` *options*

options to be passed directly to the old `postgres` command; multiple option invocations are appended

`-O` *options*
`--new-options` *options*

options to be passed directly to the new `postgres` command; multiple option invocations are appended

`-p` *port*
`--old-port=`*port*

the old cluster port number; environment variable `PGPORTOLD`

`-P` *port*
`--new-port=`*port*

the new cluster port number; environment variable `PGPORTNEW`

`-r`
`--retain`

retain SQL and log files even after successful completion

`-s` *dir*
`--socketdir=`*dir*

directory to use for postmaster sockets during upgrade; default is current working directory; environment variable `PGSOCKETDIR`

`-U` *username*
`--username=`*username*

cluster's install user name; environment variable `PGUSER`

`-v`
`--verbose`

enable verbose internal logging

`-V`
`--version`

display version information, then exit

`--clone`

Use efficient file cloning (also known as “reflinks” on some systems) instead of copying files to the new cluster. This can result in near-instantaneous copying of the data files, giving the speed advantages of `-k`/`--link` while leaving the old cluster untouched.

File cloning is only supported on some operating systems and file systems. If it is selected but not supported, the pg_upgrade run will error. At present, it is supported on Linux (kernel 4.5 or later) with Btrfs and XFS (on file systems created with reflink support), and on macOS with APFS.

`-?`
`--help`

show help, then exit

Usage

These are the steps to perform an upgrade with pg_upgrade:

1. **Optionally move the old cluster**

   If you are using a version-specific installation directory, e.g., `/opt/PostgreSQL/14`, you do not need to move the old cluster. The graphical installers all use version-specific installation directories.

   If your installation directory is not version-specific, e.g., `/usr/local/pgsql`, it is necessary to move the current Postgres Pro install directory so it does not interfere with the new Postgres Pro installation. Once the current Postgres Pro server is shut down, it is safe to rename the Postgres Pro installation directory; assuming the old directory is `/usr/local/pgsql`, you can do:

   ```
   mv /usr/local/pgsql /usr/local/pgsql.old
   ```

   to rename the directory.

2. **Install the new Postgres Pro binaries**

   Install the new server's binaries and support files. pg_upgrade is included in a default installation.

3. **Initialize the new Postgres Pro cluster**

   Initialize the new cluster using `initdb`. Use compatible `initdb` flags that match the old cluster. Many prebuilt installers do this step automatically. There is no need to start the new cluster.

4. **Install extension shared object files**

   Many extensions and custom modules, whether from `contrib` or another source, use shared object files (or DLLs), e.g., `pgcrypto.so`. If the old cluster used these, shared object files matching the new server binary must be installed in the new cluster, usually via operating system commands. Do not load the schema definitions, e.g., `CREATE EXTENSION pgcrypto`, because these will be duplicated from the old cluster. If extension updates are available, pg_upgrade will report this and create a script that can be run later to update them.

5. **Copy custom full-text search files**

   Copy any custom full text search files (dictionary, synonym, thesaurus, stop words) from the old to the new cluster.

6. **Adjust authentication**

   `pg_upgrade` will connect to the old and new servers several times, so you might want to set authentication to `peer` in `pg_hba.conf` or use a `~/.pgpass` file (see Section 36.16).

7. **Stop both servers**

   Make sure both database servers are stopped using, on Unix, e.g.:

   ```
   pg_ctl -D /opt/PostgreSQL/9.6 stop
   pg_ctl -D /opt/PostgreSQL/14 stop
   ```

   or on Windows, using the proper service names:

   ```
   NET STOP postgresql-9.6
   NET STOP postgresql-14
   ```

   Streaming replication and log-shipping standby servers must be running during this shutdown so they receive all changes.

8. **Prepare for standby server upgrades**

   If you are upgrading standby servers using methods outlined in section Step 10, verify that the old standby servers are caught up by running pg_controldata against the old primary and standby clusters. Verify that the “Latest checkpoint location” values match in all clusters. Also, make sure `wal_level` is not set to `minimal` in the `postgresql.conf` file on the new primary cluster.

9. **Run pg_upgrade**

   Always run the pg_upgrade binary of the new server, not the old one. pg_upgrade requires the specification of the old and new cluster's data and executable (`bin`) directories. You can also specify user and port values, and whether you want the data files linked or cloned instead of the default copy behavior.

   If you use link mode, the upgrade will be much faster (no file copying) and use less disk space, but you will not be able to access your old cluster once you start the new cluster after the upgrade. Link mode also requires that the old and new cluster data directories be in the same file system. (Tablespaces and `pg_wal` can be on different file systems.) Clone mode provides the same speed and disk space advantages but does not cause the old cluster to be unusable once the new cluster is started. Clone mode also requires that the old and new data directories be in the same file system. This mode is only available on certain operating systems and file systems.

   The `--jobs` option allows multiple CPU cores to be used for copying/linking of files and to dump and restore database schemas in parallel; a good place to start is the maximum of the number of CPU cores and tablespaces. This option can dramatically reduce the time to upgrade a multi-database server running on a multiprocessor machine.

   For Windows users, you must be logged into an administrative account, and then start a shell as the `postgres` user and set the proper path:

```
RUNAS /USER:postgres "CMD.EXE"
SET PATH=%PATH%;C:\Program Files\PostgreSQL\14\bin;
```

   and then run pg_upgrade with quoted directories, e.g.:

```
pg_upgrade.exe
        --old-datadir "C:/Program Files/PostgreSQL/9.6/data"
        --new-datadir "C:/Program Files/PostgreSQL/14/data"
        --old-bindir "C:/Program Files/PostgreSQL/9.6/bin"
        --new-bindir "C:/Program Files/PostgreSQL/14/bin"
```

   Once started, `pg_upgrade` will verify the two clusters are compatible and then do the upgrade. You can use `pg_upgrade --check` to perform only the checks, even if the old server is still running. `pg_upgrade --check` will also outline any manual adjustments you will need to make after the upgrade. If you are going to be using link or clone mode, you should use the option `--link` or `--clone` with `--check` to enable mode-specific checks. `pg_upgrade` requires write permission in the current directory.

   Obviously, no one should be accessing the clusters during the upgrade. pg_upgrade defaults to running servers on port 50432 to avoid unintended client connections. You can use the same port number for both clusters when doing an upgrade because the old and new clusters will not be running at the same time. However, when checking an old running server, the old and new port numbers must be different.

   If an error occurs while restoring the database schema, `pg_upgrade` will exit and you will have to revert to the old cluster as outlined in Step 16 below. To try `pg_upgrade` again, you will need to modify the old cluster so the pg_upgrade schema restore succeeds. If the problem is a `contrib` module, you might need to uninstall the `contrib` module from the old cluster and install it in the new cluster after the upgrade, assuming the module is not being used to store user data.

10. **Upgrade streaming replication and log-shipping standby servers**

    If you used link mode and have Streaming Replication (see Section 26.2.5) or Log-Shipping (see Section 26.2) standby servers, you can follow these steps to quickly upgrade them. You will not be running pg_upgrade on the standby servers, but rather rsync on the primary. Do not start any servers yet.

If you did *not* use link mode, do not have or do not want to use rsync, or want an easier solution, skip the instructions in this section and simply recreate the standby servers once pg_upgrade completes and the new primary is running.

a. **Install the new Postgres Pro binaries on standby servers**

   Make sure the new binaries and support files are installed on all standby servers.

b. **Make sure the new standby data directories do *not* exist**

   Make sure the new standby data directories do *not* exist or are empty. If initdb was run, delete the standby servers' new data directories.

c. **Install extension shared object files**

   Install the same extension shared object files on the new standbys that you installed in the new primary cluster.

d. **Stop standby servers**

   If the standby servers are still running, stop them now using the above instructions.

e. **Save configuration files**

   Save any configuration files from the old standbys' configuration directories you need to keep, e.g., `postgresql.conf` (and any files included by it), `postgresql.auto.conf`, `pg_hba.conf`, because these will be overwritten or removed in the next step.

f. **Run rsync**

   When using link mode, standby servers can be quickly upgraded using rsync. To accomplish this, from a directory on the primary server that is above the old and new database cluster directories, run this on the *primary* for each standby server:

```
rsync --archive --delete --hard-links --size-only --no-inc-recursive old_cluster
 new_cluster remote_dir
```

   where `old_cluster` and `new_cluster` are relative to the current directory on the primary, and `remote_dir` is *above* the old and new cluster directories on the standby. The directory structure under the specified directories on the primary and standbys must match. Consult the rsync manual page for details on specifying the remote directory, e.g.,

```
rsync --archive --delete --hard-links --size-only --no-inc-recursive /opt/
PostgreSQL/9.5 \
      /opt/PostgreSQL/9.6 standby.example.com:/opt/PostgreSQL
```

   You can verify what the command will do using rsync's `--dry-run` option. While rsync must be run on the primary for at least one standby, it is possible to run rsync on an upgraded standby to upgrade other standbys, as long as the upgraded standby has not been started.

   What this does is to record the links created by pg_upgrade's link mode that connect files in the old and new clusters on the primary server. It then finds matching files in the standby's old cluster and creates links for them in the standby's new cluster. Files that were not linked on the primary are copied from the primary to the standby. (They are usually small.) This provides rapid standby upgrades. Unfortunately, rsync needlessly copies files associated with temporary and unlogged tables because these files don't normally exist on standby servers.

   If you have tablespaces, you will need to run a similar rsync command for each tablespace directory, e.g.:

```
rsync --archive --delete --hard-links --size-only --no-inc-recursive /vol1/
pg_tblsp/PG_9.5_201510051 \
      /vol1/pg_tblsp/PG_9.6_201608131 standby.example.com:/vol1/pg_tblsp
```

   If you have relocated `pg_wal` outside the data directories, rsync must be run on those directories too.

g. **Configure streaming replication and log-shipping standby servers**

Configure the servers for log shipping. (You do not need to run `pg_start_backup()` and `pg_stop_backup()` or take a file system backup as the standbys are still synchronized with the primary.) Replication slots are not copied and must be recreated.

11. **Restore `pg_hba.conf`**

If you modified `pg_hba.conf`, restore its original settings. It might also be necessary to adjust other configuration files in the new cluster to match the old cluster, e.g., `postgresql.conf` (and any files included by it), `postgresql.auto.conf`.

12. **Start the new server**

The new server can now be safely started, and then any rsync'ed standby servers.

13. **Post-upgrade processing**

If any post-upgrade processing is required, pg_upgrade will issue warnings as it completes. It will also generate script files that must be run by the administrator. The script files will connect to each database that needs post-upgrade processing. Each script should be run using:

```
psql --username=postgres --file=script.sql postgres
```

The scripts can be run in any order and can be deleted once they have been run.

> **Caution**
>
> In general it is unsafe to access tables referenced in rebuild scripts until the rebuild scripts have run to completion; doing so could yield incorrect results or poor performance. Tables not referenced in rebuild scripts can be accessed immediately.

14. **Statistics**

Because optimizer statistics are not transferred by `pg_upgrade`, you will be instructed to run a command to regenerate that information at the end of the upgrade. You might need to set connection parameters to match your new cluster.

15. **Delete old cluster**

Once you are satisfied with the upgrade, you can delete the old cluster's data directories by running the script mentioned when `pg_upgrade` completes. (Automatic deletion is not possible if you have user-defined tablespaces inside the old data directory.) You can also delete the old installation directories (e.g., `bin`, `share`).

16. **Reverting to old cluster**

If, after running `pg_upgrade`, you wish to revert to the old cluster, there are several options:

- If the `--check` option was used, the old cluster was unmodified; it can be restarted.
- If the `--link` option was *not* used, the old cluster was unmodified; it can be restarted.
- If the `--link` option was used, the data files might be shared between the old and new cluster:
  - If `pg_upgrade` aborted before linking started, the old cluster was unmodified; it can be restarted.
  - If you did *not* start the new cluster, the old cluster was unmodified except that, when linking started, a `.old` suffix was appended to `$PGDATA/global/pg_control`. To reuse the old cluster, remove the `.old` suffix from `$PGDATA/global/pg_control`; you can then restart the old cluster.
  - If you did start the new cluster, it has written to shared files and it is unsafe to use the old cluster. The old cluster will need to be restored from backup in this case.

Notes

When migrating from PostgreSQL or Postgres Pro Standard using pg_upgrade, the heap pages are never converted from 32-bit to 64-bit format during or right after the upgrade as it would create an extreme load on the system. Instead, a page is converted when it is accessed for the first time after the upgrade. During conversion, heap pages are repacked because a 64-bit heap page must contain a special space storing certain values. These values, added to `xmin` and `xmax` of each tuple, allow converting `xmin` and `xmax` into the 64-bit format. However, the tuples on the original page might be arranged in such a way that neither reorganizing them nor performing a vacuum operation can free up enough space. This is why `double xmax` pages are created. Such a page doesn't contain any special space, it is basically a 32-bit page with an `xmin` field that contains a part of the 64-bit `xmax` field. It is done to comply with MVCC, as the new 64-bit `xmax` value is split into two parts that are stored under the `xmin` and `xmax` fields. It is possible because after the upgrade with pg_upgrade no transactions from the old cluster remain, thus the `xmin` field can be used to store a part of the 64-bit `xmax` value. `double xmax` pages exist until enough of free space is released for the page to include the special space, e.g. if a record is deleted or the tuples are updated. `double xmax` pages can be read, yet when updated, they are converted to the 64-bit format, as updating deletes the tuple and frees new space for the conversion.

pg_upgrade creates various working files, such as schema dumps, in the current working directory. For security, be sure that that directory is not readable or writable by any other users.

pg_upgrade launches short-lived postmasters in the old and new data directories. Temporary Unix socket files for communication with these postmasters are, by default, made in the current working directory. In some situations the path name for the current directory might be too long to be a valid socket name. In that case you can use the `-s` option to put the socket files in some directory with a shorter path name. For security, be sure that that directory is not readable or writable by any other users. (This is not supported on Windows.)

All failure, rebuild, and reindex cases will be reported by pg_upgrade if they affect your installation; post-upgrade scripts to rebuild tables and indexes will be generated automatically. If you are trying to automate the upgrade of many clusters, you should find that clusters with identical database schemas require the same post-upgrade steps for all cluster upgrades; this is because the post-upgrade steps are based on the database schemas, and not user data.

For deployment testing, create a schema-only copy of the old cluster, insert dummy data, and upgrade that.

pg_upgrade does not support upgrading of databases containing table columns using these `reg*` OID-referencing system data types:

```
regcollation
regconfig
regdictionary
regnamespace
regoper
regoperator
regproc
regprocedure
```

(`regclass`, `regrole`, and `regtype` can be upgraded.)

If you are upgrading a pre-PostgreSQL 9.2 cluster that uses a configuration-file-only directory, you must pass the real data directory location to pg_upgrade, and pass the configuration directory location to the server, e.g., `-d /real-data-directory -o '-D /configuration-directory'`.

If using a pre-9.1 old server that is using a non-default Unix-domain socket directory or a default that differs from the default of the new cluster, set `PGHOST` to point to the old server's socket location. (This is not relevant on Windows.)

When performing an upgrade from Postgres Pro 9.6 or lower, for databases with a multibyte encoding, pg_upgrade may generate SQL files with `REINDEX`/`VALIDATE` commands. You must run these files to re-build indexes and re-validate constraints. This can happen in the following cases:

- The old cluster uses indexes or constraints depending on collations other than the default collation of the database, `C`, or `POSIX`.
- On Windows, the old cluster uses indexes or constraints depending on the default collation with a verbose name, such as `"Russian_Russia[.`*encoding*`]"` or `"English_United States[.`*encoding*`]"`.

If you want to use link mode and you do not want your old cluster to be modified when the new cluster is started, consider using the clone mode. If that is not available, make a copy of the old cluster and upgrade that in link mode. To make a valid copy of the old cluster, use `rsync` to create a dirty copy of the old cluster while the server is running, then shut down the old server and run `rsync --checksum` again to update the copy with any changes to make it consistent. (`--checksum` is necessary because `rsync` only has file modification-time granularity of one second.) You might want to exclude some files, e.g., `postmaster.pid`, as documented in Section 25.3.3. If your file system supports file system snapshots or copy-on-write file copies, you can use that to make a backup of the old cluster and tablespaces, though the snapshot and copies must be created simultaneously or while the database server is down.

See Also

initdb, pg_ctl, pg_dump, postgres

pg_waldump

pg_waldump — display a human-readable rendering of the write-ahead log of a Postgres Pro database cluster

Synopsis

`pg_waldump` [`option`...] [`timestamp-option`...] [`startseg` [`endseg`]]

Description

`pg_waldump` displays the write-ahead log (WAL) and prints timestamps for WAL records. This utility is mainly useful for debugging or educational purposes.

This utility can only be run by the user who installed the server, because it requires read-only access to the data directory.

Options

The following command-line options control the location and format of the output:

`startseg`

Start reading at the specified log segment file. This implicitly determines the path in which files will be searched for, and the timeline to use.

`endseg`

Stop after reading the specified log segment file.

`-b`
`--bkp-details`

Output detailed information about backup blocks.

`-e` *`end`*
`--end=`*`end`*

Stop reading at the specified WAL location, instead of reading to the end of the log stream.

`-f`
`--follow`

After reaching the end of valid WAL, keep polling once per second for new WAL to appear.

`-n` *`limit`*
`--limit=`*`limit`*

Display the specified number of records, then stop.

`-p` *`path`*
`--path=`*`path`*

Specifies a directory to search for log segment files or a directory with a `pg_wal` subdirectory that contains such files. The default is to search in the current directory, the `pg_wal` subdirectory of the current directory, and the `pg_wal` subdirectory of `PGDATA`.

`-q`
`--quiet`

Do not print any output, except for errors. This option can be useful when you want to know whether a range of WAL records can be successfully parsed but don't care about the record contents.

`-r` *rmgr*
`--rmgr=`*rmgr*

Only display records generated by the specified resource manager. If `list` is passed as name, print a list of valid resource manager names, and exit.

`-s` *start*
`--start=`*start*

WAL location at which to start reading. The default is to start reading the first valid log record found in the earliest file found.

`-t` *timeline*
`--timeline=`*timeline*

Timeline from which to read log records. The default is to use the value in *startseg*, if that is specified; otherwise, the default is 1.

`-V`
`--version`

Print the pg_waldump version and exit.

`--save-fullpage=`*save_path*

Save full page images found in the WAL records to the *save_path* directory. The images saved are subject to the same filtering and limiting criteria as the records displayed.

The full page images are saved with the following file name format: *TIMELINE*`-`*LSN*`.`*RELTABLESPACE*`.`*DATOID*`.`*RELNODE*`.`*BLKNOFORK* The file names are composed of the following parts:

Component	**Description**
TIMELINE	The timeline of the WAL segment file where the record is located formatted as one 8-character hexadecimal number `%08X`
LSN	The LSN of the record with this image, formatted as two 8-character hexadecimal numbers `%08X-%08X`
RELTABLESPACE	tablespace OID of the block
DATOID	database OID of the block
RELNODE	filenode of the block
BLKNO	block number of the block
FORK	The name of the fork the full page image came from, as of `_main` , `_fsm` , `_vm` , or `_init` .

`-x` *xid*
`--xid=`*xid*

Only display records marked with the given transaction ID.

`-z`
`--stats[=record]`

Display summary statistics (number and size of records and full-page images) instead of individual records. Optionally generate statistics per-record instead of per-rmgr.

`-?`
`--help`

Show help about pg_waldump command line arguments, and exit.

The following command-line options enable printing timestamps for various types of WAL records. You can use these options together with *startseg*, *endseg*, `-s`, and `-e` options.

`-E`
`--end-timestamp`

Print the timestamp of the last WAL record of the specified type found in the log segment file. When using this option, you must also specify the `-S` option.

By default, pg_waldump prints timestamps only for COMMIT records. You can specify other record types using the `-F` option.

`-F` [*argument1*,*argument2*,...]
`--timestamp-filter=`*argument* [, ...]

Specify WAL record types for which to print timestamps. When using this option, you must also specify the `-S` option.

The `-F` option can take the following arguments, in the comma-separated format:

- `XLOG_RESTORE_POINT` — named restore points created with the pg_create_restore_point() function.
- `XLOG_XACT_COMMIT` — commit records for transactions. These records are caused by the COMMIT command.
- `XLOG_XACT_COMMIT_PREPARED` — commit records for transactions that were earlier prepared for a two-phase commit. These records are caused by the COMMIT PREPARED command.
- `XLOG_XACT_ABORT` — abort records for transactions. These records are caused by the ROLLBACK command.
- `XLOG_XACT_ABORT_PREPARED` — abort records for transactions that were earlier prepared for a two-phase commit. These records are caused by the ROLLBACK PREPARED command.

By default, pg_waldump prints timestamps only for COMMIT records.

`-S`
`--start-timestamp`

Print the timestamp of the first WAL record of the specified type found in the log segment file. This option is required if you are going to use `-E` or `-F` options.

By default, pg_waldump prints timestamps only for COMMIT records. You can specify other record types using the `-F` option.

Environment

`PGDATA`

Data directory; see also the `-p` option.

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

Can give wrong results when the server is running.

Only the specified timeline is displayed (or the default, if none is specified). Records in other timelines are ignored.

pg_waldump cannot read WAL files with suffix `.partial`. If those files need to be read, `.partial` suffix needs to be removed from the file name.

See Also

Section 29.7

postgres

postgres — Postgres Pro database server

Synopsis

`postgres` [*option*...]

Description

`postgres` is the Postgres Pro database server. In order for a client application to access a database it connects (over a network or locally) to a running `postgres` instance. The `postgres` instance then starts a separate server process to handle the connection.

One `postgres` instance always manages the data of exactly one database cluster. A database cluster is a collection of databases that is stored at a common file system location (the "data area"). More than one `postgres` instance can run on a system at one time, so long as they use different data areas and different communication ports (see below). When `postgres` starts it needs to know the location of the data area. The location must be specified by the `-D` option or the `PGDATA` environment variable; there is no default. Typically, `-D` or `PGDATA` points directly to the data area directory created by initdb. Other possible file layouts are discussed in Section 19.2.

By default `postgres` starts in the foreground and prints log messages to the standard error stream. In practical applications `postgres` should be started as a background process, perhaps at boot time.

The `postgres` command can also be called in single-user mode. The primary use for this mode is during bootstrapping by initdb. Sometimes it is used for debugging or disaster recovery; note that running a single-user server is not truly suitable for debugging the server, since no realistic interprocess communication and locking will happen. When invoked in single-user mode from the shell, the user can enter queries and the results will be printed to the screen, but in a form that is more useful for developers than end users. In the single-user mode, the session user will be set to the user with ID 1, and implicit superuser powers are granted to this user. This user does not actually have to exist, so the single-user mode can be used to manually recover from certain kinds of accidental damage to the system catalogs.

Options

`postgres` accepts the following command-line arguments. For a detailed discussion of the options consult Chapter 19. You can save typing most of these options by setting up a configuration file. Some (safe) options can also be set from the connecting client in an application-dependent way to apply only for that session. For example, if the environment variable `PGOPTIONS` is set, then libpq-based clients will pass that string to the server, which will interpret it as `postgres` command-line options.

General Purpose

`-B` *nbuffers*

Sets the number of shared buffers for use by the server processes. The default value of this parameter is chosen automatically by initdb. Specifying this option is equivalent to setting the shared_buffers configuration parameter.

`-c` *name=value*

Sets a named run-time parameter. The configuration parameters supported by Postgres Pro are described in Chapter 19. Most of the other command line options are in fact short forms of such a parameter assignment. `-c` can appear multiple times to set multiple parameters.

`-C` *name*

Prints the value of the named run-time parameter, and exits. (See the `-c` option above for details.) This can be used on a running server, and returns values from `postgresql.conf`, modified by any

parameters supplied in this invocation. It does not reflect parameters supplied when the cluster was started.

This option is meant for other programs that interact with a server instance, such as pg_ctl, to query configuration parameter values. User-facing applications should instead use SHOW or the pg_settings view.

-d *debug-level*

Sets the debug level. The higher this value is set, the more debugging output is written to the server log. Values are from 1 to 5. It is also possible to pass -d 0 for a specific session, which will prevent the server log level of the parent postgres process from being propagated to this session.

-D *datadir*

Specifies the file system location of the database configuration files. See Section 19.2 for details.

-e

Sets the default date style to "European", that is DMY ordering of input date fields. This also causes the day to be printed before the month in certain date output formats. See Section 8.5 for more information.

-F

Disables fsync calls for improved performance, at the risk of data corruption in the event of a system crash. Specifying this option is equivalent to disabling the fsync configuration parameter. Read the detailed documentation before using this!

-h *hostname*

Specifies the IP host name or address on which postgres is to listen for TCP/IP connections from client applications. The value can also be a comma-separated list of addresses, or * to specify listening on all available interfaces. An empty value specifies not listening on any IP addresses, in which case only Unix-domain sockets can be used to connect to the server. Defaults to listening only on localhost. Specifying this option is equivalent to setting the listen_addresses configuration parameter.

-i

Allows remote clients to connect via TCP/IP (Internet domain) connections. Without this option, only local connections are accepted. This option is equivalent to setting listen_addresses to * in postgresql.conf or via -h.

This option is deprecated since it does not allow access to the full functionality of listen_addresses. It's usually better to set listen_addresses directly.

-k *directory*

Specifies the directory of the Unix-domain socket on which postgres is to listen for connections from client applications. The value can also be a comma-separated list of directories. An empty value specifies not listening on any Unix-domain sockets, in which case only TCP/IP sockets can be used to connect to the server. The default value is normally /tmp, but that can be changed at build time. Specifying this option is equivalent to setting the unix_socket_directories configuration parameter.

-l

Enables secure connections using SSL. Postgres Pro must have been compiled with support for SSL for this option to be available. For more information on using SSL, refer to Section 18.9.

-N *max-connections*

Sets the maximum number of client connections that this server will accept. The default value of this parameter is chosen automatically by initdb. Specifying this option is equivalent to setting the max_connections configuration parameter.

`-p` *port*

Specifies the TCP/IP port or local Unix domain socket file extension on which `postgres` is to listen for connections from client applications. Defaults to the value of the `PGPORT` environment variable, or if `PGPORT` is not set, then defaults to the value established during compilation (normally 5432). If you specify a port other than the default port, then all client applications must specify the same port using either command-line options or `PGPORT`.

`-s`

Print time information and other statistics at the end of each command. This is useful for benchmarking or for use in tuning the number of buffers.

`-S` *work-mem*

Specifies the base amount of memory to be used by sorts and hash tables before resorting to temporary disk files. See the description of the `work_mem` configuration parameter in Section 19.4.1.

`-V`
`--version`

Print the postgres version and exit.

`--`*name*`=`*value*

Sets a named run-time parameter; a shorter form of `-c`.

`--describe-config`

This option dumps out the server's internal configuration variables, descriptions, and defaults in tab-delimited `COPY` format. It is designed primarily for use by administration tools.

`-?`
`--help`

Show help about postgres command line arguments, and exit.

Semi-Internal Options

The options described here are used mainly for debugging purposes, and in some cases to assist with recovery of severely damaged databases. There should be no reason to use them in a production database setup. They are listed here only for use by Postgres Pro system developers. Furthermore, these options might change or be removed in a future release without notice.

`-f { s | i | o | b | t | n | m | h }`

Forbids the use of particular scan and join methods: `s` and `i` disable sequential and index scans respectively, `o`, `b` and `t` disable index-only scans, bitmap index scans, and TID scans respectively, while `n`, `m`, and `h` disable nested-loop, merge and hash joins respectively.

Neither sequential scans nor nested-loop joins can be disabled completely; the `-fs` and `-fn` options simply discourage the optimizer from using those plan types if it has any other alternative.

`-n`

This option is for debugging problems that cause a server process to die abnormally. The ordinary strategy in this situation is to notify all other server processes that they must terminate and then reinitialize the shared memory and semaphores. This is because an errant server process could have corrupted some shared state before terminating. This option specifies that `postgres` will not reinitialize shared data structures. A knowledgeable system programmer can then use a debugger to examine shared memory and semaphore state.

`-O`

Allows the structure of system tables to be modified. This is used by `initdb`.

`-P`

Ignore system indexes when reading system tables, but still update the indexes when modifying the tables. This is useful when recovering from damaged system indexes.

`-t pa[rser] | pl[anner] | e[xecutor]`

Print timing statistics for each query relating to each of the major system modules. This option cannot be used together with the `-s` option.

`-T`

This option is for debugging problems that cause a server process to die abnormally. The ordinary strategy in this situation is to notify all other server processes that they must terminate and then reinitialize the shared memory and semaphores. This is because an errant server process could have corrupted some shared state before terminating. This option specifies that `postgres` will stop all other server processes by sending the signal `SIGSTOP`, but will not cause them to terminate. This permits system programmers to collect core dumps from all server processes by hand.

`-v` *`protocol`*

Specifies the version number of the frontend/backend protocol to be used for a particular session. This option is for internal use only.

`-W` *`seconds`*

A delay of this many seconds occurs when a new server process is started, after it conducts the authentication procedure. This is intended to give an opportunity to attach to the server process with a debugger.

`-Z`

Verifies that the current postgres binary is compatible with the specified cluster. If the architecture type or any compilation options that affect cluster compatibility do not match, returns an exit status of 1 and provides an error message specifying the first detected incompatibility. Otherwise, reports success and exits without starting the cluster.

You must provide the path to the data directory of the cluster to check.

The cluster and the binary must have the same byte order and architecture type for this option to work correctly.

> **Tip**
>
> If the binary appears to be incompatible with the specified cluster, run pgpro_controldata with the `-P` or `-C` command-line argument to view all parameters of the cluster that affect the compatibility.

Options for Single-User Mode

The following options only apply to the single-user mode (see Single-User Mode below).

`--single`

Selects the single-user mode. This must be the first argument on the command line.

`database`

Specifies the name of the database to be accessed. This must be the last argument on the command line. If it is omitted it defaults to the user name.

`-E`

Echo all commands to standard output before executing them.

`-j`

Use semicolon followed by two newlines, rather than just newline, as the command entry terminator.

`-r` *`filename`*

Send all server log output to *`filename`*. This option is only honored when supplied as a command-line option.

Environment

`PGCLIENTENCODING`

Default character encoding used by clients. (The clients can override this individually.) This value can also be set in the configuration file.

`PGDATA`

Default data directory location

`PGDATESTYLE`

Default value of the DateStyle run-time parameter. (The use of this environment variable is deprecated.)

`PGPORT`

Default port number (preferably set in the configuration file)

Diagnostics

A failure message mentioning `semget` or `shmget` probably indicates you need to configure your kernel to provide adequate shared memory and semaphores. For more discussion see Section 18.4. You might be able to postpone reconfiguring your kernel by decreasing shared_buffers to reduce the shared memory consumption of Postgres Pro, and/or by reducing max_connections to reduce the semaphore consumption.

A failure message suggesting that another server is already running should be checked carefully, for example by using the command

```
$ ps ax | grep postgres
```

or

```
$ ps -ef | grep postgres
```

depending on your system. If you are certain that no conflicting server is running, you can remove the lock file mentioned in the message and try again.

A failure message indicating inability to bind to a port might indicate that that port is already in use by some non-Postgres Pro process. You might also get this error if you terminate `postgres` and immediately restart it using the same port; in this case, you must simply wait a few seconds until the operating system closes the port before trying again. Finally, you might get this error if you specify a port number that your operating system considers to be reserved. For example, many versions of Unix consider port numbers under 1024 to be “trusted” and only permit the Unix superuser to access them.

Notes

The utility command pg_ctl can be used to start and shut down the `postgres` server safely and comfortably.

If at all possible, *do not* use `SIGKILL` to kill the main `postgres` server. Doing so will prevent `postgres` from freeing the system resources (e.g., shared memory and semaphores) that it holds before terminating. This might cause problems for starting a fresh `postgres` run.

To terminate the postgres server normally, the signals SIGTERM, SIGINT, or SIGQUIT can be used. The first will wait for all clients to terminate before quitting, the second will forcefully disconnect all clients, and the third will quit immediately without proper shutdown, resulting in a recovery run during restart.

The SIGHUP signal will reload the server configuration files. It is also possible to send SIGHUP to an individual server process, but that is usually not sensible.

To cancel a running query, send the SIGINT signal to the process running that command. To terminate a backend process cleanly, send SIGTERM to that process. See also pg_cancel_backend and pg_terminate_backend in Section 9.27.2 for the SQL-callable equivalents of these two actions.

The postgres server uses SIGQUIT to tell subordinate server processes to terminate without normal cleanup. This signal *should not* be used by users. It is also unwise to send SIGKILL to a server process — the main postgres process will interpret this as a crash and will force all the sibling processes to quit as part of its standard crash-recovery procedure.

Bugs

The -- options will not work on FreeBSD or OpenBSD. Use -c instead. This is a bug in the affected operating systems; a future release of Postgres Pro will provide a workaround if this is not fixed.

Single-User Mode

To start a single-user mode server, use a command like

postgres --single -D /usr/local/pgsql/data *other-options* my_database

Provide the correct path to the database directory with -D, or make sure that the environment variable PGDATA is set. Also specify the name of the particular database you want to work in.

Normally, the single-user mode server treats newline as the command entry terminator; there is no intelligence about semicolons, as there is in psql. To continue a command across multiple lines, you must type backslash just before each newline except the last one. The backslash and adjacent newline are both dropped from the input command. Note that this will happen even when within a string literal or comment.

But if you use the -j command line switch, a single newline does not terminate command entry; instead, the sequence semicolon-newline-newline does. That is, type a semicolon immediately followed by a completely empty line. Backslash-newline is not treated specially in this mode. Again, there is no intelligence about such a sequence appearing within a string literal or comment.

In either input mode, if you type a semicolon that is not just before or part of a command entry terminator, it is considered a command separator. When you do type a command entry terminator, the multiple statements you've entered will be executed as a single transaction.

To quit the session, type EOF (**Control+D**, usually). If you've entered any text since the last command entry terminator, then EOF will be taken as a command entry terminator, and another EOF will be needed to exit.

Note that the single-user mode server does not provide sophisticated line-editing features (no command history, for example). Single-user mode also does not do any background processing, such as automatic checkpoints or replication.

Examples

To start postgres in the background using default values, type:

```
$ nohup postgres >logfile 2>&1 </dev/null &
```

To start postgres with a specific port, e.g., 1234:

```
$ postgres -p 1234
```

To connect to this server using psql, specify this port with the -p option:

```
$ psql -p 1234
```

or set the environment variable `PGPORT`:

```
$ export PGPORT=1234
$ psql
```

Named run-time parameters can be set in either of these styles:

```
$ postgres -c work_mem=1234
$ postgres --work-mem=1234
```

Either form overrides whatever setting might exist for `work_mem` in `postgresql.conf`. Notice that underscores in parameter names can be written as either underscore or dash on the command line. Except for short-term experiments, it's probably better practice to edit the setting in `postgresql.conf` than to rely on a command-line switch to set a parameter.

See Also

initdb, pg_ctl

postmaster

postmaster — Postgres Pro database server

Synopsis

`postmaster` [*option*...]

Description

`postmaster` is a deprecated alias of `postgres`.

See Also

postgres

Part VII. Internals

This part contains assorted information that might be of use to Postgres Pro developers.

Chapter 53. Overview of Postgres Pro Internals

Author

This chapter originated as part of sim98 Stefan Simkovics' Master's Thesis prepared at Vienna University of Technology under the direction of O.Univ.Prof.Dr. Georg Gottlob and Univ.Ass. Mag. Katrin Seyr.

This chapter gives an overview of the internal structure of the backend of Postgres Pro. After having read the following sections you should have an idea of how a query is processed. This chapter is intended to help the reader understand the general sequence of operations that occur within the backend from the point at which a query is received, to the point at which the results are returned to the client.

53.1. The Path of a Query

Here we give a short overview of the stages a query has to pass to obtain a result.

1. A connection from an application program to the Postgres Pro server has to be established. The application program transmits a query to the server and waits to receive the results sent back by the server.
2. The *parser stage* checks the query transmitted by the application program for correct syntax and creates a *query tree*.
3. The *rewrite system* takes the query tree created by the parser stage and looks for any *rules* (stored in the *system catalogs*) to apply to the query tree. It performs the transformations given in the *rule bodies*.

   One application of the rewrite system is in the realization of *views*. Whenever a query against a view (i.e., a *virtual table*) is made, the rewrite system rewrites the user's query to a query that accesses the *base tables* given in the *view definition* instead.
4. The *planner/optimizer* takes the (rewritten) query tree and creates a *query plan* that will be the input to the *executor*.

   It does so by first creating all possible *paths* leading to the same result. For example if there is an index on a relation to be scanned, there are two paths for the scan. One possibility is a simple sequential scan and the other possibility is to use the index. Next the cost for the execution of each path is estimated and the cheapest path is chosen. The cheapest path is expanded into a complete plan that the executor can use.
5. The executor recursively steps through the *plan tree* and retrieves rows in the way represented by the plan. The executor makes use of the *storage system* while scanning relations, performs *sorts* and *joins*, evaluates *qualifications* and finally hands back the rows derived.

In the following sections we will cover each of the above listed items in more detail to give a better understanding of Postgres Pro's internal control and data structures.

53.2. How Connections Are Established

Postgres Pro implements a “process per user” client/server model. In this model, every *client process* connects to exactly one *backend process*. As we do not know ahead of time how many connections will be made, we have to use a “supervisor process” that spawns a new backend process every time a connection is requested. This supervisor process is called *postmaster* and listens at a specified TCP/IP port for incoming connections. Whenever it detects a request for a connection, it spawns a new backend process. Those backend processes communicate with each other and with other processes of the *instance* using *semaphores* and *shared memory* to ensure data integrity throughout concurrent data access.

The client process can be any program that understands the Postgres Pro protocol described in Chapter 55. Many clients are based on the C-language library libpq, but several independent implementations of the protocol exist, such as the Java JDBC driver.

Once a connection is established, the client process can send a query to the backend process it's connected to. The query is transmitted using plain text, i.e., there is no parsing done in the client. The backend process parses the query, creates an *execution plan*, executes the plan, and returns the retrieved rows to the client by transmitting them over the established connection.

53.3. The Parser Stage

The *parser stage* consists of two parts:

- The *parser* defined in `gram.y` and `scan.l` is built using the Unix tools bison and flex.
- The *transformation process* does modifications and augmentations to the data structures returned by the parser.

53.3.1. Parser

The parser has to check the query string (which arrives as plain text) for valid syntax. If the syntax is correct a *parse tree* is built up and handed back; otherwise an error is returned. The parser and lexer are implemented using the well-known Unix tools bison and flex.

The *lexer* is defined in the file `scan.l` and is responsible for recognizing *identifiers*, the *SQL key words* etc. For every key word or identifier that is found, a *token* is generated and handed to the parser.

The parser is defined in the file `gram.y` and consists of a set of *grammar rules* and *actions* that are executed whenever a rule is fired. The code of the actions (which is actually C code) is used to build up the parse tree.

The file `scan.l` is transformed to the C source file `scan.c` using the program flex and `gram.y` is transformed to `gram.c` using bison. After these transformations have taken place a normal C compiler can be used to create the parser. Never make any changes to the generated C files as they will be overwritten the next time flex or bison is called.

> **Note**
>
> The mentioned transformations and compilations are normally done automatically using the *makefiles* shipped with the Postgres Pro source distribution.

A detailed description of bison or the grammar rules given in `gram.y` would be beyond the scope of this manual. There are many books and documents dealing with flex and bison. You should be familiar with bison before you start to study the grammar given in `gram.y` otherwise you won't understand what happens there.

53.3.2. Transformation Process

The parser stage creates a parse tree using only fixed rules about the syntactic structure of SQL. It does not make any lookups in the system catalogs, so there is no possibility to understand the detailed semantics of the requested operations. After the parser completes, the *transformation process* takes the tree handed back by the parser as input and does the semantic interpretation needed to understand which tables, functions, and operators are referenced by the query. The data structure that is built to represent this information is called the *query tree*.

The reason for separating raw parsing from semantic analysis is that system catalog lookups can only be done within a transaction, and we do not wish to start a transaction immediately upon receiving a query string. The raw parsing stage is sufficient to identify the transaction control commands (`BEGIN`,

`ROLLBACK`, etc), and these can then be correctly executed without any further analysis. Once we know that we are dealing with an actual query (such as `SELECT` or `UPDATE`), it is okay to start a transaction if we're not already in one. Only then can the transformation process be invoked.

The query tree created by the transformation process is structurally similar to the raw parse tree in most places, but it has many differences in detail. For example, a `FuncCall` node in the parse tree represents something that looks syntactically like a function call. This might be transformed to either a `FuncExpr` or `Aggref` node depending on whether the referenced name turns out to be an ordinary function or an aggregate function. Also, information about the actual data types of columns and expression results is added to the query tree.

53.4. The Postgres Pro Rule System

Postgres Pro supports a powerful *rule system* for the specification of *views* and ambiguous *view updates*. Originally the Postgres Pro rule system consisted of two implementations:

- The first one worked using *row level* processing and was implemented deep in the *executor*. The rule system was called whenever an individual row had been accessed. This implementation was removed in 1995 when the last official release of the Berkeley Postgres project was transformed into Postgres95.
- The second implementation of the rule system is a technique called *query rewriting*. The *rewrite system* is a module that exists between the *parser stage* and the *planner/optimizer*. This technique is still implemented.

The query rewriter is discussed in some detail in Chapter 43, so there is no need to cover it here. We will only point out that both the input and the output of the rewriter are query trees, that is, there is no change in the representation or level of semantic detail in the trees. Rewriting can be thought of as a form of macro expansion.

53.5. Planner/Optimizer

The task of the *planner/optimizer* is to create an optimal execution plan. A given SQL query (and hence, a query tree) can be actually executed in a wide variety of different ways, each of which will produce the same set of results. If it is computationally feasible, the query optimizer will examine each of these possible execution plans, ultimately selecting the execution plan that is expected to run the fastest.

> **Note**
>
> In some situations, examining each possible way in which a query can be executed would take an excessive amount of time and memory. In particular, this occurs when executing queries involving large numbers of join operations. In order to determine a reasonable (not necessarily optimal) query plan in a reasonable amount of time, Postgres Pro uses a *Genetic Query Optimizer* (see Chapter 60) when the number of joins exceeds a threshold (see geqo_threshold).

The planner's search procedure actually works with data structures called *paths*, which are simply cut-down representations of plans containing only as much information as the planner needs to make its decisions. After the cheapest path is determined, a full-fledged *plan tree* is built to pass to the executor. This represents the desired execution plan in sufficient detail for the executor to run it. In the rest of this section we'll ignore the distinction between paths and plans.

53.5.1. Generating Possible Plans

The planner/optimizer starts by generating plans for scanning each individual relation (table) used in the query. The possible plans are determined by the available indexes on each relation. There is always the possibility of performing a sequential scan on a relation, so a sequential scan plan is always created. Assume an index is defined on a relation (for example a B-tree index) and a query contains the restriction `relation.attribute OPR constant`. If `relation.attribute` happens to match the key of the B-tree

index and OPR is one of the operators listed in the index's *operator class*, another plan is created using the B-tree index to scan the relation. If there are further indexes present and the restrictions in the query happen to match a key of an index, further plans will be considered. Index scan plans are also generated for indexes that have a sort ordering that can match the query's ORDER BY clause (if any), or a sort ordering that might be useful for merge joining (see below).

If the query requires joining two or more relations, plans for joining relations are considered after all feasible plans have been found for scanning single relations. The three available join strategies are:

- *nested loop join*: The right relation is scanned once for every row found in the left relation. This strategy is easy to implement but can be very time consuming. (However, if the right relation can be scanned with an index scan, this can be a good strategy. It is possible to use values from the current row of the left relation as keys for the index scan of the right.)
- *merge join*: Each relation is sorted on the join attributes before the join starts. Then the two relations are scanned in parallel, and matching rows are combined to form join rows. This kind of join is attractive because each relation has to be scanned only once. The required sorting might be achieved either by an explicit sort step, or by scanning the relation in the proper order using an index on the join key.
- *hash join*: the right relation is first scanned and loaded into a hash table, using its join attributes as hash keys. Next the left relation is scanned and the appropriate values of every row found are used as hash keys to locate the matching rows in the table.

When the query involves more than two relations, the final result must be built up by a tree of join steps, each with two inputs. The planner examines different possible join sequences to find the cheapest one.

If the query uses fewer than geqo_threshold relations, a near-exhaustive search is conducted to find the best join sequence. The planner preferentially considers joins between any two relations for which there exists a corresponding join clause in the WHERE qualification (i.e., for which a restriction like `where rel1.attr1=rel2.attr2` exists). Join pairs with no join clause are considered only when there is no other choice, that is, a particular relation has no available join clauses to any other relation. All possible plans are generated for every join pair considered by the planner, and the one that is (estimated to be) the cheapest is chosen.

When geqo_threshold is exceeded, the join sequences considered are determined by heuristics, as described in Chapter 60. Otherwise the process is the same.

The finished plan tree consists of sequential or index scans of the base relations, plus nested-loop, merge, or hash join nodes as needed, plus any auxiliary steps needed, such as sort nodes or aggregate-function calculation nodes. Most of these plan node types have the additional ability to do *selection* (discarding rows that do not meet a specified Boolean condition) and *projection* (computation of a derived column set based on given column values, that is, evaluation of scalar expressions where needed). One of the responsibilities of the planner is to attach selection conditions from the WHERE clause and computation of required output expressions to the most appropriate nodes of the plan tree.

53.6. Executor

The *executor* takes the plan created by the planner/optimizer and recursively processes it to extract the required set of rows. This is essentially a demand-pull pipeline mechanism. Each time a plan node is called, it must deliver one more row, or report that it is done delivering rows.

To provide a concrete example, assume that the top node is a MergeJoin node. Before any merge can be done two rows have to be fetched (one from each subplan). So the executor recursively calls itself to process the subplans (it starts with the subplan attached to lefttree). The new top node (the top node of the left subplan) is, let's say, a Sort node and again recursion is needed to obtain an input row. The child node of the Sort might be a SeqScan node, representing actual reading of a table. Execution of this node causes the executor to fetch a row from the table and return it up to the calling node. The Sort node will repeatedly call its child to obtain all the rows to be sorted. When the input is exhausted (as indicated by the child node returning a NULL instead of a row), the Sort code performs the sort, and

finally is able to return its first output row, namely the first one in sorted order. It keeps the remaining rows stored so that it can deliver them in sorted order in response to later demands.

The `MergeJoin` node similarly demands the first row from its right subplan. Then it compares the two rows to see if they can be joined; if so, it returns a join row to its caller. On the next call, or immediately if it cannot join the current pair of inputs, it advances to the next row of one table or the other (depending on how the comparison came out), and again checks for a match. Eventually, one subplan or the other is exhausted, and the `MergeJoin` node returns NULL to indicate that no more join rows can be formed.

Complex queries can involve many levels of plan nodes, but the general approach is the same: each node computes and returns its next output row each time it is called. Each node is also responsible for applying any selection or projection expressions that were assigned to it by the planner.

The executor mechanism is used to evaluate all four basic SQL query types: `SELECT`, `INSERT`, `UPDATE`, and `DELETE`. For `SELECT`, the top-level executor code only needs to send each row returned by the query plan tree off to the client. `INSERT ... SELECT`, `UPDATE`, and `DELETE` are effectively `SELECT`s under a special top-level plan node called `ModifyTable`.

`INSERT ... SELECT` feeds the rows up to `ModifyTable` for insertion. For `UPDATE`, the planner arranges that each computed row includes all the updated column values, plus the *TID* (tuple ID, or row ID) of the original target row; this data is fed up to the `ModifyTable` node, which uses the information to create a new updated row and mark the old row deleted. For `DELETE`, the only column that is actually returned by the plan is the TID, and the `ModifyTable` node simply uses the TID to visit each target row and mark it deleted.

A simple `INSERT ... VALUES` command creates a trivial plan tree consisting of a single `Result` node, which computes just one result row, feeding that up to `ModifyTable` to perform the insertion.

Chapter 54. System Catalogs

The system catalogs are the place where a relational database management system stores schema metadata, such as information about tables and columns, and internal bookkeeping information. Postgres Pro's system catalogs are regular tables. You can drop and recreate the tables, add columns, insert and update values, and severely mess up your system that way. Normally, one should not change the system catalogs by hand, there are normally SQL commands to do that. (For example, `CREATE DATABASE` inserts a row into the `pg_database` catalog — and actually creates the database on disk.) There are some exceptions for particularly esoteric operations, but many of those have been made available as SQL commands over time, and so the need for direct manipulation of the system catalogs is ever decreasing.

54.1. Overview

Table 54.1 lists the system catalogs. More detailed documentation of each catalog follows below.

Most system catalogs are copied from the template database during database creation and are thereafter database-specific. A few catalogs are physically shared across all databases in a cluster; these are noted in the descriptions of the individual catalogs.

Table 54.1. System Catalogs

Catalog Name	Purpose
pg_aggregate	aggregate functions
pg_am	relation access methods
pg_amop	access method operators
pg_amproc	access method support functions
pg_attrdef	column default values
pg_attribute	table columns (“attributes”)
pg_authid	authorization identifiers (roles)
pg_auth_members	authorization identifier membership relationships
pg_cast	casts (data type conversions)
pg_class	tables, indexes, sequences, views (“relations”)
pg_collation	collations (locale information)
pg_constraint	check constraints, unique constraints, primary key constraints, foreign key constraints
pg_conversion	encoding conversion information
pg_database	databases within this database cluster
pg_db_role_setting	per-role and per-database settings
pg_default_acl	default privileges for object types
pg_depend	dependencies between database objects
pg_description	descriptions or comments on database objects
pg_enum	enum label and value definitions
pg_event_trigger	event triggers
pg_extension	installed extensions
pg_foreign_data_wrapper	foreign-data wrapper definitions
pg_foreign_server	foreign server definitions
pg_foreign_table	additional foreign table information
pg_index	additional index information

Catalog Name	Purpose
pg_inherits	table inheritance hierarchy
pg_init_privs	object initial privileges
pg_language	languages for writing functions
pg_largeobject	data pages for large objects
pg_largeobject_metadata	metadata for large objects
pg_namespace	schemas
pg_opclass	access method operator classes
pg_operator	operators
pg_opfamily	access method operator families
pg_partitioned_table	information about partition key of tables
pg_policy	row-security policies
pg_proc	functions and procedures
pg_profile	profiles, a set of authentication restrictions
pg_publication	publications for logical replication
pg_publication_rel	relation to publication mapping
pg_range	information about range types
pg_replication_origin	registered replication origins
pg_rewrite	query rewrite rules
pg_role_password	roles password history
pg_seclabel	security labels on database objects
pg_sequence	information about sequences
pg_shdepend	dependencies on shared objects
pg_shdescription	comments on shared objects
pg_shseclabel	security labels on shared database objects
pg_statistic	planner statistics
pg_statistic_ext	extended planner statistics (definition)
pg_statistic_ext_data	extended planner statistics (built statistics)
pg_subscription	logical replication subscriptions
pg_subscription_rel	relation state for subscriptions
pg_tablespace	tablespaces within this database cluster
pg_transform	transforms (data type to procedural language conversions)
pg_trigger	triggers
pg_ts_config	text search configurations
pg_ts_config_map	text search configurations' token mappings
pg_ts_dict	text search dictionaries
pg_ts_parser	text search parsers
pg_ts_template	text search templates
pg_type	data types
pg_user_mapping	mappings of users to foreign servers

54.2. pg_aggregate

The catalog pg_aggregate stores information about aggregate functions. An aggregate function is a function that operates on a set of values (typically one column from each row that matches a query condition) and returns a single value computed from all these values. Typical aggregate functions are sum, count, and max. Each entry in pg_aggregate is an extension of an entry in pg_proc. The pg_proc entry carries the aggregate's name, input and output data types, and other information that is similar to ordinary functions.

Table 54.2. pg_aggregate Columns

Column Type Description
aggfnoid regproc (references pg_proc .oid) pg_proc OID of the aggregate function
aggkind char Aggregate kind: n for “normal” aggregates, o for “ordered-set” aggregates, or h for “hypothetical-set” aggregates
aggnumdirectargs int2 Number of direct (non-aggregated) arguments of an ordered-set or hypothetical-set aggregate, counting a variadic array as one argument. If equal to pronargs, the aggregate must be variadic and the variadic array describes the aggregated arguments as well as the final direct arguments. Always zero for normal aggregates.
aggtransfn regproc (references pg_proc .oid) Transition function
aggfinalfn regproc (references pg_proc .oid) Final function (zero if none)
aggcombinefn regproc (references pg_proc .oid) Combine function (zero if none)
aggserialfn regproc (references pg_proc .oid) Serialization function (zero if none)
aggdeserialfn regproc (references pg_proc .oid) Deserialization function (zero if none)
aggmtransfn regproc (references pg_proc .oid) Forward transition function for moving-aggregate mode (zero if none)
aggminvtransfn regproc (references pg_proc .oid) Inverse transition function for moving-aggregate mode (zero if none)
aggmfinalfn regproc (references pg_proc .oid) Final function for moving-aggregate mode (zero if none)
aggfinalextra bool True to pass extra dummy arguments to aggfinalfn
aggmfinalextra bool True to pass extra dummy arguments to aggmfinalfn
aggfinalmodify char Whether aggfinalfn modifies the transition state value: r if it is read-only, s if the aggtransfn cannot be applied after the aggfinalfn, or w if it writes on the value
aggmfinalmodify char Like aggfinalmodify, but for the aggmfinalfn
aggsortop oid (references pg_operator .oid) Associated sort operator (zero if none)
aggtranstype oid (references pg_type .oid)

Column Type Description
Data type of the aggregate function's internal transition (state) data
`aggtransspace` `int4` Approximate average size (in bytes) of the transition state data, or zero to use a default estimate
`aggmtranstype` `oid` (references `pg_type` `.oid`) Data type of the aggregate function's internal transition (state) data for moving-aggregate mode (zero if none)
`aggmtransspace` `int4` Approximate average size (in bytes) of the transition state data for moving-aggregate mode, or zero to use a default estimate
`agginitval` `text` The initial value of the transition state. This is a text field containing the initial value in its external string representation. If this field is null, the transition state value starts out null.
`aggminitval` `text` The initial value of the transition state for moving-aggregate mode. This is a text field containing the initial value in its external string representation. If this field is null, the transition state value starts out null.

New aggregate functions are registered with the `CREATE AGGREGATE` command. See Section 40.12 for more information about writing aggregate functions and the meaning of the transition functions, etc.

54.3. pg_am

The catalog `pg_am` stores information about relation access methods. There is one row for each access method supported by the system. Currently, only tables and indexes have access methods. The requirements for table and index access methods are discussed in detail in Chapter 61 and Chapter 62 respectively.

Table 54.3. `pg_am` Columns

Column Type Description
`oid` `oid` Row identifier
`amname` `name` Name of the access method
`amhandler` `regproc` (references `pg_proc` `.oid`) OID of a handler function that is responsible for supplying information about the access method
`amtype` `char` `t` = table (including materialized views), `i` = index.

> **Note**
>
> Before Postgres Pro 9.6, `pg_am` contained many additional columns representing properties of index access methods. That data is now only directly visible at the C code level. However, `pg_index_column_has_property()` and related functions have been added to allow SQL queries to inspect index access method properties; see Table 9.70.

54.4. pg_amop

The catalog pg_amop stores information about operators associated with access method operator families. There is one row for each operator that is a member of an operator family. A family member can be either a *search* operator or an *ordering* operator. An operator can appear in more than one family, but cannot appear in more than one search position nor more than one ordering position within a family. (It is allowed, though unlikely, for an operator to be used for both search and ordering purposes.)

Table 54.4. pg_amop Columns

Column Type Description
oid oid Row identifier
amopfamily oid (references pg_opfamily .oid) The operator family this entry is for
amoplefttype oid (references pg_type .oid) Left-hand input data type of operator
amoprighttype oid (references pg_type .oid) Right-hand input data type of operator
amopstrategy int2 Operator strategy number
amoppurpose char Operator purpose, either s for search or o for ordering
amopopr oid (references pg_operator .oid) OID of the operator
amopmethod oid (references pg_am .oid) Index access method operator family is for
amopsortfamily oid (references pg_opfamily .oid) The B-tree operator family this entry sorts according to, if an ordering operator; zero if a search operator

A “search” operator entry indicates that an index of this operator family can be searched to find all rows satisfying WHERE *indexed_column operator constant*. Obviously, such an operator must return boolean, and its left-hand input type must match the index's column data type.

An “ordering” operator entry indicates that an index of this operator family can be scanned to return rows in the order represented by ORDER BY *indexed_column operator constant*. Such an operator could return any sortable data type, though again its left-hand input type must match the index's column data type. The exact semantics of the ORDER BY are specified by the amopsortfamily column, which must reference a B-tree operator family for the operator's result type.

> **Note**
>
> At present, it's assumed that the sort order for an ordering operator is the default for the referenced operator family, i.e., ASC NULLS LAST. This might someday be relaxed by adding additional columns to specify sort options explicitly.

An entry's amopmethod must match the opfmethod of its containing operator family (including amopmethod here is an intentional denormalization of the catalog structure for performance reasons). Also, amoplefttype and amoprighttype must match the oprleft and oprright fields of the referenced pg_operator entry.

54.5. pg_amproc

The catalog pg_amproc stores information about support functions associated with access method operator families. There is one row for each support function belonging to an operator family.

Table 54.5. `pg_amproc` Columns

Column Type Description
`oid oid` Row identifier
`amprocfamily oid` (references `pg_opfamily .oid`) The operator family this entry is for
`amproclefttype oid` (references `pg_type .oid`) Left-hand input data type of associated operator
`amprocrighttype oid` (references `pg_type .oid`) Right-hand input data type of associated operator
`amprocnum int2` Support function number
`amproc regproc` (references `pg_proc .oid`) OID of the function

The usual interpretation of the `amproclefttype` and `amprocrighttype` fields is that they identify the left and right input types of the operator(s) that a particular support function supports. For some access methods these match the input data type(s) of the support function itself, for others not. There is a notion of "default" support functions for an index, which are those with `amproclefttype` and `amprocrighttype` both equal to the index operator class's `opcintype`.

54.6. `pg_attrdef`

The catalog `pg_attrdef` stores column default values. The main information about columns is stored in `pg_attribute`. Only columns for which a default value has been explicitly set will have an entry here.

Table 54.6. `pg_attrdef` Columns

Column Type Description
`oid oid` Row identifier
`adrelid oid` (references `pg_class .oid`) The table this column belongs to
`adnum int2` (references `pg_attribute .attnum`) The number of the column
`adbin pg_node_tree` The column default value, in `nodeToString()` representation. Use `pg_get_expr(adbin, adrelid)` to convert it to an SQL expression.

54.7. `pg_attribute`

The catalog `pg_attribute` stores information about table columns. There will be exactly one `pg_attribute` row for every column in every table in the database. (There will also be attribute entries for indexes, and indeed all objects that have `pg_class` entries.)

The term attribute is equivalent to column and is used for historical reasons.

Table 54.7. `pg_attribute` Columns

Column Type Description
`attrelid oid` (references `pg_class .oid`) The table this column belongs to

Column Type Description
attname name The column name
atttypid oid (references pg_type .oid) The data type of this column (zero for a dropped column)
attstattarget int4 attstattarget controls the level of detail of statistics accumulated for this column by ANALYZE. A zero value indicates that no statistics should be collected. A negative value says to use the system default statistics target. The exact meaning of positive values is data type-dependent. For scalar data types, attstattarget is both the target number of "most common values" to collect, and the target number of histogram bins to create.
attlen int2 A copy of pg_type.typlen of this column's type
attnum int2 The number of the column. Ordinary columns are numbered from 1 up. System columns, such as ctid, have (arbitrary) negative numbers.
attndims int4 Number of dimensions, if the column is an array type; otherwise 0. (Presently, the number of dimensions of an array is not enforced, so any nonzero value effectively means "it's an array".)
attcacheoff int4 Always -1 in storage, but when loaded into a row descriptor in memory this might be updated to cache the offset of the attribute within the row
atttypmod int4 atttypmod records type-specific data supplied at table creation time (for example, the maximum length of a varchar column). It is passed to type-specific input functions and length coercion functions. The value will generally be -1 for types that do not need atttypmod.
attbyval bool A copy of pg_type.typbyval of this column's type
attalign char A copy of pg_type.typalign of this column's type
attstorage char Normally a copy of pg_type.typstorage of this column's type. For TOAST-able data types, this can be altered after column creation to control storage policy.
attcompression char The current compression method of the column. Typically this is '\0' to specify use of the current default setting (see default_toast_compression). Otherwise, 'p' selects pglz compression, while 'l' selects LZ4 compression. However, this field is ignored whenever attstorage does not allow compression.
attnotnull bool This represents a not-null constraint.
atthasdef bool This column has a default expression or generation expression, in which case there will be a corresponding entry in the pg_attrdef catalog that actually defines the expression. (Check attgenerated to determine whether this is a default or a generation expression.)
atthasmissing bool This column has a value which is used where the column is entirely missing from the row, as happens when a column is added with a non-volatile DEFAULT value after the row is created. The actual value used is stored in the attmissingval column.

Column Type Description
attidentity char If a zero byte (''), then not an identity column. Otherwise, a = generated always, d = generated by default.
attgenerated char If a zero byte (''), then not a generated column. Otherwise, s = stored. (Other values might be added in the future.)
attisdropped bool This column has been dropped and is no longer valid. A dropped column is still physically present in the table, but is ignored by the parser and so cannot be accessed via SQL.
attislocal bool This column is defined locally in the relation. Note that a column can be locally defined and inherited simultaneously.
attinhcount int4 The number of direct ancestors this column has. A column with a nonzero number of ancestors cannot be dropped nor renamed.
attcollation oid (references pg_collation .oid) The defined collation of the column, or zero if the column is not of a collatable data type
attacl aclitem[] Column-level access privileges, if any have been granted specifically on this column
attoptions text[] Attribute-level options, as “keyword=value” strings
attfdwoptions text[] Attribute-level foreign data wrapper options, as “keyword=value” strings
attmissingval anyarray This column has a one element array containing the value used when the column is entirely missing from the row, as happens when the column is added with a non-volatile DEFAULT value after the row is created. The value is only used when atthasmissing is true. If there is no value the column is null.

In a dropped column's pg_attribute entry, atttypid is reset to zero, but attlen and the other fields copied from pg_type are still valid. This arrangement is needed to cope with the situation where the dropped column's data type was later dropped, and so there is no pg_type row anymore. attlen and the other fields can be used to interpret the contents of a row of the table.

54.8. pg_authid

The catalog pg_authid contains information about database authorization identifiers (roles). A role subsumes the concepts of “users” and “groups”. A user is essentially just a role with the rolcanlogin flag set. Any role (with or without rolcanlogin) can have other roles as members; see pg_auth_members.

Since this catalog contains passwords, it must not be publicly readable. pg_roles is a publicly readable view on pg_authid that blanks out the password field.

Chapter 21 contains detailed information about user and privilege management.

Because user identities are cluster-wide, pg_authid is shared across all databases of a cluster: there is only one copy of pg_authid per cluster, not one per database.

Table 54.8. pg_authid Columns

Column Type Description
oid oid

Column Type **Description**
Row identifier
`rolname name` Role name
`rolsuper bool` Role has superuser privileges
`rolinherit bool` Role automatically inherits privileges of roles it is a member of
`rolcreaterole bool` Role can create more roles
`rolcreatedb bool` Role can create databases
`rolcanlogin bool` Role can log in. That is, this role can be given as the initial session authorization identifier.
`rolreplication bool` Role is a replication role. A replication role can initiate replication connections and create and drop replication slots.
`rolbypassrls bool` Role bypasses every row-level security policy, see Section 5.8 for more information.
`rolconnlimit int4` For roles that can log in, this sets maximum number of concurrent connections this role can make. -1 means no limit.
`rolprofile regprofile` (references `pg_profile .oid`) The OID of the role's profile
`rolloginattempts int4` Number of consecutive failed login attempts of a user. It is always `0` if `FAILED_LOGIN_ATTEMPTS` value of the corresponding role profile is `UNLIMITED` (see CREATE PROFILE). After a successful login, `rolloginattempts` is reset to `0`.
`rolstatus int2` Status of the role: `0` for the active role, `1` the role is manually locked (see `ACCOUNT LOCK` in ALTER ROLE), `2` the role is locked because of inactivity (see parameter `USER_INACTIVE_TIME` in CREATE PROFILE), `4` the role is locked because the number of consecutive authentication failures has reached the limit (see parameter `FAILED_LOGIN_ATTEMPTS` in CREATE PROFILE)
`rollastlogin timestamptz` The timestamp the role logged in last time
`rolfirstfailedauth timestamptz` The timestamp of the role's first authentication failure
`rolpassword text` Password (possibly encrypted); null if none. The format depends on the form of encryption used.
`rolvaliduntil timestamptz` Password expiry time (only used for password authentication); null if no expiration
`rolpasssetat timestamptz` Password set time (only used for password authentication); null if password is not set.

For an MD5 encrypted password, `rolpassword` column will begin with the string `md5` followed by a 32-character hexadecimal MD5 hash. The MD5 hash will be of the user's password concatenated to

their user name. For example, if user `joe` has password `xyzzy`, Postgres Pro will store the md5 hash of `xyzzyjoe`.

If the password is encrypted with SCRAM-SHA-256, it has the format:

`SCRAM-SHA-256$<iteration count>:<salt>$<StoredKey>:<ServerKey>`

where *`salt`*, *`StoredKey`* and *`ServerKey`* are in Base64 encoded format. This format is the same as that specified by *RFC 5803*.

A password that does not follow either of those formats is assumed to be unencrypted.

54.9. pg_auth_members

The catalog `pg_auth_members` shows the membership relations between roles. Any non-circular set of relationships is allowed.

Because user identities are cluster-wide, `pg_auth_members` is shared across all databases of a cluster: there is only one copy of `pg_auth_members` per cluster, not one per database.

Table 54.9. `pg_auth_members` Columns

Column Type Description
`roleid oid` (references `pg_authid .oid`) ID of a role that has a member
`member oid` (references `pg_authid .oid`) ID of a role that is a member of `roleid`
`grantor oid` (references `pg_authid .oid`) ID of the role that granted this membership
`admin_option bool` True if `member` can grant membership in `roleid` to others

54.10. pg_cast

The catalog `pg_cast` stores data type conversion paths, both built-in and user-defined.

It should be noted that `pg_cast` does not represent every type conversion that the system knows how to perform; only those that cannot be deduced from some generic rule. For example, casting between a domain and its base type is not explicitly represented in `pg_cast`. Another important exception is that "automatic I/O conversion casts", those performed using a data type's own I/O functions to convert to or from `text` or other string types, are not explicitly represented in `pg_cast`.

Table 54.10. `pg_cast` Columns

Column Type Description
`oid oid` Row identifier
`castsource oid` (references `pg_type .oid`) OID of the source data type
`casttarget oid` (references `pg_type .oid`) OID of the target data type
`castfunc oid` (references `pg_proc .oid`) The OID of the function to use to perform this cast. Zero is stored if the cast method doesn't require a function.
`castcontext char`

Column Type Description
Indicates what contexts the cast can be invoked in. `e` means only as an explicit cast (using `CAST` or `::` syntax). `a` means implicitly in assignment to a target column, as well as explicitly. `i` means implicitly in expressions, as well as the other cases.
`castmethod char` Indicates how the cast is performed. `f` means that the function specified in the `castfunc` field is used. `i` means that the input/output functions are used. `b` means that the types are binary-coercible, thus no conversion is required.

The cast functions listed in `pg_cast` must always take the cast source type as their first argument type, and return the cast destination type as their result type. A cast function can have up to three arguments. The second argument, if present, must be type `integer`; it receives the type modifier associated with the destination type, or -1 if there is none. The third argument, if present, must be type `boolean`; it receives `true` if the cast is an explicit cast, `false` otherwise.

It is legitimate to create a `pg_cast` entry in which the source and target types are the same, if the associated function takes more than one argument. Such entries represent "length coercion functions" that coerce values of the type to be legal for a particular type modifier value.

When a `pg_cast` entry has different source and target types and a function that takes more than one argument, it represents converting from one type to another and applying a length coercion in a single step. When no such entry is available, coercion to a type that uses a type modifier involves two steps, one to convert between data types and a second to apply the modifier.

54.11. `pg_class`

The catalog `pg_class` describes tables and other objects that have columns or are otherwise similar to a table. This includes indexes (but see also `pg_index`), sequences (but see also `pg_sequence`), views, materialized views, composite types, and TOAST tables; see `relkind`. Below, when we mean all of these kinds of objects we speak of "relations". Not all of `pg_class`'s columns are meaningful for all relation kinds.

Table 54.11. `pg_class` Columns

Column Type Description
`oid oid` Row identifier
`relname name` Name of the table, index, view, etc.
`relnamespace oid` (references `pg_namespace .oid`) The OID of the namespace that contains this relation
`reltype oid` (references `pg_type .oid`) The OID of the data type that corresponds to this table's row type, if any; zero for indexes, sequences, and toast tables, which have no `pg_type` entry
`reloftype oid` (references `pg_type .oid`) For typed tables, the OID of the underlying composite type; zero for all other relations
`relowner oid` (references `pg_authid .oid`) Owner of the relation
`relam oid` (references `pg_am .oid`) If this is a table or an index, the access method used (heap, B-tree, hash, etc.); otherwise zero (zero occurs for sequences, as well as relations without storage, such as views)
`relfilenode oid`

Column Type Description
Name of the on-disk file of this relation; zero means this is a “mapped” relation whose disk file name is determined by low-level state
`reltablespace` `oid` (references `pg_tablespace` .`oid`) The tablespace in which this relation is stored. If zero, the database's default tablespace is implied. Not meaningful if the relation has no on-disk file, except for partitioned tables, where this is the tablespace in which partitions will be created when one is not specified in the creation command.
`relpages` `int4` Size of the on-disk representation of this table in pages (of size `BLCKSZ`). This is only an estimate used by the planner. It is updated by `VACUUM`, `ANALYZE`, and a few DDL commands such as `CREATE INDEX`.
`reltuples` `float4` Number of live rows in the table. This is only an estimate used by the planner. It is updated by `VACUUM`, `ANALYZE`, and a few DDL commands such as `CREATE INDEX`. If the table has never yet been vacuumed or analyzed, `reltuples` contains `-1` indicating that the row count is unknown.
`relallvisible` `int4` Number of pages that are marked all-visible in the table's visibility map. This is only an estimate used by the planner. It is updated by `VACUUM`, `ANALYZE`, and a few DDL commands such as `CREATE INDEX`.
`reltoastrelid` `oid` (references `pg_class` .`oid`) OID of the TOAST table associated with this table, zero if none. The TOAST table stores large attributes “out of line” in a secondary table.
`relhasindex` `bool` True if this is a table and it has (or recently had) any indexes
`relisshared` `bool` True if this table is shared across all databases in the cluster. Only certain system catalogs (such as `pg_database`) are shared.
`relpersistence` `char` `p` = permanent table, `u` = unlogged table, `t` = temporary table, `c` = constant table
`relkind` `char` `r` = ordinary table, `i` = index, `S` = sequence, `t` = TOAST table, `v` = view, `m` = materialized view, `c` = composite type, `f` = foreign table, `p` = partitioned table, `I` = partitioned index
`relnatts` `int2` Number of user columns in the relation (system columns not counted). There must be this many corresponding entries in `pg_attribute` . See also `pg_attribute` .`attnum`.
`relchecks` `int2` Number of `CHECK` constraints on the table; see `pg_constraint` catalog
`relhasrules` `bool` True if table has (or once had) rules; see `pg_rewrite` catalog
`relhastriggers` `bool` True if table has (or once had) triggers; see `pg_trigger` catalog
`relhassubclass` `bool` True if table or index has (or once had) any inheritance children
`relrowsecurity` `bool` True if table has row-level security enabled; see `pg_policy` catalog
`relforcerowsecurity` `bool`

Column Type Description
True if row-level security (when enabled) will also apply to table owner; see pg_policy catalog
relispopulated bool True if relation is populated (this is true for all relations other than some materialized views)
relreplident char Columns used to form "replica identity" for rows: d = default (primary key, if any), n = nothing, f = all columns, i = index with indisreplident set (same as nothing if the index used has been dropped)
relispartition bool True if table or index is a partition
relrewrite oid (references pg_class .oid) For new relations being written during a DDL operation that requires a table rewrite, this contains the OID of the original relation; otherwise zero. That state is only visible internally; this field should never contain anything other than zero for a user-visible relation.
relfrozenxid xid All transaction IDs before this one have been replaced with a permanent ("frozen") transaction ID in this table. This is used to track whether the table needs to be vacuumed in order to allow pg_xact to be shrunk. Zero (InvalidTransactionId) if the relation is not a table.
relminmxid xid All multixact IDs before this one have been replaced by a transaction ID in this table. This is used to track whether the table needs to be vacuumed in order to allow pg_multixact to be shrunk. Zero (InvalidMultiXactId) if the relation is not a table.
relacl aclitem[] Access privileges; see Section 5.7 for details
reloptions text[] Access-method-specific options, as "keyword=value" strings
relpartbound pg_node_tree If table is a partition (see relispartition), internal representation of the partition bound

Several of the Boolean flags in pg_class are maintained lazily: they are guaranteed to be true if that's the correct state, but may not be reset to false immediately when the condition is no longer true. For example, relhasindex is set by CREATE INDEX, but it is never cleared by DROP INDEX. Instead, VACUUM clears relhasindex if it finds the table has no indexes. This arrangement avoids race conditions and improves concurrency.

54.12. pg_collation

The catalog pg_collation describes the available collations, which are essentially mappings from an SQL name to operating system locale categories. See Section 23.2 for more information.

Table 54.12. pg_collation Columns

Column Type Description
oid oid Row identifier
collname name Collation name (unique per namespace and encoding)
collnamespace oid (references pg_namespace .oid) The OID of the namespace that contains this collation
collowner oid (references pg_authid .oid)

Column Type Description
Owner of the collation
collprovider char Provider of the collation: d = database default, c = libc, i = icu
collisdeterministic bool Is the collation deterministic?
collencoding int4 Encoding in which the collation is applicable, or -1 if it works for any encoding
collcollate name LC_COLLATE for this collation object
collctype name LC_CTYPE for this collation object
collversion text Provider-specific version of the collation. This is recorded when the collation is created and then checked when it is used, to detect changes in the collation definition that could lead to data corruption.

Note that the unique key on this catalog is (collname, collencoding, collnamespace) not just (collname, collnamespace). Postgres Pro generally ignores all collations that do not have collencoding equal to either the current database's encoding or -1, and creation of new entries with the same name as an entry with collencoding = -1 is forbidden. Therefore it is sufficient to use a qualified SQL name (*schema*.*name*) to identify a collation, even though this is not unique according to the catalog definition. The reason for defining the catalog this way is that initdb fills it in at cluster initialization time with entries for all locales available on the system, so it must be able to hold entries for all encodings that might ever be used in the cluster.

In the template0 database, it could be useful to create collations whose encoding does not match the database encoding, since they could match the encodings of databases later cloned from template0. This would currently have to be done manually.

54.13. pg_constraint

The catalog pg_constraint stores check, primary key, unique, foreign key, and exclusion constraints on tables. (Column constraints are not treated specially. Every column constraint is equivalent to some table constraint.) Not-null constraints are represented in the pg_attribute catalog, not here.

User-defined constraint triggers (created with CREATE CONSTRAINT TRIGGER) also give rise to an entry in this table.

Check constraints on domains are stored here, too.

Table 54.13. pg_constraint Columns

Column Type Description
oid oid Row identifier
conname name Constraint name (not necessarily unique!)
connamespace oid (references pg_namespace .oid) The OID of the namespace that contains this constraint
contype char c = check constraint, f = foreign key constraint, p = primary key constraint, u = unique constraint, t = constraint trigger, x = exclusion constraint

Column Type Description
condeferrable bool Is the constraint deferrable?
condeferred bool Is the constraint deferred by default?
convalidated bool Has the constraint been validated? Currently, can be false only for foreign keys and CHECK constraints
conrelid oid (references pg_class .oid) The table this constraint is on; zero if not a table constraint
contypid oid (references pg_type .oid) The domain this constraint is on; zero if not a domain constraint
conindid oid (references pg_class .oid) The index supporting this constraint, if it's a unique, primary key, foreign key, or exclusion constraint; else zero
conparentid oid (references pg_constraint .oid) The corresponding constraint of the parent partitioned table, if this is a constraint on a partition; else zero
confrelid oid (references pg_class .oid) If a foreign key, the referenced table; else zero
confupdtype char Foreign key update action code: a = no action, r = restrict, c = cascade, n = set null, d = set default
confdeltype char Foreign key deletion action code: a = no action, r = restrict, c = cascade, n = set null, d = set default
confmatchtype char Foreign key match type: f = full, p = partial, s = simple
conislocal bool This constraint is defined locally for the relation. Note that a constraint can be locally defined and inherited simultaneously.
coninhcount int4 The number of direct inheritance ancestors this constraint has. A constraint with a nonzero number of ancestors cannot be dropped nor renamed.
connoinherit bool This constraint is defined locally for the relation. It is a non-inheritable constraint.
conkey int2[] (references pg_attribute .attnum) If a table constraint (including foreign keys, but not constraint triggers), list of the constrained columns
confkey int2[] (references pg_attribute .attnum) If a foreign key, list of the referenced columns
conpfeqop oid[] (references pg_operator .oid) If a foreign key, list of the equality operators for PK = FK comparisons
conppeqop oid[] (references pg_operator .oid) If a foreign key, list of the equality operators for PK = PK comparisons
conffeqop oid[] (references pg_operator .oid) If a foreign key, list of the equality operators for FK = FK comparisons
conexclop oid[] (references pg_operator .oid)

Column Type Description
If an exclusion constraint, list of the per-column exclusion operators
conbin pg_node_tree If a check constraint, an internal representation of the expression. (It's recommended to use pg_get_constraintdef() to extract the definition of a check constraint.)

In the case of an exclusion constraint, conkey is only useful for constraint elements that are simple column references. For other cases, a zero appears in conkey and the associated index must be consulted to discover the expression that is constrained. (conkey thus has the same contents as pg_index.indkey for the index.)

> **Note**
>
> pg_class.relchecks needs to agree with the number of check-constraint entries found in this table for each relation.

54.14. pg_conversion

The catalog pg_conversion describes encoding conversion functions. See CREATE CONVERSION for more information.

Table 54.14. pg_conversion Columns

Column Type Description
oid oid Row identifier
conname name Conversion name (unique within a namespace)
connamespace oid (references pg_namespace .oid) The OID of the namespace that contains this conversion
conowner oid (references pg_authid .oid) Owner of the conversion
conforencoding int4 Source encoding ID
contoencoding int4 Destination encoding ID
conproc regproc (references pg_proc .oid) Conversion function
condefault bool True if this is the default conversion

54.15. pg_database

The catalog pg_database stores information about the available databases. Databases are created with the CREATE DATABASE command. Consult Chapter 22 for details about the meaning of some of the parameters.

Unlike most system catalogs, pg_database is shared across all databases of a cluster: there is only one copy of pg_database per cluster, not one per database.

Table 54.15. `pg_database` Columns

Column Type Description
`oid oid` Row identifier
`datname name` Database name
`datdba oid` (references `pg_authid .oid`) Owner of the database, usually the user who created it
`encoding int4` Character encoding for this database (`pg_encoding_to_char()` can translate this number to the encoding name)
`datcollate name` LC_COLLATE for this database
`datctype name` LC_CTYPE for this database
`datistemplate bool` If true, then this database can be cloned by any user with `CREATEDB` privileges; if false, then only superusers or the owner of the database can clone it.
`datallowconn bool` If false then no one can connect to this database. This is used to protect the `template0` database from being altered.
`dathasloginevt bool` Indicates that there are login event triggers defined for this database. This flag is used to avoid extra lookups on the `pg_event_trigger` table during each backend startup. This flag is used internally by Postgres Pro and should not be manually altered or read for monitoring purposes.
`datconnlimit int4` Sets maximum number of concurrent connections that can be made to this database. -1 means no limit, -2 indicates the database is invalid.
`datlastsysoid oid` Last system OID in the database; useful particularly to pg_dump
`datfrozenxid xid` All transaction IDs before this one have been replaced with a permanent ("frozen") transaction ID in this database. This is used to track whether the database needs to be vacuumed in order to allow `pg_xact` to be shrunk. It is the minimum of the per-table `pg_class .relfrozenxid` values.
`datminmxid xid` All multixact IDs before this one have been replaced with a transaction ID in this database. This is used to track whether the database needs to be vacuumed in order to allow `pg_multixact` to be shrunk. It is the minimum of the per-table `pg_class .relminmxid` values.
`dattablespace oid` (references `pg_tablespace .oid`) The default tablespace for the database. Within this database, all tables for which `pg_class .reltablespace` is zero will be stored in this tablespace; in particular, all the non-shared system catalogs will be there.
`datacl aclitem[]` Access privileges; see Section 5.7 for details

54.16. `pg_db_role_setting`

The catalog pg_db_role_setting records the default values that have been set for run-time configuration variables, for each role and database combination.

Unlike most system catalogs, pg_db_role_setting is shared across all databases of a cluster: there is only one copy of pg_db_role_setting per cluster, not one per database.

Table 54.16. pg_db_role_setting Columns

Column Type Description
setdatabase oid (references pg_database .oid) The OID of the database the setting is applicable to, or zero if not database-specific
setrole oid (references pg_authid .oid) The OID of the role the setting is applicable to, or zero if not role-specific
setconfig text[] Defaults for run-time configuration variables

54.17. pg_default_acl

The catalog pg_default_acl stores initial privileges to be assigned to newly created objects.

Table 54.17. pg_default_acl Columns

Column Type Description
oid oid Row identifier
defaclrole oid (references pg_authid .oid) The OID of the role associated with this entry
defaclnamespace oid (references pg_namespace .oid) The OID of the namespace associated with this entry, or zero if none
defaclobjtype char Type of object this entry is for: r = relation (table, view), S = sequence, f = function, T = type, n = schema
defaclacl aclitem[] Access privileges that this type of object should have on creation

A pg_default_acl entry shows the initial privileges to be assigned to an object belonging to the indicated user. There are currently two types of entry: "global" entries with defaclnamespace = zero, and "per-schema" entries that reference a particular schema. If a global entry is present then it *overrides* the normal hard-wired default privileges for the object type. A per-schema entry, if present, represents privileges to be *added to* the global or hard-wired default privileges.

Note that when an ACL entry in another catalog is null, it is taken to represent the hard-wired default privileges for its object, *not* whatever might be in pg_default_acl at the moment. pg_default_acl is only consulted during object creation.

54.18. pg_depend

The catalog pg_depend records the dependency relationships between database objects. This information allows DROP commands to find which other objects must be dropped by DROP CASCADE or prevent dropping in the DROP RESTRICT case.

See also pg_shdepend, which performs a similar function for dependencies involving objects that are shared across a database cluster.

Table 54.18. pg_depend Columns

Column Type Description
classid oid (references pg_class .oid) The OID of the system catalog the dependent object is in, or zero for a DEPENDENCY_PIN entry
objid oid (references any OID column) The OID of the specific dependent object, or zero for a DEPENDENCY_PIN entry
objsubid int4 For a table column, this is the column number (the objid and classid refer to the table itself). For all other object types, this column is zero.
refclassid oid (references pg_class .oid) The OID of the system catalog the referenced object is in
refobjid oid (references any OID column) The OID of the specific referenced object
refobjsubid int4 For a table column, this is the column number (the refobjid and refclassid refer to the table itself). For all other object types, this column is zero.
deptype char A code defining the specific semantics of this dependency relationship; see text

In all cases, a pg_depend entry indicates that the referenced object cannot be dropped without also dropping the dependent object. However, there are several subflavors identified by deptype:

DEPENDENCY_NORMAL (n)

A normal relationship between separately-created objects. The dependent object can be dropped without affecting the referenced object. The referenced object can only be dropped by specifying CASCADE, in which case the dependent object is dropped, too. Example: a table column has a normal dependency on its data type.

DEPENDENCY_AUTO (a)

The dependent object can be dropped separately from the referenced object, and should be automatically dropped (regardless of RESTRICT or CASCADE mode) if the referenced object is dropped. Example: a named constraint on a table is made auto-dependent on the table, so that it will go away if the table is dropped.

DEPENDENCY_INTERNAL (i)

The dependent object was created as part of creation of the referenced object, and is really just a part of its internal implementation. A direct DROP of the dependent object will be disallowed outright (we'll tell the user to issue a DROP against the referenced object, instead). A DROP of the referenced object will result in automatically dropping the dependent object whether CASCADE is specified or not. If the dependent object has to be dropped due to a dependency on some other object being removed, its drop is converted to a drop of the referenced object, so that NORMAL and AUTO dependencies of the dependent object behave much like they were dependencies of the referenced object. Example: a view's ON SELECT rule is made internally dependent on the view, preventing it from being dropped while the view remains. Dependencies of the rule (such as tables it refers to) act as if they were dependencies of the view.

DEPENDENCY_PARTITION_PRI (P)
DEPENDENCY_PARTITION_SEC (S)

The dependent object was created as part of creation of the referenced object, and is really just a part of its internal implementation; however, unlike INTERNAL, there is more than one such referenced object. The dependent object must not be dropped unless at least one of these referenced objects is

dropped; if any one is, the dependent object should be dropped whether or not CASCADE is specified. Also unlike INTERNAL, a drop of some other object that the dependent object depends on does not result in automatic deletion of any partition-referenced object. Hence, if the drop does not cascade to at least one of these objects via some other path, it will be refused. (In most cases, the dependent object shares all its non-partition dependencies with at least one partition-referenced object, so that this restriction does not result in blocking any cascaded delete.) Primary and secondary partition dependencies behave identically except that the primary dependency is preferred for use in error messages; hence, a partition-dependent object should have one primary partition dependency and one or more secondary partition dependencies. Note that partition dependencies are made in addition to, not instead of, any dependencies the object would normally have. This simplifies ATTACH/DETACH PARTITION operations: the partition dependencies need only be added or removed. Example: a child partitioned index is made partition-dependent on both the partition table it is on and the parent partitioned index, so that it goes away if either of those is dropped, but not otherwise. The dependency on the parent index is primary, so that if the user tries to drop the child partitioned index, the error message will suggest dropping the parent index instead (not the table).

DEPENDENCY_EXTENSION (e)

The dependent object is a member of the *extension* that is the referenced object (see pg_extension). The dependent object can be dropped only via DROP EXTENSION on the referenced object. Functionally this dependency type acts the same as an INTERNAL dependency, but it's kept separate for clarity and to simplify pg_dump.

DEPENDENCY_AUTO_EXTENSION (x)

The dependent object is not a member of the extension that is the referenced object (and so it should not be ignored by pg_dump), but it cannot function without the extension and should be auto-dropped if the extension is. The dependent object may be dropped on its own as well. Functionally this dependency type acts the same as an AUTO dependency, but it's kept separate for clarity and to simplify pg_dump.

DEPENDENCY_PIN (p)

There is no dependent object; this type of entry is a signal that the system itself depends on the referenced object, and so that object must never be deleted. Entries of this type are created only by initdb. The columns for the dependent object contain zeroes.

Other dependency flavors might be needed in future.

Note that it's quite possible for two objects to be linked by more than one pg_depend entry. For example, a child partitioned index would have both a partition-type dependency on its associated partition table, and an auto dependency on each column of that table that it indexes. This sort of situation expresses the union of multiple dependency semantics. A dependent object can be dropped without CASCADE if any of its dependencies satisfies its condition for automatic dropping. Conversely, all the dependencies' restrictions about which objects must be dropped together must be satisfied.

54.19. pg_description

The catalog pg_description stores optional descriptions (comments) for each database object. Descriptions can be manipulated with the COMMENT command and viewed with psql's \d commands. Descriptions of many built-in system objects are provided in the initial contents of pg_description.

See also pg_shdescription, which performs a similar function for descriptions involving objects that are shared across a database cluster.

Table 54.19. pg_description Columns

Column Type Description
objoid oid (references any OID column)

Column Type Description
The OID of the object this description pertains to
`classoid` `oid` (references `pg_class` .`oid`) The OID of the system catalog this object appears in
`objsubid` `int4` For a comment on a table column, this is the column number (the `objoid` and `classoid` refer to the table itself). For all other object types, this column is zero.
`description` `text` Arbitrary text that serves as the description of this object

54.20. pg_enum

The `pg_enum` catalog contains entries showing the values and labels for each enum type. The internal representation of a given enum value is actually the OID of its associated row in `pg_enum`.

Table 54.20. `pg_enum` Columns

Column Type Description
`oid` `oid` Row identifier
`enumtypid` `oid` (references `pg_type` .`oid`) The OID of the `pg_type` entry owning this enum value
`enumsortorder` `float4` The sort position of this enum value within its enum type
`enumlabel` `name` The textual label for this enum value

The OIDs for `pg_enum` rows follow a special rule: even-numbered OIDs are guaranteed to be ordered in the same way as the sort ordering of their enum type. That is, if two even OIDs belong to the same enum type, the smaller OID must have the smaller `enumsortorder` value. Odd-numbered OID values need bear no relationship to the sort order. This rule allows the enum comparison routines to avoid catalog lookups in many common cases. The routines that create and alter enum types attempt to assign even OIDs to enum values whenever possible.

When an enum type is created, its members are assigned sort-order positions 1..*n*. But members added later might be given negative or fractional values of `enumsortorder`. The only requirement on these values is that they be correctly ordered and unique within each enum type.

54.21. pg_event_trigger

The catalog `pg_event_trigger` stores event triggers. See Chapter 42 for more information.

Table 54.21. `pg_event_trigger` Columns

Column Type Description
`oid` `oid` Row identifier
`evtname` `name` Trigger name (must be unique)
`evtevent` `name`

Column Type Description
Identifies the event for which this trigger fires
`evtowner` `oid` (references `pg_authid` .`oid`) Owner of the event trigger
`evtfoid` `oid` (references `pg_proc` .`oid`) The function to be called
`evtenabled` `char` Controls in which session_replication_role modes the event trigger fires. `O` = trigger fires in "origin" and "local" modes, `D` = trigger is disabled, `R` = trigger fires in "replica" mode, `A` = trigger fires always.
`evttags` `text[]` Command tags for which this trigger will fire. If NULL, the firing of this trigger is not restricted on the basis of the command tag.

54.22. pg_extension

The catalog `pg_extension` stores information about the installed extensions. See Section 40.17 for details about extensions.

Table 54.22. `pg_extension` Columns

Column Type Description
`oid` `oid` Row identifier
`extname` `name` Name of the extension
`extowner` `oid` (references `pg_authid` .`oid`) Owner of the extension
`extnamespace` `oid` (references `pg_namespace` .`oid`) Schema containing the extension's exported objects
`extrelocatable` `bool` True if extension can be relocated to another schema
`extversion` `text` Version name for the extension
`extconfig` `oid[]` (references `pg_class` .`oid`) Array of `regclass` OIDs for the extension's configuration table(s), or `NULL` if none
`extcondition` `text[]` Array of `WHERE`-clause filter conditions for the extension's configuration table(s), or `NULL` if none

Note that unlike most catalogs with a "namespace" column, `extnamespace` is not meant to imply that the extension belongs to that schema. Extension names are never schema-qualified. Rather, `extnamespace` indicates the schema that contains most or all of the extension's objects. If `extrelocatable` is true, then this schema must in fact contain all schema-qualifiable objects belonging to the extension.

54.23. pg_foreign_data_wrapper

The catalog `pg_foreign_data_wrapper` stores foreign-data wrapper definitions. A foreign-data wrapper is the mechanism by which external data, residing on foreign servers, is accessed.

Table 54.23. `pg_foreign_data_wrapper` Columns

Column Type Description
`oid oid` Row identifier
`fdwname name` Name of the foreign-data wrapper
`fdwowner oid` (references `pg_authid .oid`) Owner of the foreign-data wrapper
`fdwhandler oid` (references `pg_proc .oid`) References a handler function that is responsible for supplying execution routines for the foreign-data wrapper. Zero if no handler is provided
`fdwvalidator oid` (references `pg_proc .oid`) References a validator function that is responsible for checking the validity of the options given to the foreign-data wrapper, as well as options for foreign servers and user mappings using the foreign-data wrapper. Zero if no validator is provided
`fdwacl aclitem[]` Access privileges; see Section 5.7 for details
`fdwoptions text[]` Foreign-data wrapper specific options, as “keyword=value” strings

54.24. `pg_foreign_server`

The catalog `pg_foreign_server` stores foreign server definitions. A foreign server describes a source of external data, such as a remote server. Foreign servers are accessed via foreign-data wrappers.

Table 54.24. `pg_foreign_server` Columns

Column Type Description
`oid oid` Row identifier
`srvname name` Name of the foreign server
`srvowner oid` (references `pg_authid .oid`) Owner of the foreign server
`srvfdw oid` (references `pg_foreign_data_wrapper .oid`) OID of the foreign-data wrapper of this foreign server
`srvtype text` Type of the server (optional)
`srvversion text` Version of the server (optional)
`srvacl aclitem[]` Access privileges; see Section 5.7 for details
`srvoptions text[]` Foreign server specific options, as “keyword=value” strings

54.25. `pg_foreign_table`

The catalog `pg_foreign_table` contains auxiliary information about foreign tables. A foreign table is primarily represented by a `pg_class` entry, just like a regular table. Its `pg_foreign_table` entry contains the information that is pertinent only to foreign tables and not any other kind of relation.

Table 54.25. `pg_foreign_table` Columns

Column Type Description
`ftrelid` `oid` (references `pg_class` .`oid`) The OID of the `pg_class` entry for this foreign table
`ftserver` `oid` (references `pg_foreign_server` .`oid`) OID of the foreign server for this foreign table
`ftoptions` `text[]` Foreign table options, as “keyword=value” strings

54.26. `pg_index`

The catalog `pg_index` contains part of the information about indexes. The rest is mostly in `pg_class`.

Table 54.26. `pg_index` Columns

Column Type Description
`indexrelid` `oid` (references `pg_class` .`oid`) The OID of the `pg_class` entry for this index
`indrelid` `oid` (references `pg_class` .`oid`) The OID of the `pg_class` entry for the table this index is for
`indnatts` `int2` The total number of columns in the index (duplicates `pg_class.relnatts`); this number includes both key and included attributes
`indnkeyatts` `int2` The number of *key columns* in the index, not counting any *included columns*, which are merely stored and do not participate in the index semantics
`indisunique` `bool` If true, this is a unique index
`indisprimary` `bool` If true, this index represents the primary key of the table (`indisunique` should always be true when this is true)
`indisexclusion` `bool` If true, this index supports an exclusion constraint
`indimmediate` `bool` If true, the uniqueness check is enforced immediately on insertion (irrelevant if `indisunique` is not true)
`indisclustered` `bool` If true, the table was last clustered on this index
`indisvalid` `bool` If true, the index is currently valid for queries. False means the index is possibly incomplete: it must still be modified by `INSERT`/`UPDATE` operations, but it cannot safely be used for queries. If it is unique, the uniqueness property is not guaranteed true either.
`indcheckxmin` `bool` If true, queries must not use the index until the `xmin` of this `pg_index` row is below their `TransactionXmin` event horizon, because the table may contain broken HOT chains with incompatible rows that they can see
`indisready` `bool` If true, the index is currently ready for inserts. False means the index must be ignored by `INSERT`/`UPDATE` operations.

Column Type Description
indislive bool If false, the index is in process of being dropped, and should be ignored for all purposes (including HOT-safety decisions)
indisreplident bool If true this index has been chosen as "replica identity" using ALTER TABLE ... REPLICA IDENTITY USING INDEX ...
indkey int2vector (references pg_attribute .attnum) This is an array of indnatts values that indicate which table columns this index indexes. For example a value of 1 3 would mean that the first and the third table columns make up the index entries. Key columns come before non-key (included) columns. A zero in this array indicates that the corresponding index attribute is an expression over the table columns, rather than a simple column reference.
indcollation oidvector (references pg_collation .oid) For each column in the index key (indnkeyatts values), this contains the OID of the collation to use for the index, or zero if the column is not of a collatable data type.
indclass oidvector (references pg_opclass .oid) For each column in the index key (indnkeyatts values), this contains the OID of the operator class to use. See pg_opclass for details.
indoption int2vector This is an array of indnkeyatts values that store per-column flag bits. The meaning of the bits is defined by the index's access method.
indexprs pg_node_tree Expression trees (in nodeToString() representation) for index attributes that are not simple column references. This is a list with one element for each zero entry in indkey. Null if all index attributes are simple references.
indpred pg_node_tree Expression tree (in nodeToString() representation) for partial index predicate. Null if not a partial index.

54.27. pg_inherits

The catalog pg_inherits records information about table and index inheritance hierarchies. There is one entry for each direct parent-child table or index relationship in the database. (Indirect inheritance can be determined by following chains of entries.)

Table 54.27. pg_inherits Columns

Column Type Description
inhrelid oid (references pg_class .oid) The OID of the child table or index
inhparent oid (references pg_class .oid) The OID of the parent table or index
inhseqno int4 If there is more than one direct parent for a child table (multiple inheritance), this number tells the order in which the inherited columns are to be arranged. The count starts at 1. Indexes cannot have multiple inheritance, since they can only inherit when using declarative partitioning.
inhdetachpending bool true for a partition that is in the process of being detached; false otherwise.

54.28. pg_init_privs

The catalog pg_init_privs records information about the initial privileges of objects in the system. There is one entry for each object in the database which has a non-default (non-NULL) initial set of privileges.

Objects can have initial privileges either by having those privileges set when the system is initialized (by initdb) or when the object is created during a CREATE EXTENSION and the extension script sets initial privileges using the GRANT system. Note that the system will automatically handle recording of the privileges during the extension script and that extension authors need only use the GRANT and REVOKE statements in their script to have the privileges recorded. The privtype column indicates if the initial privilege was set by initdb or during a CREATE EXTENSION command.

Objects which have initial privileges set by initdb will have entries where privtype is 'i', while objects which have initial privileges set by CREATE EXTENSION will have entries where privtype is 'e'.

Table 54.28. pg_init_privs Columns

Column Type Description
objoid oid (references any OID column) The OID of the specific object
classoid oid (references pg_class .oid) The OID of the system catalog the object is in
objsubid int4 For a table column, this is the column number (the objoid and classoid refer to the table itself). For all other object types, this column is zero.
privtype char A code defining the type of initial privilege of this object; see text
initprivs aclitem[] The initial access privileges; see Section 5.7 for details

54.29. pg_language

The catalog pg_language registers languages in which you can write functions or stored procedures. See CREATE LANGUAGE and Chapter 44 for more information about language handlers.

Table 54.29. pg_language Columns

Column Type Description
oid oid Row identifier
lanname name Name of the language
lanowner oid (references pg_authid .oid) Owner of the language
lanispl bool This is false for internal languages (such as SQL) and true for user-defined languages. Currently, pg_dump still uses this to determine which languages need to be dumped, but this might be replaced by a different mechanism in the future.
lanpltrusted bool True if this is a trusted language, which means that it is believed not to grant access to anything outside the normal SQL execution environment. Only superusers can create functions in untrusted languages.

Column Type Description
`lanplcallfoid oid` (references `pg_proc .oid`) For noninternal languages this references the language handler, which is a special function that is responsible for executing all functions that are written in the particular language. Zero for internal languages.
`laninline oid` (references `pg_proc .oid`) This references a function that is responsible for executing "inline" anonymous code blocks (DO blocks). Zero if inline blocks are not supported.
`lanvalidator oid` (references `pg_proc .oid`) This references a language validator function that is responsible for checking the syntax and validity of new functions when they are created. Zero if no validator is provided.
`lanacl aclitem[]` Access privileges; see Section 5.7 for details

54.30. pg_largeobject

The catalog `pg_largeobject` holds the data making up "large objects". A large object is identified by an OID assigned when it is created. Each large object is broken into segments or "pages" small enough to be conveniently stored as rows in `pg_largeobject`. The amount of data per page is defined to be `LOBLKSIZE` (which is currently `BLCKSZ/4`, or typically 2 kB).

Prior to PostgreSQL 9.0, there was no permission structure associated with large objects. As a result, `pg_largeobject` was publicly readable and could be used to obtain the OIDs (and contents) of all large objects in the system. This is no longer the case; use `pg_largeobject_metadata` to obtain a list of large object OIDs.

Table 54.30. `pg_largeobject` Columns

Column Type Description
`loid oid` (references `pg_largeobject_metadata .oid`) Identifier of the large object that includes this page
`pageno int4` Page number of this page within its large object (counting from zero)
`data bytea` Actual data stored in the large object. This will never be more than `LOBLKSIZE` bytes and might be less.

Each row of `pg_largeobject` holds data for one page of a large object, beginning at byte offset (`pageno * LOBLKSIZE`) within the object. The implementation allows sparse storage: pages might be missing, and might be shorter than `LOBLKSIZE` bytes even if they are not the last page of the object. Missing regions within a large object read as zeroes.

54.31. pg_largeobject_metadata

The catalog `pg_largeobject_metadata` holds metadata associated with large objects. The actual large object data is stored in `pg_largeobject`.

Table 54.31. `pg_largeobject_metadata` Columns

Column Type Description
`oid oid` Row identifier
`lomowner oid` (references `pg_authid .oid`)

Column Type Description
Owner of the large object
`lomacl aclitem[]` Access privileges; see Section 5.7 for details

54.32. pg_namespace

The catalog `pg_namespace` stores namespaces. A namespace is the structure underlying SQL schemas: each namespace can have a separate collection of relations, types, etc. without name conflicts.

Table 54.32. `pg_namespace` Columns

Column Type Description
`oid oid` Row identifier
`nspname name` Name of the namespace
`nspowner oid` (references `pg_authid .oid`) Owner of the namespace
`nspacl aclitem[]` Access privileges; see Section 5.7 for details

54.33. pg_opclass

The catalog `pg_opclass` defines index access method operator classes. Each operator class defines semantics for index columns of a particular data type and a particular index access method. An operator class essentially specifies that a particular operator family is applicable to a particular indexable column data type. The set of operators from the family that are actually usable with the indexed column are whichever ones accept the column's data type as their left-hand input.

Operator classes are described at length in Section 40.16.

Table 54.33. `pg_opclass` Columns

Column Type Description
`oid oid` Row identifier
`opcmethod oid` (references `pg_am .oid`) Index access method operator class is for
`opcname name` Name of this operator class
`opcnamespace oid` (references `pg_namespace .oid`) Namespace of this operator class
`opcowner oid` (references `pg_authid .oid`) Owner of the operator class
`opcfamily oid` (references `pg_opfamily .oid`) Operator family containing the operator class
`opcintype oid` (references `pg_type .oid`) Data type that the operator class indexes
`opcdefault bool`

Column Type Description
True if this operator class is the default for `opcintype`
`opckeytype oid` (references `pg_type .oid`) Type of data stored in index, or zero if same as `opcintype`

An operator class's `opcmethod` must match the `opfmethod` of its containing operator family. Also, there must be no more than one `pg_opclass` row having `opcdefault` true for any given combination of `opcmethod` and `opcintype`.

54.34. pg_operator

The catalog `pg_operator` stores information about operators. See CREATE OPERATOR and Section 40.14 for more information.

Table 54.34. `pg_operator` Columns

Column Type Description
`oid oid` Row identifier
`oprname name` Name of the operator
`oprnamespace oid` (references `pg_namespace .oid`) The OID of the namespace that contains this operator
`oprowner oid` (references `pg_authid .oid`) Owner of the operator
`oprkind char` `b` = infix operator (“both”), or `l` = prefix operator (“left”)
`oprcanmerge bool` This operator supports merge joins
`oprcanhash bool` This operator supports hash joins
`oprleft oid` (references `pg_type .oid`) Type of the left operand (zero for a prefix operator)
`oprright oid` (references `pg_type .oid`) Type of the right operand
`oprresult oid` (references `pg_type .oid`) Type of the result (zero for a not-yet-defined “shell” operator)
`oprcom oid` (references `pg_operator .oid`) Commutator of this operator (zero if none)
`oprnegate oid` (references `pg_operator .oid`) Negator of this operator (zero if none)
`oprcode regproc` (references `pg_proc .oid`) Function that implements this operator (zero for a not-yet-defined “shell” operator)
`oprrest regproc` (references `pg_proc .oid`) Restriction selectivity estimation function for this operator (zero if none)
`oprjoin regproc` (references `pg_proc .oid`) Join selectivity estimation function for this operator (zero if none)

54.35. pg_opfamily

The catalog pg_opfamily defines operator families. Each operator family is a collection of operators and associated support routines that implement the semantics specified for a particular index access method. Furthermore, the operators in a family are all "compatible", in a way that is specified by the access method. The operator family concept allows cross-data-type operators to be used with indexes and to be reasoned about using knowledge of access method semantics.

Operator families are described at length in Section 40.16.

Table 54.35. pg_opfamily Columns

Column Type Description
oid oid Row identifier
opfmethod oid (references pg_am .oid) Index access method operator family is for
opfname name Name of this operator family
opfnamespace oid (references pg_namespace .oid) Namespace of this operator family
opfowner oid (references pg_authid .oid) Owner of the operator family

The majority of the information defining an operator family is not in its pg_opfamily row, but in the associated rows in pg_amop, pg_amproc, and pg_opclass.

54.36. pg_partitioned_table

The catalog pg_partitioned_table stores information about how tables are partitioned.

Table 54.36. pg_partitioned_table Columns

Column Type Description
partrelid oid (references pg_class .oid) The OID of the pg_class entry for this partitioned table
partstrat char Partitioning strategy; h = hash partitioned table, l = list partitioned table, r = range partitioned table
partnatts int2 The number of columns in the partition key
partdefid oid (references pg_class .oid) The OID of the pg_class entry for the default partition of this partitioned table, or zero if this partitioned table does not have a default partition
partattrs int2vector (references pg_attribute .attnum) This is an array of partnatts values that indicate which table columns are part of the partition key. For example, a value of 1 3 would mean that the first and the third table columns make up the partition key. A zero in this array indicates that the corresponding partition key column is an expression, rather than a simple column reference.
partclass oidvector (references pg_opclass .oid) For each column in the partition key, this contains the OID of the operator class to use. See pg_opclass for details.
partcollation oidvector (references pg_collation .oid)

Column Type Description
For each column in the partition key, this contains the OID of the collation to use for partitioning, or zero if the column is not of a collatable data type.
`partexprs` `pg_node_tree` Expression trees (in `nodeToString()` representation) for partition key columns that are not simple column references. This is a list with one element for each zero entry in `partattrs`. Null if all partition key columns are simple references.

54.37. pg_policy

The catalog `pg_policy` stores row-level security policies for tables. A policy includes the kind of command that it applies to (possibly all commands), the roles that it applies to, the expression to be added as a security-barrier qualification to queries that include the table, and the expression to be added as a `WITH CHECK` option for queries that attempt to add new records to the table.

Table 54.37. `pg_policy` Columns

Column Type Description
`oid` `oid` Row identifier
`polname` `name` The name of the policy
`polrelid` `oid` (references `pg_class` .`oid`) The table to which the policy applies
`polcmd` `char` The command type to which the policy is applied: `r` for SELECT, `a` for INSERT, `w` for UPDATE, `d` for DELETE, or `*` for all
`polpermissive` `bool` Is the policy permissive or restrictive?
`polroles` `oid[]` (references `pg_authid` .`oid`) The roles to which the policy is applied; zero means `PUBLIC` (and normally appears alone in the array)
`polqual` `pg_node_tree` The expression tree to be added to the security barrier qualifications for queries that use the table
`polwithcheck` `pg_node_tree` The expression tree to be added to the WITH CHECK qualifications for queries that attempt to add rows to the table

> **Note**
>
> Policies stored in `pg_policy` are applied only when `pg_class`.`relrowsecurity` is set for their table.

54.38. pg_proc

The catalog `pg_proc` stores information about functions, procedures, aggregate functions, and window functions (collectively also known as routines). See CREATE FUNCTION, CREATE PROCEDURE, and Section 40.3 for more information.

If `prokind` indicates that the entry is for an aggregate function, there should be a matching row in `pg_aggregate`.

Table 54.38. `pg_proc` Columns

Column Type Description
`oid` `oid` Row identifier
`proname` `name` Name of the function
`pronamespace` `oid` (references `pg_namespace` .`oid`) The OID of the namespace that contains this function
`proowner` `oid` (references `pg_authid` .`oid`) Owner of the function
`prolang` `oid` (references `pg_language` .`oid`) Implementation language or call interface of this function
`procost` `float4` Estimated execution cost (in units of cpu_operator_cost); if `proretset`, this is cost per row returned
`prorows` `float4` Estimated number of result rows (zero if not `proretset`)
`provariadic` `oid` (references `pg_type` .`oid`) Data type of the variadic array parameter's elements, or zero if the function does not have a variadic parameter
`prosupport` `regproc` (references `pg_proc` .`oid`) Planner support function for this function (see Section 40.11), or zero if none
`prokind` `char` `f` for a normal function, `p` for a procedure, `a` for an aggregate function, or `w` for a window function
`prosecdef` `bool` Function is a security definer (i.e., a “setuid” function)
`proleakproof` `bool` The function has no side effects. No information about the arguments is conveyed except via the return value. Any function that might throw an error depending on the values of its arguments is not leak-proof.
`proisstrict` `bool` Function returns null if any call argument is null. In that case the function won't actually be called at all. Functions that are not “strict” must be prepared to handle null inputs.
`proretset` `bool` Function returns a set (i.e., multiple values of the specified data type)
`provolatile` `char` `provolatile` tells whether the function's result depends only on its input arguments, or is affected by outside factors. It is `i` for “immutable” functions, which always deliver the same result for the same inputs. It is `s` for “stable” functions, whose results (for fixed inputs) do not change within a scan. It is `v` for “volatile” functions, whose results might change at any time. (Use `v` also for functions with side-effects, so that calls to them cannot get optimized away.)
`proparallel` `char` `proparallel` tells whether the function can be safely run in parallel mode. It is `s` for functions which are safe to run in parallel mode without restriction. It is `r` for functions which can be run in parallel mode, but their execution is restricted to the parallel group leader; parallel worker processes cannot invoke these functions. It is `u` for functions which are unsafe in parallel mode; the presence of such a function forces a serial execution plan.
`pronargs` `int2`

Column Type Description
Number of input arguments
`pronargdefaults` `int2` Number of arguments that have defaults
`prorettype` `oid` (references `pg_type` .`oid`) Data type of the return value
`proargtypes` `oidvector` (references `pg_type` .`oid`) An array of the data types of the function arguments. This includes only input arguments (including `INOUT` and `VARIADIC` arguments), and thus represents the call signature of the function.
`proallargtypes` `oid[]` (references `pg_type` .`oid`) An array of the data types of the function arguments. This includes all arguments (including `OUT` and `INOUT` arguments); however, if all the arguments are `IN` arguments, this field will be null. Note that subscripting is 1-based, whereas for historical reasons `proargtypes` is subscripted from 0.
`proargmodes` `char[]` An array of the modes of the function arguments, encoded as `i` for `IN` arguments, `o` for `OUT` arguments, `b` for `INOUT` arguments, `v` for `VARIADIC` arguments, `t` for `TABLE` arguments. If all the arguments are `IN` arguments, this field will be null. Note that subscripts correspond to positions of `proallargtypes` not `proargtypes`.
`proargnames` `text[]` An array of the names of the function arguments. Arguments without a name are set to empty strings in the array. If none of the arguments have a name, this field will be null. Note that subscripts correspond to positions of `proallargtypes` not `proargtypes`.
`proargdefaults` `pg_node_tree` Expression trees (in `nodeToString()` representation) for default values. This is a list with `pronargdefaults` elements, corresponding to the last *`N`* *input* arguments (i.e., the last *`N`* `proargtypes` positions). If none of the arguments have defaults, this field will be null.
`protrftypes` `oid[]` (references `pg_type` .`oid`) An array of the argument/result data type(s) for which to apply transforms (from the function's `TRANSFORM` clause). Null if none.
`prosrc` `text` This tells the function handler how to invoke the function. It might be the actual source code of the function for interpreted languages, a link symbol, a file name, or just about anything else, depending on the implementation language/call convention.
`probin` `text` Additional information about how to invoke the function. Again, the interpretation is language-specific.
`prosqlbody` `pg_node_tree` Pre-parsed SQL function body. This is used for SQL-language functions when the body is given in SQL-standard notation rather than as a string literal. It's null in other cases.
`proconfig` `text[]` Function's local settings for run-time configuration variables
`proacl` `aclitem[]` Access privileges; see Section 5.7 for details

For compiled functions, both built-in and dynamically loaded, `prosrc` contains the function's C-language name (link symbol). For SQL-language functions, `prosrc` contains the function's source text if that is specified as a string literal; but if the function body is specified in SQL-standard style, `prosrc` is unused (typically it's an empty string) and `prosqlbody` contains the pre-parsed definition. For all other current-

ly-known language types, prosrc contains the function's source text. probin is null except for dynamically-loaded C functions, for which it gives the name of the shared library file containing the function.

54.39. pg_profile

The catalog pg_profile lists all profiles available for your cluster. For details on profiles, see CREATE PROFILE.

Profiles are cluster-wide, so pg_profile is shared across all databases of a cluster. This catalog is not publicly readable.

Table 54.39. pg_profile Columns

Column Type Description
oid oid Row identifier
pflname name Profile name
pflfailedloginattempts int4 FAILED_LOGIN_ATTEMPTS parameter value
pflfailedauthkeeptime int4 FAILED_AUTH_KEEP_TIME parameter value (in seconds)
pfluserinactivetime int4 USER_INACTIVE_TIME parameter value (in seconds)
pflpasswordreusetime int4 PASSWORD_REUSE_TIME parameter value (in seconds)
pflpasswordreusemax int4 PASSWORD_REUSE_MAX parameter value
pflpasswordlifetime int4 PASSWORD_LIFE_TIME parameter value (in seconds)
pflpasswordgracetime int4 PASSWORD_GRACE_TIME parameter value (in seconds)
pflpasswordminuniqchars int4 PASSWORD_MIN_UNIQUE_CHARS parameter value
pflpasswordminlen int4 PASSWORD_MIN_LEN parameter value
pflpasswordrequirecomplex int4 PASSWORD_REQUIRE_COMPLEX parameter value

The UNLIMITED and DEFAULT parameter values are stored in pg_profile as -1 and -2, respectively.

54.40. pg_publication

The catalog pg_publication contains all publications created in the database. For more on publications see Section 30.1.

Table 54.40. pg_publication Columns

Column Type Description
oid oid Row identifier
pubname name

Column Type Description
Name of the publication
pubowner oid (references pg_authid .oid) Owner of the publication
puballtables bool If true, this publication automatically includes all tables in the database, including any that will be created in the future.
pubinsert bool If true, INSERT operations are replicated for tables in the publication.
pubupdate bool If true, UPDATE operations are replicated for tables in the publication.
pubdelete bool If true, DELETE operations are replicated for tables in the publication.
pubtruncate bool If true, TRUNCATE operations are replicated for tables in the publication.
pubviaroot bool If true, operations on a leaf partition are replicated using the identity and schema of its top-most partitioned ancestor mentioned in the publication instead of its own.

54.41. pg_publication_rel

The catalog pg_publication_rel contains the mapping between relations and publications in the database. This is a many-to-many mapping. See also Section 54.82 for a more user-friendly view of this information.

Table 54.41. pg_publication_rel Columns

Column Type Description
oid oid Row identifier
prpubid oid (references pg_publication .oid) Reference to publication
prrelid oid (references pg_class .oid) Reference to relation

54.42. pg_range

The catalog pg_range stores information about range types. This is in addition to the types' entries in pg_type.

Table 54.42. pg_range Columns

Column Type Description
rngtypid oid (references pg_type .oid) OID of the range type
rngsubtype oid (references pg_type .oid) OID of the element type (subtype) of this range type
rngmultitypid oid (references pg_type .oid) OID of the multirange type for this range type
rngcollation oid (references pg_collation .oid)

Column Type Description
OID of the collation used for range comparisons, or zero if none
`rngsubopc` `oid` (references `pg_opclass` .`oid`) OID of the subtype's operator class used for range comparisons
`rngcanonical` `regproc` (references `pg_proc` .`oid`) OID of the function to convert a range value into canonical form, or zero if none
`rngsubdiff` `regproc` (references `pg_proc` .`oid`) OID of the function to return the difference between two element values as `double precision`, or zero if none

`rngsubopc` (plus `rngcollation`, if the element type is collatable) determines the sort ordering used by the range type. `rngcanonical` is used when the element type is discrete. `rngsubdiff` is optional but should be supplied to improve performance of GiST indexes on the range type.

54.43. pg_replication_origin

The `pg_replication_origin` catalog contains all replication origins created. For more on replication origins see Chapter 52.

Unlike most system catalogs, `pg_replication_origin` is shared across all databases of a cluster: there is only one copy of `pg_replication_origin` per cluster, not one per database.

Table 54.43. `pg_replication_origin` Columns

Column Type Description
`roident` `oid` A unique, cluster-wide identifier for the replication origin. Should never leave the system.
`roname` `text` The external, user defined, name of a replication origin.

54.44. pg_rewrite

The catalog `pg_rewrite` stores rewrite rules for tables and views.

Table 54.44. `pg_rewrite` Columns

Column Type Description
`oid` `oid` Row identifier
`rulename` `name` Rule name
`ev_class` `oid` (references `pg_class` .`oid`) The table this rule is for
`ev_type` `char` Event type that the rule is for: 1 = SELECT, 2 = UPDATE, 3 = INSERT, 4 = DELETE
`ev_enabled` `char` Controls in which session_replication_role modes the rule fires. `O` = rule fires in “origin” and “local” modes, `D` = rule is disabled, `R` = rule fires in “replica” mode, `A` = rule fires always.
`is_instead` `bool` True if the rule is an `INSTEAD` rule
`ev_qual` `pg_node_tree`

Column Type Description
Expression tree (in the form of a `nodeToString()` representation) for the rule's qualifying condition
`ev_action pg_node_tree` Query tree (in the form of a `nodeToString()` representation) for the rule's action

> **Note**
>
> `pg_class.relhasrules` must be true if a table has any rules in this catalog.

54.45. `pg_role_password`

The catalog `pg_role_password` records role's passwords history used to enforce authentication restrictions.

Unlike most system catalogs, `pg_role_password` is shared across all databases of a cluster: there is only one copy of `pg_role_password` per cluster, not one per database.

Table 54.45. `pg_role_password` Columns

Column Type Description
`passrole regrole` (references `pg_authid .oid`) The OID of the role
`passpassword text` Password of the role (possibly encrypted)
`passsetat timestamptz` Password set time

54.46. `pg_seclabel`

The catalog `pg_seclabel` stores security labels on database objects. Security labels can be manipulated with the `SECURITY LABEL` command. For an easier way to view security labels, see Section 54.87.

See also `pg_shseclabel`, which performs a similar function for security labels of database objects that are shared across a database cluster.

Table 54.46. `pg_seclabel` Columns

Column Type Description
`objoid oid` (references any OID column) The OID of the object this security label pertains to
`classoid oid` (references `pg_class .oid`) The OID of the system catalog this object appears in
`objsubid int4` For a security label on a table column, this is the column number (the `objoid` and `classoid` refer to the table itself). For all other object types, this column is zero.
`provider text` The label provider associated with this label.
`label text` The security label applied to this object.

54.47. pg_sequence

The catalog pg_sequence contains information about sequences. Some of the information about sequences, such as the name and the schema, is in pg_class

Table 54.47. pg_sequence Columns

Column Type Description
seqrelid oid (references pg_class .oid) The OID of the pg_class entry for this sequence
seqtypid oid (references pg_type .oid) Data type of the sequence
seqstart int8 Start value of the sequence
seqincrement int8 Increment value of the sequence
seqmax int8 Maximum value of the sequence
seqmin int8 Minimum value of the sequence
seqcache int8 Cache size of the sequence
seqcycle bool Whether the sequence cycles

54.48. pg_shdepend

The catalog pg_shdepend records the dependency relationships between database objects and shared objects, such as roles. This information allows Postgres Pro to ensure that those objects are unreferenced before attempting to delete them.

See also pg_depend, which performs a similar function for dependencies involving objects within a single database.

Unlike most system catalogs, pg_shdepend is shared across all databases of a cluster: there is only one copy of pg_shdepend per cluster, not one per database.

Table 54.48. pg_shdepend Columns

Column Type Description
dbid oid (references pg_database .oid) The OID of the database the dependent object is in, or zero for a shared object or a SHARED_DEPENDENCY_PIN entry
classid oid (references pg_class .oid) The OID of the system catalog the dependent object is in, or zero for a SHARED_DEPENDENCY_PIN entry
objid oid (references any OID column) The OID of the specific dependent object, or zero for a SHARED_DEPENDENCY_PIN entry
objsubid int4 For a table column, this is the column number (the objid and classid refer to the table itself). For all other object types, this column is zero.

Column Type Description
refclassid oid (references pg_class .oid) The OID of the system catalog the referenced object is in (must be a shared catalog)
refobjid oid (references any OID column) The OID of the specific referenced object
deptype char A code defining the specific semantics of this dependency relationship; see text

In all cases, a pg_shdepend entry indicates that the referenced object cannot be dropped without also dropping the dependent object. However, there are several subflavors identified by deptype:

SHARED_DEPENDENCY_OWNER (o)

The referenced object (which must be a role) is the owner of the dependent object.

SHARED_DEPENDENCY_ACL (a)

The referenced object (which must be a role) is mentioned in the ACL (access control list, i.e., privileges list) of the dependent object. (A SHARED_DEPENDENCY_ACL entry is not made for the owner of the object, since the owner will have a SHARED_DEPENDENCY_OWNER entry anyway.)

SHARED_DEPENDENCY_POLICY (r)

The referenced object (which must be a role) is mentioned as the target of a dependent policy object.

SHARED_DEPENDENCY_PIN (p)

There is no dependent object; this type of entry is a signal that the system itself depends on the referenced object, and so that object must never be deleted. Entries of this type are created only by initdb. The columns for the dependent object contain zeroes.

SHARED_DEPENDENCY_TABLESPACE (t)

The referenced object (which must be a tablespace) is mentioned as the tablespace for a relation that doesn't have storage.

Other dependency flavors might be needed in future. Note in particular that the current definition only supports roles and tablespaces as referenced objects.

54.49. pg_shdescription

The catalog pg_shdescription stores optional descriptions (comments) for shared database objects. Descriptions can be manipulated with the COMMENT command and viewed with psql's \d commands.

See also pg_description, which performs a similar function for descriptions involving objects within a single database.

Unlike most system catalogs, pg_shdescription is shared across all databases of a cluster: there is only one copy of pg_shdescription per cluster, not one per database.

Table 54.49. pg_shdescription Columns

Column Type Description
objoid oid (references any OID column) The OID of the object this description pertains to
classoid oid (references pg_class .oid) The OID of the system catalog this object appears in
description text

Column Type Description
Arbitrary text that serves as the description of this object

54.50. pg_shseclabel

The catalog pg_shseclabel stores security labels on shared database objects. Security labels can be manipulated with the SECURITY LABEL command. For an easier way to view security labels, see Section 54.87.

See also pg_seclabel, which performs a similar function for security labels involving objects within a single database.

Unlike most system catalogs, pg_shseclabel is shared across all databases of a cluster: there is only one copy of pg_shseclabel per cluster, not one per database.

Table 54.50. pg_shseclabel Columns

Column Type Description
objoid oid (references any OID column) The OID of the object this security label pertains to
classoid oid (references pg_class .oid) The OID of the system catalog this object appears in
provider text The label provider associated with this label.
label text The security label applied to this object.

54.51. pg_statistic

The catalog pg_statistic stores statistical data about the contents of the database. Entries are created by ANALYZE and subsequently used by the query planner. Note that all the statistical data is inherently approximate, even assuming that it is up-to-date.

Normally there is one entry, with stainherit = false, for each table column that has been analyzed. If the table has inheritance children, a second entry with stainherit = true is also created. This row represents the column's statistics over the inheritance tree, i.e., statistics for the data you'd see with SELECT *column* FROM *table**, whereas the stainherit = false row represents the results of SELECT *column* FROM ONLY *table*.

pg_statistic also stores statistical data about the values of index expressions. These are described as if they were actual data columns; in particular, starelid references the index. No entry is made for an ordinary non-expression index column, however, since it would be redundant with the entry for the underlying table column. Currently, entries for index expressions always have stainherit = false.

Since different kinds of statistics might be appropriate for different kinds of data, pg_statistic is designed not to assume very much about what sort of statistics it stores. Only extremely general statistics (such as nullness) are given dedicated columns in pg_statistic. Everything else is stored in “slots”, which are groups of associated columns whose content is identified by a code number in one of the slot's columns.

pg_statistic should not be readable by the public, since even statistical information about a table's contents might be considered sensitive. (Example: minimum and maximum values of a salary column might be quite interesting.) pg_stats is a publicly readable view on pg_statistic that only exposes information about those tables that are readable by the current user.

Table 54.51. `pg_statistic` Columns

Column Type Description
`starelid oid` (references `pg_class .oid`) The table or index that the described column belongs to
`staattnum int2` (references `pg_attribute .attnum`) The number of the described column
`stainherit bool` If true, the stats include inheritance child columns, not just the values in the specified relation
`stanullfrac float4` The fraction of the column's entries that are null
`stawidth int4` The average stored width, in bytes, of nonnull entries
`stadistinct float4` The number of distinct nonnull data values in the column. A value greater than zero is the actual number of distinct values. A value less than zero is the negative of a multiplier for the number of rows in the table; for example, a column in which about 80% of the values are nonnull and each nonnull value appears about twice on average could be represented by `stadistinct` = -0.4. A zero value means the number of distinct values is unknown.
`stakind`*N* `int2` A code number indicating the kind of statistics stored in the *N*th "slot" of the `pg_statistic` row.
`staop`*N* `oid` (references `pg_operator .oid`) An operator used to derive the statistics stored in the *N*th "slot". For example, a histogram slot would show the < operator that defines the sort order of the data. Zero if the statistics kind does not require an operator.
`stacoll`*N* `oid` (references `pg_collation .oid`) The collation used to derive the statistics stored in the *N*th "slot". For example, a histogram slot for a collatable column would show the collation that defines the sort order of the data. Zero for noncollatable data.
`stanumbers`*N* `float4[]` Numerical statistics of the appropriate kind for the *N*th "slot", or null if the slot kind does not involve numerical values
`stavalues`*N* `anyarray` Column data values of the appropriate kind for the *N*th "slot", or null if the slot kind does not store any data values. Each array's element values are actually of the specific column's data type, or a related type such as an array's element type, so there is no way to define these columns' type more specifically than `anyarray`.

54.52. `pg_statistic_ext`

The catalog `pg_statistic_ext` holds definitions of extended planner statistics. Each row in this catalog corresponds to a *statistics object* created with `CREATE STATISTICS`.

Table 54.52. `pg_statistic_ext` Columns

Column Type Description
`oid oid` Row identifier
`stxrelid oid` (references `pg_class .oid`)

Column Type Description
Table containing the columns described by this object
`stxname name` Name of the statistics object
`stxnamespace oid` (references `pg_namespace .oid`) The OID of the namespace that contains this statistics object
`stxowner oid` (references `pg_authid .oid`) Owner of the statistics object
`stxstattarget int4` `stxstattarget` controls the level of detail of statistics accumulated for this statistics object by `ANALYZE`. A zero value indicates that no statistics should be collected. A negative value says to use the maximum of the statistics targets of the referenced columns, if set, or the system default statistics target. Positive values of `stxstattarget` determine the target number of "most common values" to collect.
`stxkeys int2vector` (references `pg_attribute .attnum`) An array of attribute numbers, indicating which table columns are covered by this statistics object; for example a value of `1 3` would mean that the first and the third table columns are covered
`stxkind char[]` An array containing codes for the enabled statistics kinds; valid values are: `d` for n-distinct statistics, `f` for functional dependency statistics, `m` for most common values (MCV) list statistics, and `e` for expression statistics
`stxexprs pg_node_tree` Expression trees (in `nodeToString()` representation) for statistics object attributes that are not simple column references. This is a list with one element per expression. Null if all statistics object attributes are simple references.

The `pg_statistic_ext` entry is filled in completely during `CREATE STATISTICS`, but the actual statistical values are not computed then. Subsequent `ANALYZE` commands compute the desired values and populate an entry in the `pg_statistic_ext_data` catalog.

54.53. pg_statistic_ext_data

The catalog `pg_statistic_ext_data` holds data for extended planner statistics defined in `pg_statistic_ext`. Each row in this catalog corresponds to a *statistics object* created with `CREATE STATISTICS`.

Like `pg_statistic`, `pg_statistic_ext_data` should not be readable by the public, since the contents might be considered sensitive. (Example: most common combinations of values in columns might be quite interesting.) `pg_stats_ext` is a publicly readable view on `pg_statistic_ext_data` (after joining with `pg_statistic_ext`) that only exposes information about tables the current user owns.

Table 54.53. `pg_statistic_ext_data` Columns

Column Type Description
`stxoid oid` (references `pg_statistic_ext .oid`) Extended statistics object containing the definition for this data
`stxdndistinct pg_ndistinct` N-distinct counts, serialized as `pg_ndistinct` type
`stxddependencies pg_dependencies` Functional dependency statistics, serialized as `pg_dependencies` type
`stxdmcv pg_mcv_list`

Column Type Description
MCV (most-common values) list statistics, serialized as `pg_mcv_list` type
`stxdexpr` `pg_statistic[]` Per-expression statistics, serialized as an array of `pg_statistic` type

54.54. pg_subscription

The catalog `pg_subscription` contains all existing logical replication subscriptions. For more information about logical replication see Chapter 30.

Unlike most system catalogs, `pg_subscription` is shared across all databases of a cluster: there is only one copy of `pg_subscription` per cluster, not one per database.

Access to the column `subconninfo` is revoked from normal users, because it could contain plain-text passwords.

Table 54.54. `pg_subscription` Columns

Column Type Description
`oid` `oid` Row identifier
`subdbid` `oid` (references `pg_database` .`oid`) OID of the database that the subscription resides in
`subname` `name` Name of the subscription
`subowner` `oid` (references `pg_authid` .`oid`) Owner of the subscription
`subenabled` `bool` If true, the subscription is enabled and should be replicating
`subbinary` `bool` If true, the subscription will request that the publisher send data in binary format
`substream` `bool` If true, the subscription will allow streaming of in-progress transactions
`subconninfo` `text` Connection string to the upstream database
`subslotname` `name` Name of the replication slot in the upstream database (also used for the local replication origin name); null represents `NONE`
`subsynccommit` `text` The `synchronous_commit` setting for the subscription's workers to use
`subpublications` `text[]` Array of subscribed publication names. These reference publications defined in the upstream database. For more on publications see Section 30.1.

54.55. pg_subscription_rel

The catalog `pg_subscription_rel` contains the state for each replicated relation in each subscription. This is a many-to-many mapping.

This catalog only contains tables known to the subscription after running either `CREATE SUBSCRIPTION` or `ALTER SUBSCRIPTION ... REFRESH PUBLICATION`.

Table 54.55. `pg_subscription_rel` Columns

Column Type Description
`srsubid oid` (references `pg_subscription .oid`) Reference to subscription
`srrelid oid` (references `pg_class .oid`) Reference to relation
`srsubstate char` State code: `i` = initialize, `d` = data is being copied, `f` = finished table copy, `s` = synchronized, `r` = ready (normal replication)
`srsublsn pg_lsn` Remote LSN of the state change used for synchronization coordination when in `s` or `r` states, otherwise null

54.56. `pg_tablespace`

The catalog `pg_tablespace` stores information about the available tablespaces. Tables can be placed in particular tablespaces to aid administration of disk layout.

Unlike most system catalogs, `pg_tablespace` is shared across all databases of a cluster: there is only one copy of `pg_tablespace` per cluster, not one per database.

Table 54.56. `pg_tablespace` Columns

Column Type Description
`oid oid` Row identifier
`spcname name` Tablespace name
`spcowner oid` (references `pg_authid .oid`) Owner of the tablespace, usually the user who created it
`spcacl aclitem[]` Access privileges; see Section 5.7 for details
`spcoptions text[]` Tablespace-level options, as “keyword=value” strings

54.57. `pg_transform`

The catalog `pg_transform` stores information about transforms, which are a mechanism to adapt data types to procedural languages. See CREATE TRANSFORM for more information.

Table 54.57. `pg_transform` Columns

Column Type Description
`oid oid` Row identifier
`trftype oid` (references `pg_type .oid`) OID of the data type this transform is for
`trflang oid` (references `pg_language .oid`) OID of the language this transform is for
`trffromsql regproc` (references `pg_proc .oid`)

Column Type Description
The OID of the function to use when converting the data type for input to the procedural language (e.g., function parameters). Zero is stored if the default behavior should be used.
`trftosql regproc` (references `pg_proc .oid`) The OID of the function to use when converting output from the procedural language (e.g., return values) to the data type. Zero is stored if the default behavior should be used.

54.58. `pg_trigger`

The catalog `pg_trigger` stores triggers on tables and views. See CREATE TRIGGER for more information.

Table 54.58. `pg_trigger` Columns

Column Type Description
`oid oid` Row identifier
`tgrelid oid` (references `pg_class .oid`) The table this trigger is on
`tgparentid oid` (references `pg_trigger .oid`) Parent trigger that this trigger is cloned from (this happens when partitions are created or attached to a partitioned table); zero if not a clone
`tgname name` Trigger name (must be unique among triggers of same table)
`tgfoid oid` (references `pg_proc .oid`) The function to be called
`tgtype int2` Bit mask identifying trigger firing conditions
`tgenabled char` Controls in which session_replication_role modes the trigger fires. `O` = trigger fires in "origin" and "local" modes, `D` = trigger is disabled, `R` = trigger fires in "replica" mode, `A` = trigger fires always.
`tgisinternal bool` True if trigger is internally generated (usually, to enforce the constraint identified by `tgconstraint`)
`tgconstrrelid oid` (references `pg_class .oid`) The table referenced by a referential integrity constraint (zero if trigger is not for a referential integrity constraint)
`tgconstrindid oid` (references `pg_class .oid`) The index supporting a unique, primary key, referential integrity, or exclusion constraint (zero if trigger is not for one of these types of constraint)
`tgconstraint oid` (references `pg_constraint .oid`) The `pg_constraint` entry associated with the trigger (zero if trigger is not for a constraint)
`tgdeferrable bool` True if constraint trigger is deferrable
`tginitdeferred bool` True if constraint trigger is initially deferred
`tgnargs int2` Number of argument strings passed to trigger function

Column Type Description
tgattr int2vector (references pg_attribute .attnum) Column numbers, if trigger is column-specific; otherwise an empty array
tgargs bytea Argument strings to pass to trigger, each NULL-terminated
tgqual pg_node_tree Expression tree (in nodeToString() representation) for the trigger's WHEN condition, or null if none
tgoldtable name REFERENCING clause name for OLD TABLE, or null if none
tgnewtable name REFERENCING clause name for NEW TABLE, or null if none

Currently, column-specific triggering is supported only for UPDATE events, and so tgattr is relevant only for that event type. tgtype might contain bits for other event types as well, but those are presumed to be table-wide regardless of what is in tgattr.

> **Note**
>
> When tgconstraint is nonzero, tgconstrrelid, tgconstrindid, tgdeferrable, and tginitdeferred are largely redundant with the referenced pg_constraint entry. However, it is possible for a non-deferrable trigger to be associated with a deferrable constraint: foreign key constraints can have some deferrable and some non-deferrable triggers.

> **Note**
>
> pg_class.relhastriggers must be true if a relation has any triggers in this catalog.

54.59. pg_ts_config

The pg_ts_config catalog contains entries representing text search configurations. A configuration specifies a particular text search parser and a list of dictionaries to use for each of the parser's output token types. The parser is shown in the pg_ts_config entry, but the token-to-dictionary mapping is defined by subsidiary entries in pg_ts_config_map.

Postgres Pro's text search features are described at length in Chapter 12.

Table 54.59. pg_ts_config Columns

Column Type Description
oid oid Row identifier
cfgname name Text search configuration name
cfgnamespace oid (references pg_namespace .oid) The OID of the namespace that contains this configuration
cfgowner oid (references pg_authid .oid) Owner of the configuration
cfgparser oid (references pg_ts_parser .oid)

Column Type Description
The OID of the text search parser for this configuration

54.60. pg_ts_config_map

The pg_ts_config_map catalog contains entries showing which text search dictionaries should be consulted, and in what order, for each output token type of each text search configuration's parser.

Postgres Pro's text search features are described at length in Chapter 12.

Table 54.60. pg_ts_config_map Columns

Column Type Description
mapcfg oid (references pg_ts_config .oid) The OID of the pg_ts_config entry owning this map entry
maptokentype int4 A token type emitted by the configuration's parser
mapseqno int4 Order in which to consult this entry (lower mapseqnos first)
mapdict oid (references pg_ts_dict .oid) The OID of the text search dictionary to consult

54.61. pg_ts_dict

The pg_ts_dict catalog contains entries defining text search dictionaries. A dictionary depends on a text search template, which specifies all the implementation functions needed; the dictionary itself provides values for the user-settable parameters supported by the template. This division of labor allows dictionaries to be created by unprivileged users. The parameters are specified by a text string dictinitoption, whose format and meaning vary depending on the template.

Postgres Pro's text search features are described at length in Chapter 12.

Table 54.61. pg_ts_dict Columns

Column Type Description
oid oid Row identifier
dictname name Text search dictionary name
dictnamespace oid (references pg_namespace .oid) The OID of the namespace that contains this dictionary
dictowner oid (references pg_authid .oid) Owner of the dictionary
dicttemplate oid (references pg_ts_template .oid) The OID of the text search template for this dictionary
dictinitoption text Initialization option string for the template

54.62. pg_ts_parser

The pg_ts_parser catalog contains entries defining text search parsers. A parser is responsible for splitting input text into lexemes and assigning a token type to each lexeme. Since a parser must be implemented by C-language-level functions, creation of new parsers is restricted to database superusers.

Postgres Pro's text search features are described at length in Chapter 12.

Table 54.62. `pg_ts_parser` Columns

Column Type Description
`oid oid` Row identifier
`prsname name` Text search parser name
`prsnamespace oid` (references `pg_namespace .oid`) The OID of the namespace that contains this parser
`prsstart regproc` (references `pg_proc .oid`) OID of the parser's startup function
`prstoken regproc` (references `pg_proc .oid`) OID of the parser's next-token function
`prsend regproc` (references `pg_proc .oid`) OID of the parser's shutdown function
`prsheadline regproc` (references `pg_proc .oid`) OID of the parser's headline function (zero if none)
`prslextype regproc` (references `pg_proc .oid`) OID of the parser's lextype function

54.63. `pg_ts_template`

The `pg_ts_template` catalog contains entries defining text search templates. A template is the implementation skeleton for a class of text search dictionaries. Since a template must be implemented by C-language-level functions, creation of new templates is restricted to database superusers.

Postgres Pro's text search features are described at length in Chapter 12.

Table 54.63. `pg_ts_template` Columns

Column Type Description
`oid oid` Row identifier
`tmplname name` Text search template name
`tmplnamespace oid` (references `pg_namespace .oid`) The OID of the namespace that contains this template
`tmplinit regproc` (references `pg_proc .oid`) OID of the template's initialization function (zero if none)
`tmpllexize regproc` (references `pg_proc .oid`) OID of the template's lexize function

54.64. `pg_type`

The catalog `pg_type` stores information about data types. Base types and enum types (scalar types) are created with `CREATE TYPE`, and domains with `CREATE DOMAIN`. A composite type is automatically created for each table in the database, to represent the row structure of the table. It is also possible to create composite types with `CREATE TYPE AS`.

Table 54.64. `pg_type` Columns

Column Type Description
`oid oid` Row identifier
`typname name` Data type name
`typnamespace oid` (references `pg_namespace .oid`) The OID of the namespace that contains this type
`typowner oid` (references `pg_authid .oid`) Owner of the type
`typlen int2` For a fixed-size type, `typlen` is the number of bytes in the internal representation of the type. But for a variable-length type, `typlen` is negative. -1 indicates a “varlena” type (one that has a length word), -2 indicates a null-terminated C string.
`typbyval bool` `typbyval` determines whether internal routines pass a value of this type by value or by reference. `typbyval` had better be false if `typlen` is not 1, 2, or 4 (or 8 on machines where Datum is 8 bytes). Variable-length types are always passed by reference. Note that `typbyval` can be false even if the length would allow pass-by-value.
`typtype char` `typtype` is `b` for a base type, `c` for a composite type (e.g., a table's row type), `d` for a domain, `e` for an enum type, `p` for a pseudo-type, `r` for a range type, or `m` for a multirange type. See also `typrelid` and `typbasetype`.
`typcategory char` `typcategory` is an arbitrary classification of data types that is used by the parser to determine which implicit casts should be “preferred”. See Table 54.65.
`typispreferred bool` True if the type is a preferred cast target within its `typcategory`
`typisdefined bool` True if the type is defined, false if this is a placeholder entry for a not-yet-defined type. When `typisdefined` is false, nothing except the type name, namespace, and OID can be relied on.
`typdelim char` Character that separates two values of this type when parsing array input. Note that the delimiter is associated with the array element data type, not the array data type.
`typrelid oid` (references `pg_class .oid`) If this is a composite type (see `typtype`), then this column points to the `pg_class` entry that defines the corresponding table. (For a free-standing composite type, the `pg_class` entry doesn't really represent a table, but it is needed anyway for the type's `pg_attribute` entries to link to.) Zero for non-composite types.
`typsubscript regproc` (references `pg_proc .oid`) Subscripting handler function's OID, or zero if this type doesn't support subscripting. Types that are “true” array types have `typsubscript` = `array_subscript_handler`, but other types may have other handler functions to implement specialized subscripting behavior.
`typelem oid` (references `pg_type .oid`) If `typelem` is not zero then it identifies another row in `pg_type`, defining the type yielded by subscripting. This should be zero if `typsubscript` is zero. However, it can be zero when `typsubscript` isn't zero, if the handler doesn't need `typelem` to determine the subscripting result type. Note that a `typelem` dependency is considered to imply physical containment of the element type in this type; so DDL changes on the element type might be restricted by the presence of this type.

Column Type **Description**
`typarray oid` (references `pg_type .oid`) If `typarray` is not zero then it identifies another row in `pg_type` , which is the “true” array type having this type as element
`typinput regproc` (references `pg_proc .oid`) Input conversion function (text format)
`typoutput regproc` (references `pg_proc .oid`) Output conversion function (text format)
`typreceive regproc` (references `pg_proc .oid`) Input conversion function (binary format), or zero if none
`typsend regproc` (references `pg_proc .oid`) Output conversion function (binary format), or zero if none
`typmodin regproc` (references `pg_proc .oid`) Type modifier input function, or zero if type does not support modifiers
`typmodout regproc` (references `pg_proc .oid`) Type modifier output function, or zero to use the standard format
`typanalyze regproc` (references `pg_proc .oid`) Custom ANALYZE function, or zero to use the standard function
`typalign char` `typalign` is the alignment required when storing a value of this type. It applies to storage on disk as well as most representations of the value inside Postgres Pro. When multiple values are stored consecutively, such as in the representation of a complete row on disk, padding is inserted before a datum of this type so that it begins on the specified boundary. The alignment reference is the beginning of the first datum in the sequence. Possible values are: • `c` = `char` alignment, i.e., no alignment needed. • `s` = `short` alignment (2 bytes on most machines). • `i` = `int` alignment (4 bytes on most machines). • `d` = `double` alignment (8 bytes on many machines, but by no means all).
`typstorage char` `typstorage` tells for varlena types (those with `typlen` = -1) if the type is prepared for toasting and what the default strategy for attributes of this type should be. Possible values are: • `p` (plain): Values must always be stored plain (non-varlena types always use this value). • `e` (external): Values can be stored in a secondary “TOAST” relation (if relation has one, see `pg_class.reltoastrelid`). • `m` (main): Values can be compressed and stored inline. • `x` (extended): Values can be compressed and/or moved to a secondary relation. `x` is the usual choice for toast-able types. Note that `m` values can also be moved out to secondary storage, but only as a last resort (`e` and `x` values are moved first).
`typnotnull bool` `typnotnull` represents a not-null constraint on a type. Used for domains only.
`typbasetype oid` (references `pg_type .oid`) If this is a domain (see `typtype`), then `typbasetype` identifies the type that this one is based on. Zero if this type is not a domain.
`typtypmod int4` Domains use `typtypmod` to record the `typmod` to be applied to their base type (-1 if base type does not use a `typmod`). -1 if this type is not a domain.

Column Type Description
`typndims` `int4` `typndims` is the number of array dimensions for a domain over an array (that is, `typbasetype` is an array type). Zero for types other than domains over array types.
`typcollation` `oid` (references `pg_collation` .`oid`) `typcollation` specifies the collation of the type. If the type does not support collations, this will be zero. A base type that supports collations will have a nonzero value here, typically `DEFAULT_COLLATION_OID` . A domain over a collatable type can have a collation OID different from its base type's, if one was specified for the domain.
`typdefaultbin` `pg_node_tree` If `typdefaultbin` is not null, it is the `nodeToString()` representation of a default expression for the type. This is only used for domains.
`typdefault` `text` `typdefault` is null if the type has no associated default value. If `typdefaultbin` is not null, `typdefault` must contain a human-readable version of the default expression represented by `typdefaultbin`. If `typdefaultbin` is null and `typdefault` is not, then `typdefault` is the external representation of the type's default value, which can be fed to the type's input converter to produce a constant.
`typacl` `aclitem[]` Access privileges; see Section 5.7 for details

Note

For fixed-width types used in system tables, it is critical that the size and alignment defined in `pg_type` agree with the way that the compiler will lay out the column in a structure representing a table row.

Table 54.65 lists the system-defined values of `typcategory`. Any future additions to this list will also be upper-case ASCII letters. All other ASCII characters are reserved for user-defined categories.

Table 54.65. `typcategory` Codes

Code	Category
`A`	Array types
`B`	Boolean types
`C`	Composite types
`D`	Date/time types
`E`	Enum types
`G`	Geometric types
`I`	Network address types
`N`	Numeric types
`P`	Pseudo-types
`R`	Range types
`S`	String types
`T`	Timespan types
`U`	User-defined types
`V`	Bit-string types
`X`	`unknown` type

54.65. pg_user_mapping

The catalog pg_user_mapping stores the mappings from local user to remote. Access to this catalog is restricted from normal users, use the view pg_user_mappings instead.

Table 54.66. pg_user_mapping Columns

Column Type Description
oid oid Row identifier
umuser oid (references pg_authid .oid) OID of the local role being mapped, or zero if the user mapping is public
umserver oid (references pg_foreign_server .oid) The OID of the foreign server that contains this mapping
umoptions text[] User mapping specific options, as “keyword=value” strings

54.66. System Views

In addition to the system catalogs, Postgres Pro provides a number of built-in views. Some system views provide convenient access to some commonly used queries on the system catalogs. Other views provide access to internal server state.

The information schema (Chapter 39) provides an alternative set of views which overlap the functionality of the system views. Since the information schema is SQL-standard whereas the views described here are Postgres Pro-specific, it's usually better to use the information schema if it provides all the information you need.

Table 54.67 lists the system views described here. More detailed documentation of each view follows below. There are some additional views that provide access to the results of the statistics collector; they are described in Table 27.2.

Except where noted, all the views described here are read-only.

Table 54.67. System Views

View Name	Purpose
pg_available_extensions	available extensions
pg_available_extension_versions	available versions of extensions
pg_backend_memory_contexts	backend memory contexts
pg_config	compile-time configuration parameters
pg_cursors	open cursors
pg_file_settings	summary of configuration file contents
pg_group	groups of database users
pg_hba_file_rules	summary of client authentication configuration file contents
pg_indexes	indexes
pg_locks	locks currently held or awaited
pg_matviews	materialized views
pg_policies	policies
pg_prepared_statements	prepared statements

View Name	Purpose
pg_autoprepared_statements	autoprepared statements
pg_prepared_xacts	prepared transactions
pg_publication_tables	publications and their associated tables
pg_replication_origin_status	information about replication origins, including replication progress
pg_replication_slots	replication slot information
pg_roles	database roles
pg_rules	rules
pg_seclabels	security labels
pg_sequences	sequences
pg_settings	parameter settings
pg_shadow	database users
pg_shmem_allocations	shared memory allocations
pg_stats	planner statistics
pg_stats_ext	extended planner statistics
pg_stats_ext_exprs	extended planner statistics for expressions
pg_tables	tables
pg_timezone_abbrevs	time zone abbreviations
pg_timezone_names	time zone names
pg_user	database users
pg_user_mappings	user mappings
pg_views	views

54.67. pg_available_extensions

The pg_available_extensions view lists the extensions that are available for installation. See also the pg_extension catalog, which shows the extensions currently installed.

Table 54.68. pg_available_extensions Columns

Column Type Description
name name Extension name
default_version text Name of default version, or NULL if none is specified
installed_version text Currently installed version of the extension, or NULL if not installed
comment text Comment string from the extension's control file

The pg_available_extensions view is read-only.

54.68. pg_available_extension_versions

The pg_available_extension_versions view lists the specific extension versions that are available for installation. See also the pg_extension catalog, which shows the extensions currently installed.

Table 54.69. `pg_available_extension_versions` Columns

Column Type Description
`name name` Extension name
`version text` Version name
`installed bool` True if this version of this extension is currently installed
`superuser bool` True if only superusers are allowed to install this extension (but see `trusted`)
`trusted bool` True if the extension can be installed by non-superusers with appropriate privileges
`relocatable bool` True if extension can be relocated to another schema
`schema name` Name of the schema that the extension must be installed into, or `NULL` if partially or fully relocatable
`requires name[]` Names of prerequisite extensions, or `NULL` if none
`comment text` Comment string from the extension's control file

The `pg_available_extension_versions` view is read-only.

54.69. `pg_backend_memory_contexts`

The view `pg_backend_memory_contexts` displays all the memory contexts of the server process attached to the current session.

`pg_backend_memory_contexts` contains one row for each memory context.

Table 54.70. `pg_backend_memory_contexts` Columns

Column Type Description
`name text` Name of the memory context
`ident text` Identification information of the memory context. This field is truncated at 1024 bytes
`parent text` Name of the parent of this memory context
`level int4` Distance from TopMemoryContext in context tree
`total_bytes int8` Total bytes allocated for this memory context
`total_nblocks int8` Total number of blocks allocated for this memory context
`free_bytes int8` Free space in bytes

Column Type Description
free_chunks int8 Total number of free chunks
used_bytes int8 Used space in bytes

By default, the pg_backend_memory_contexts view can be read only by superusers.

54.70. pg_config

The view pg_config describes the compile-time configuration parameters of the currently installed version of Postgres Pro. It is intended, for example, to be used by software packages that want to interface to Postgres Pro to facilitate finding the required header files and libraries. It provides the same basic information as the pg_config Postgres Pro client application.

By default, the pg_config view can be read only by superusers.

Table 54.71. pg_config Columns

Column Type Description
name text The parameter name
setting text The parameter value

54.71. pg_cursors

The pg_cursors view lists the cursors that are currently available. Cursors can be defined in several ways:

- via the DECLARE statement in SQL
- via the Bind message in the frontend/backend protocol, as described in Section 55.2.3
- via the Server Programming Interface (SPI), as described in Section 49.1

The pg_cursors view displays cursors created by any of these means. Cursors only exist for the duration of the transaction that defines them, unless they have been declared WITH HOLD. Therefore non-holdable cursors are only present in the view until the end of their creating transaction.

> **Note**
>
> Cursors are used internally to implement some of the components of Postgres Pro, such as procedural languages. Therefore, the pg_cursors view might include cursors that have not been explicitly created by the user.

Table 54.72. pg_cursors Columns

Column Type Description
name text The name of the cursor
statement text

Column Type Description
The verbatim query string submitted to declare this cursor
`is_holdable` `bool` `true` if the cursor is holdable (that is, it can be accessed after the transaction that declared the cursor has committed); `false` otherwise
`is_binary` `bool` `true` if the cursor was declared `BINARY`; `false` otherwise
`is_scrollable` `bool` `true` if the cursor is scrollable (that is, it allows rows to be retrieved in a nonsequential manner); `false` otherwise
`creation_time` `timestamptz` The time at which the cursor was declared

The `pg_cursors` view is read-only.

54.72. `pg_file_settings`

The view `pg_file_settings` provides a summary of the contents of the server's configuration file(s). A row appears in this view for each "name = value" entry appearing in the files, with annotations indicating whether the value could be applied successfully. Additional row(s) may appear for problems not linked to a "name = value" entry, such as syntax errors in the files.

This view is helpful for checking whether planned changes in the configuration files will work, or for diagnosing a previous failure. Note that this view reports on the *current* contents of the files, not on what was last applied by the server. (The `pg_settings` view is usually sufficient to determine that.)

By default, the `pg_file_settings` view can be read only by superusers.

Table 54.73. `pg_file_settings` Columns

Column Type Description
`sourcefile` `text` Full path name of the configuration file
`sourceline` `int4` Line number within the configuration file where the entry appears
`seqno` `int4` Order in which the entries are processed (1..*n*)
`name` `text` Configuration parameter name
`setting` `text` Value to be assigned to the parameter
`applied` `bool` True if the value can be applied successfully
`error` `text` If not null, an error message indicating why this entry could not be applied

If the configuration file contains syntax errors or invalid parameter names, the server will not attempt to apply any settings from it, and therefore all the `applied` fields will read as false. In such a case there will be one or more rows with non-null `error` fields indicating the problem(s). Otherwise, individual settings will be applied if possible. If an individual setting cannot be applied (e.g., invalid value, or the setting cannot be changed after server start) it will have an appropriate message in the `error` field. Another way

that an entry might have applied = false is that it is overridden by a later entry for the same parameter name; this case is not considered an error so nothing appears in the error field.

See Section 19.1 for more information about the various ways to change run-time parameters.

54.73. pg_group

The view pg_group exists for backwards compatibility: it emulates a catalog that existed in PostgreSQL before version 8.1. It shows the names and members of all roles that are marked as not rolcanlogin, which is an approximation to the set of roles that are being used as groups.

Table 54.74. pg_group Columns

Column Type Description
groname name (references pg_authid .rolname) Name of the group
grosysid oid (references pg_authid .oid) ID of this group
grolist oid[] (references pg_authid .oid) An array containing the IDs of the roles in this group

54.74. pg_hba_file_rules

The view pg_hba_file_rules provides a summary of the contents of the client authentication configuration file, pg_hba.conf. A row appears in this view for each non-empty, non-comment line in the file, with annotations indicating whether the rule could be applied successfully.

This view can be helpful for checking whether planned changes in the authentication configuration file will work, or for diagnosing a previous failure. Note that this view reports on the *current* contents of the file, not on what was last loaded by the server.

By default, the pg_hba_file_rules view can be read only by superusers.

Table 54.75. pg_hba_file_rules Columns

Column Type Description
line_number int4 Line number of this rule in pg_hba.conf
type text Type of connection
database text[] List of database name(s) to which this rule applies
user_name text[] List of user and group name(s) to which this rule applies
address text Host name or IP address, or one of all, samehost, or samenet, or null for local connections
netmask text IP address mask, or null if not applicable
auth_method text Authentication method
options text[] Options specified for authentication method, if any

Column Type Description
error text If not null, an error message indicating why this line could not be processed

Usually, a row reflecting an incorrect entry will have values for only the line_number and error fields.

See Chapter 20 for more information about client authentication configuration.

54.75. pg_indexes

The view pg_indexes provides access to useful information about each index in the database.

Table 54.76. pg_indexes Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing table and index
tablename name (references pg_class .relname) Name of table the index is for
indexname name (references pg_class .relname) Name of index
tablespace name (references pg_tablespace .spcname) Name of tablespace containing index (null if default for database)
indexdef text Index definition (a reconstructed CREATE INDEX command)

54.76. pg_locks

The view pg_locks provides access to information about the locks held by active processes within the database server. See Chapter 13 for more discussion of locking.

pg_locks contains one row per active lockable object, requested lock mode, and relevant process. Thus, the same lockable object might appear many times, if multiple processes are holding or waiting for locks on it. However, an object that currently has no locks on it will not appear at all.

There are several distinct types of lockable objects: whole relations (e.g., tables), individual pages of relations, individual tuples of relations, transaction IDs (both virtual and permanent IDs), and general database objects (identified by class OID and object OID, in the same way as in pg_description or pg_depend). Also, the right to extend a relation is represented as a separate lockable object, as is the right to update pg_database.datfrozenxid. Also, "advisory" locks can be taken on numbers that have user-defined meanings.

Table 54.77. pg_locks Columns

Column Type Description
locktype text Type of the lockable object: relation, extend, frozenid, page, tuple, transactionid, virtualxid, spectoken, object, userlock, or advisory. (See also Table 27.11.)
database oid (references pg_database .oid) OID of the database in which the lock target exists, or zero if the target is a shared object, or null if the target is a transaction ID

Column Type Description
`relation` `oid` (references `pg_class` .`oid`) OID of the relation targeted by the lock, or null if the target is not a relation or part of a relation
`page` `int4` Page number targeted by the lock within the relation, or null if the target is not a relation page or tuple
`tuple` `int2` Tuple number targeted by the lock within the page, or null if the target is not a tuple
`virtualxid` `text` Virtual ID of the transaction targeted by the lock, or null if the target is not a virtual transaction ID
`transactionid` `xid` ID of the transaction targeted by the lock, or null if the target is not a transaction ID
`classid` `oid` (references `pg_class` .`oid`) OID of the system catalog containing the lock target, or null if the target is not a general database object
`objid` `oid` (references any OID column) OID of the lock target within its system catalog, or null if the target is not a general database object
`objsubid` `int2` Column number targeted by the lock (the `classid` and `objid` refer to the table itself), or zero if the target is some other general database object, or null if the target is not a general database object
`virtualtransaction` `text` Virtual ID of the transaction that is holding or awaiting this lock
`pid` `int4` Process ID of the server process holding or awaiting this lock, or null if the lock is held by a prepared transaction
`mode` `text` Name of the lock mode held or desired by this process (see Section 13.3.1 and Section 13.2.3)
`granted` `bool` True if lock is held, false if lock is awaited
`fastpath` `bool` True if lock was taken via fast path, false if taken via main lock table
`waitstart` `timestamptz` Time when the server process started waiting for this lock, or null if the lock is held. Note that this can be null for a very short period of time after the wait started even though `granted` is `false`.

`granted` is true in a row representing a lock held by the indicated process. False indicates that this process is currently waiting to acquire this lock, which implies that at least one other process is holding or waiting for a conflicting lock mode on the same lockable object. The waiting process will sleep until the other lock is released (or a deadlock situation is detected). A single process can be waiting to acquire at most one lock at a time.

Throughout running a transaction, a server process holds an exclusive lock on the transaction's virtual transaction ID. If a permanent ID is assigned to the transaction (which normally happens only if the transaction changes the state of the database), it also holds an exclusive lock on the transaction's permanent transaction ID until it ends. When a process finds it necessary to wait specifically for another transaction to end, it does so by attempting to acquire share lock on the other transaction's ID (either

virtual or permanent ID depending on the situation). That will succeed only when the other transaction terminates and releases its locks.

Although tuples are a lockable type of object, information about row-level locks is stored on disk, not in memory, and therefore row-level locks normally do not appear in this view. If a process is waiting for a row-level lock, it will usually appear in the view as waiting for the permanent transaction ID of the current holder of that row lock.

Advisory locks can be acquired on keys consisting of either a single `bigint` value or two integer values. A `bigint` key is displayed with its high-order half in the `classid` column, its low-order half in the `objid` column, and `objsubid` equal to 1. The original `bigint` value can be reassembled with the expression `(classid::bigint << 32) | objid::bigint`. Integer keys are displayed with the first key in the `classid` column, the second key in the `objid` column, and `objsubid` equal to 2. The actual meaning of the keys is up to the user. Advisory locks are local to each database, so the `database` column is meaningful for an advisory lock.

`pg_locks` provides a global view of all locks in the database cluster, not only those relevant to the current database. Although its `relation` column can be joined against `pg_class.oid` to identify locked relations, this will only work correctly for relations in the current database (those for which the `database` column is either the current database's OID or zero).

The `pid` column can be joined to the `pid` column of the `pg_stat_activity` view to get more information on the session holding or awaiting each lock, for example

```
SELECT * FROM pg_locks pl LEFT JOIN pg_stat_activity psa
    ON pl.pid = psa.pid;
```

Also, if you are using prepared transactions, the `virtualtransaction` column can be joined to the `transaction` column of the `pg_prepared_xacts` view to get more information on prepared transactions that hold locks. (A prepared transaction can never be waiting for a lock, but it continues to hold the locks it acquired while running.) For example:

```
SELECT * FROM pg_locks pl LEFT JOIN pg_prepared_xacts ppx
    ON pl.virtualtransaction = '-1/' || ppx.transaction;
```

While it is possible to obtain information about which processes block which other processes by joining `pg_locks` against itself, this is very difficult to get right in detail. Such a query would have to encode knowledge about which lock modes conflict with which others. Worse, the `pg_locks` view does not expose information about which processes are ahead of which others in lock wait queues, nor information about which processes are parallel workers running on behalf of which other client sessions. It is better to use the `pg_blocking_pids()` function (see Table 9.65) to identify which process(es) a waiting process is blocked behind.

The `pg_locks` view displays data from both the regular lock manager and the predicate lock manager, which are separate systems; in addition, the regular lock manager subdivides its locks into regular and *fast-path* locks. This data is not guaranteed to be entirely consistent. When the view is queried, data on fast-path locks (with `fastpath` = `true`) is gathered from each backend one at a time, without freezing the state of the entire lock manager, so it is possible for locks to be taken or released while information is gathered. Note, however, that these locks are known not to conflict with any other lock currently in place. After all backends have been queried for fast-path locks, the remainder of the regular lock manager is locked as a unit, and a consistent snapshot of all remaining locks is collected as an atomic action. After unlocking the regular lock manager, the predicate lock manager is similarly locked and all predicate locks are collected as an atomic action. Thus, with the exception of fast-path locks, each lock manager will deliver a consistent set of results, but as we do not lock both lock managers simultaneously, it is possible for locks to be taken or released after we interrogate the regular lock manager and before we interrogate the predicate lock manager.

Locking the regular and/or predicate lock manager could have some impact on database performance if this view is very frequently accessed. The locks are held only for the minimum amount of time necessary to obtain data from the lock managers, but this does not completely eliminate the possibility of a performance impact.

54.77. pg_matviews

The view pg_matviews provides access to useful information about each materialized view in the database.

Table 54.78. pg_matviews Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing materialized view
matviewname name (references pg_class .relname) Name of materialized view
matviewowner name (references pg_authid .rolname) Name of materialized view's owner
tablespace name (references pg_tablespace .spcname) Name of tablespace containing materialized view (null if default for database)
hasindexes bool True if materialized view has (or recently had) any indexes
ispopulated bool True if materialized view is currently populated
definition text Materialized view definition (a reconstructed SELECT query)

54.78. pg_policies

The view pg_policies provides access to useful information about each row-level security policy in the database.

Table 54.79. pg_policies Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing table policy is on
tablename name (references pg_class .relname) Name of table policy is on
policyname name (references pg_policy .polname) Name of policy
permissive text Is the policy permissive or restrictive?
roles name[] The roles to which this policy applies
cmd text The command type to which the policy is applied
qual text The expression added to the security barrier qualifications for queries that this policy applies to
with_check text The expression added to the WITH CHECK qualifications for queries that attempt to add rows to this table

54.79. pg_prepared_statements

The pg_prepared_statements view displays all the prepared statements that are available in the current session. See PREPARE for more information about prepared statements.

pg_prepared_statements contains one row for each prepared statement. Rows are added to the view when a new prepared statement is created and removed when a prepared statement is released (for example, via the DEALLOCATE command).

Table 54.80. pg_prepared_statements Columns

Column Type Description
name text The identifier of the prepared statement
statement text The query string submitted by the client to create this prepared statement. For prepared statements created via SQL, this is the PREPARE statement submitted by the client. For prepared statements created via the frontend/backend protocol, this is the text of the prepared statement itself.
prepare_time timestamptz The time at which the prepared statement was created
parameter_types regtype[] The expected parameter types for the prepared statement in the form of an array of regtype. The OID corresponding to an element of this array can be obtained by casting the regtype value to oid.
from_sql bool true if the prepared statement was created via the PREPARE SQL command; false if the statement was prepared via the frontend/backend protocol
generic_plans int8 Number of times generic plan was chosen
custom_plans int8 Number of times custom plan was chosen

The pg_prepared_statements view is read-only.

54.80. pg_autoprepared_statements

The pg_autoprepared_statements view displays all the autoprepared statements that are available in the current session. See Section 14.6 for more information about autoprepared statements.

Table 54.81. pg_autoprepared_statements Columns

Name	Type	Description
statement	text	The query string submitted by the client from which this prepared statement was created. Note that literals in this string are not replaced with prepared statement placeholders.
parameter_types	regtype[]	The expected parameter types for the autoprepared statement in the form of an array of regtype. The OID corresponding to an element of this array can be obtained by casting the regtype value to oid.

Name	Type	Description
exec_count	int8	Number of times this statement was executed.

The pg_autoprepared_statements view is read only.

54.81. pg_prepared_xacts

The view pg_prepared_xacts displays information about transactions that are currently prepared for two-phase commit (see PREPARE TRANSACTION for details).

pg_prepared_xacts contains one row per prepared transaction. An entry is removed when the transaction is committed or rolled back.

Table 54.82. pg_prepared_xacts Columns

Column Type Description
transaction xid Numeric transaction identifier of the prepared transaction
gid text Global transaction identifier that was assigned to the transaction
prepared timestamptz Time at which the transaction was prepared for commit
owner name (references pg_authid .rolname) Name of the user that executed the transaction
database name (references pg_database .datname) Name of the database in which the transaction was executed
state3pc text State of the three-phase commit (used only by multimaster)

When the pg_prepared_xacts view is accessed, the internal transaction manager data structures are momentarily locked, and a copy is made for the view to display. This ensures that the view produces a consistent set of results, while not blocking normal operations longer than necessary. Nonetheless there could be some impact on database performance if this view is frequently accessed.

54.82. pg_publication_tables

The view pg_publication_tables provides information about the mapping between publications and the tables they contain. Unlike the underlying catalog pg_publication_rel, this view expands publications defined as FOR ALL TABLES, so for such publications there will be a row for each eligible table.

Table 54.83. pg_publication_tables Columns

Column Type Description
pubname name (references pg_publication .pubname) Name of publication
schemaname name (references pg_namespace .nspname) Name of schema containing table
tablename name (references pg_class .relname) Name of table

54.83. pg_replication_origin_status

The pg_replication_origin_status view contains information about how far replay for a certain origin has progressed. For more on replication origins see Chapter 52.

Table 54.84. pg_replication_origin_status Columns

Column Type Description
local_id oid (references pg_replication_origin .roident) internal node identifier
external_id text (references pg_replication_origin .roname) external node identifier
remote_lsn pg_lsn The origin node's LSN up to which data has been replicated.
local_lsn pg_lsn This node's LSN at which remote_lsn has been replicated. Used to flush commit records before persisting data to disk when using asynchronous commits.

54.84. pg_replication_slots

The pg_replication_slots view provides a listing of all replication slots that currently exist on the database cluster, along with their current state.

For more on replication slots, see Section 26.2.6 and Chapter 51.

Table 54.85. pg_replication_slots Columns

Column Type Description
slot_name name A unique, cluster-wide identifier for the replication slot
plugin name The base name of the shared object containing the output plugin this logical slot is using, or null for physical slots.
slot_type text The slot type: physical or logical
datoid oid (references pg_database .oid) The OID of the database this slot is associated with, or null. Only logical slots have an associated database.
database name (references pg_database .datname) The name of the database this slot is associated with, or null. Only logical slots have an associated database.
temporary bool True if this is a temporary replication slot. Temporary slots are not saved to disk and are automatically dropped on error or when the session has finished.
active bool True if this slot is currently actively being used
active_pid int4 The process ID of the session using this slot if the slot is currently actively being used. NULL if inactive.
xmin xid The oldest transaction that this slot needs the database to retain. VACUUM cannot remove tuples deleted by any later transaction.
catalog_xmin xid

Column Type Description
The oldest transaction affecting the system catalogs that this slot needs the database to retain. VACUUM cannot remove catalog tuples deleted by any later transaction.
restart_lsn pg_lsn The address (LSN) of oldest WAL which still might be required by the consumer of this slot and thus won't be automatically removed during checkpoints unless this LSN gets behind more than max_slot_wal_keep_size from the current LSN. NULL if the LSN of this slot has never been reserved.
confirmed_flush_lsn pg_lsn The address (LSN) up to which the logical slot's consumer has confirmed receiving data. Data older than this is not available anymore. NULL for physical slots.
wal_status text Availability of WAL files claimed by this slot. Possible values are: • reserved means that the claimed files are within max_wal_size . • extended means that max_wal_size is exceeded but the files are still retained, either by the replication slot or by wal_keep_size . • unreserved means that the slot no longer retains the required WAL files and some of them are to be removed at the next checkpoint. This state can return to reserved or extended. • lost means that some required WAL files have been removed and this slot is no longer usable. The last two states are seen only when max_slot_wal_keep_size is non-negative. If restart_lsn is NULL, this field is null.
safe_wal_size int8 The number of bytes that can be written to WAL such that this slot is not in danger of getting in state "lost". It is NULL for lost slots, as well as if max_slot_wal_keep_size is -1.
two_phase bool True if the slot is enabled for decoding prepared transactions. Always false for physical slots.

54.85. pg_roles

The view pg_roles provides access to information about database roles. This is simply a publicly readable view of pg_authid that blanks out the password field.

Table 54.86. pg_roles Columns

Column Type Description
rolname name Role name
rolsuper bool Role has superuser privileges
rolinherit bool Role automatically inherits privileges of roles it is a member of
rolcreaterole bool Role can create more roles
rolcreatedb bool Role can create databases
rolcanlogin bool Role can log in. That is, this role can be given as the initial session authorization identifier

Column Type Description
rolreplication bool Role is a replication role. A replication role can initiate replication connections and create and drop replication slots.
rolconnlimit int4 For roles that can log in, this sets maximum number of concurrent connections this role can make. -1 means no limit.
rolprofile regprofile (references pg_profile .oid) The OID of the role's profile
rolloginattempts int4 Number of consecutive failed login attempts of a user. It is always 0 if FAILED_LOGIN_ATTEMPTS value of the corresponding role profile is UNLIMITED. After a successful login, rolloginattempts is reset to 0.
rolstatus int2 Status of the role: 0 for the active role, 1 the role is manually locked (see ACCOUNT LOCK in ALTER ROLE), 2 the role is locked because of inactivity (see parameter USER_INACTIVE_TIME in CREATE PROFILE), 4 the role is locked because the number of consecutive authentication failures has reached the limit (see parameter FAILED_LOGIN_ATTEMPTS in CREATE PROFILE)
rollastlogin timestamptz The timestamp the role logged in last time
rolfirstfailedauth timestamptz The timestamp of the role's first authentication failure
rolpassword text Not the password (always reads as ********)
rolvaliduntil timestamptz Password expiry time (only used for password authentication); null if no expiration
rolpasssetat timestamptz Password set time (only used for password authentication); null if password is not set.
rolbypassrls bool Role bypasses every row-level security policy, see Section 5.8 for more information.
rolconfig text[] Role-specific defaults for run-time configuration variables
oid oid (references pg_authid .oid) ID of role

54.86. pg_rules

The view pg_rules provides access to useful information about query rewrite rules.

Table 54.87. pg_rules Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing table
tablename name (references pg_class .relname) Name of table the rule is for
rulename name (references pg_rewrite .rulename) Name of rule

Column Type Description
definition text Rule definition (a reconstructed creation command)

The pg_rules view excludes the ON SELECT rules of views and materialized views; those can be seen in pg_views and pg_matviews.

54.87. pg_seclabels

The view pg_seclabels provides information about security labels. It as an easier-to-query version of the pg_seclabel catalog.

Table 54.88. pg_seclabels Columns

Column Type Description
objoid oid (references any OID column) The OID of the object this security label pertains to
classoid oid (references pg_class .oid) The OID of the system catalog this object appears in
objsubid int4 For a security label on a table column, this is the column number (the objoid and classoid refer to the table itself). For all other object types, this column is zero.
objtype text The type of object to which this label applies, as text.
objnamespace oid (references pg_namespace .oid) The OID of the namespace for this object, if applicable; otherwise NULL.
objname text The name of the object to which this label applies, as text.
provider text (references pg_seclabel .provider) The label provider associated with this label.
label text (references pg_seclabel .label) The security label applied to this object.

54.88. pg_sequences

The view pg_sequences provides access to useful information about each sequence in the database.

Table 54.89. pg_sequences Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing sequence
sequencename name (references pg_class .relname) Name of sequence
sequenceowner name (references pg_authid .rolname) Name of sequence's owner
data_type regtype (references pg_type .oid) Data type of the sequence
start_value int8

Column Type Description
Start value of the sequence
`min_value` `int8` Minimum value of the sequence
`max_value` `int8` Maximum value of the sequence
`increment_by` `int8` Increment value of the sequence
`cycle` `bool` Whether the sequence cycles
`cache_size` `int8` Cache size of the sequence
`last_value` `int8` The last sequence value written to disk. If caching is used, this value can be greater than the last value handed out from the sequence. Null if the sequence has not been read from yet. Also, if the current user does not have `USAGE` or `SELECT` privilege on the sequence, the value is null.

54.89. `pg_settings`

The view `pg_settings` provides access to run-time parameters of the server. It is essentially an alternative interface to the `SHOW` and `SET` commands. It also provides access to some facts about each parameter that are not directly available from `SHOW`, such as minimum and maximum values.

Table 54.90. `pg_settings` Columns

Column Type Description
`name` `text` Run-time configuration parameter name
`setting` `text` Current value of the parameter
`unit` `text` Implicit unit of the parameter
`category` `text` Logical group of the parameter
`short_desc` `text` A brief description of the parameter
`extra_desc` `text` Additional, more detailed, description of the parameter
`context` `text` Context required to set the parameter's value (see below)
`vartype` `text` Parameter type (`bool`, `enum`, `integer`, `real`, or `string`)
`source` `text` Source of the current parameter value
`min_val` `text` Minimum allowed value of the parameter (null for non-numeric values)
`max_val` `text` Maximum allowed value of the parameter (null for non-numeric values)

Column Type Description
enumvals text[] Allowed values of an enum parameter (null for non-enum values)
boot_val text Parameter value assumed at server startup if the parameter is not otherwise set
reset_val text Value that RESET would reset the parameter to in the current session
sourcefile text Configuration file the current value was set in (null for values set from sources other than configuration files, or when examined by a user who is neither a superuser or a member of pg_read_all_settings); helpful when using include directives in configuration files
sourceline int4 Line number within the configuration file the current value was set at (null for values set from sources other than configuration files, or when examined by a user who is neither a superuser or a member of pg_read_all_settings).
pending_restart bool true if the value has been changed in the configuration file but needs a restart; or false otherwise.

There are several possible values of context. In order of decreasing difficulty of changing the setting, they are:

internal

These settings cannot be changed directly; they reflect internally determined values. Some of them may be adjustable by rebuilding the server with different configuration options, or by changing options supplied to initdb.

postmaster

These settings can only be applied when the server starts, so any change requires restarting the server. Values for these settings are typically stored in the postgresql.conf file, or passed on the command line when starting the server. Of course, settings with any of the lower context types can also be set at server start time.

sighup

Changes to these settings can be made in postgresql.conf without restarting the server. Send a SIGHUP signal to the postmaster to cause it to re-read postgresql.conf and apply the changes. The postmaster will also forward the SIGHUP signal to its child processes so that they all pick up the new value.

superuser-backend

Changes to these settings can be made in postgresql.conf without restarting the server. They can also be set for a particular session in the connection request packet (for example, via libpq's PGOPTIONS environment variable), but only if the connecting user is a superuser. However, these settings never change in a session after it is started. If you change them in postgresql.conf, send a SIGHUP signal to the postmaster to cause it to re-read postgresql.conf. The new values will only affect subsequently-launched sessions.

backend

Changes to these settings can be made in postgresql.conf without restarting the server. They can also be set for a particular session in the connection request packet (for example, via libpq's PGOPTIONS environment variable); any user can make such a change for their session. However, these settings never change in a session after it is started. If you change them in postgresql.conf, send

a SIGHUP signal to the postmaster to cause it to re-read `postgresql.conf`. The new values will only affect subsequently-launched sessions.

`superuser`

These settings can be set from `postgresql.conf`, or within a session via the `SET` command; but only superusers can change them via `SET`. Changes in `postgresql.conf` will affect existing sessions only if no session-local value has been established with `SET`.

`user`

These settings can be set from `postgresql.conf`, or within a session via the `SET` command. Any user is allowed to change their session-local value. Changes in `postgresql.conf` will affect existing sessions only if no session-local value has been established with `SET`.

See Section 19.1 for more information about the various ways to change these parameters.

This view does not display customized options until the extension module that defines them has been loaded.

This view cannot be inserted into or deleted from, but it can be updated. An `UPDATE` applied to a row of `pg_settings` is equivalent to executing the `SET` command on that named parameter. The change only affects the value used by the current session. If an `UPDATE` is issued within a transaction that is later aborted, the effects of the `UPDATE` command disappear when the transaction is rolled back. Once the surrounding transaction is committed, the effects will persist until the end of the session, unless overridden by another `UPDATE` or `SET`.

54.90. pg_shadow

The view `pg_shadow` exists for backwards compatibility: it emulates a catalog that existed in PostgreSQL before version 8.1. It shows properties of all roles that are marked as `rolcanlogin` in `pg_authid`.

The name stems from the fact that this table should not be readable by the public since it contains passwords. `pg_user` is a publicly readable view on `pg_shadow` that blanks out the password field.

Table 54.91. `pg_shadow` Columns

Column Type Description
`usename name` (references `pg_authid .rolname`) User name
`usesysid oid` (references `pg_authid .oid`) ID of this user
`usecreatedb bool` User can create databases
`usesuper bool` User is a superuser
`userepl bool` User can initiate streaming replication and put the system in and out of backup mode.
`usebypassrls bool` User bypasses every row-level security policy, see Section 5.8 for more information.
`passwd text` Password (possibly encrypted); null if none. See `pg_authid` for details of how encrypted passwords are stored.
`valuntil timestamptz` Password expiry time (only used for password authentication)
`useconfig text[]`

Column Type Description
Session defaults for run-time configuration variables

54.91. pg_shmem_allocations

The pg_shmem_allocations view shows allocations made from the server's main shared memory segment. This includes both memory allocated by postgres itself and memory allocated by extensions using the mechanisms detailed in Section 40.10.10.

Note that this view does not include memory allocated using the dynamic shared memory infrastructure.

Table 54.92. pg_shmem_allocations Columns

Column Type Description
name text The name of the shared memory allocation. NULL for unused memory and <anonymous> for anonymous allocations.
off int8 The offset at which the allocation starts. NULL for anonymous allocations, since details related to them are not known.
size int8 Size of the allocation
allocated_size int8 Size of the allocation including padding. For anonymous allocations, no information about padding is available, so the size and allocated_size columns will always be equal. Padding is not meaningful for free memory, so the columns will be equal in that case also.

Anonymous allocations are allocations that have been made with ShmemAlloc() directly, rather than via ShmemInitStruct() or ShmemInitHash().

By default, the pg_shmem_allocations view can be read only by superusers.

54.92. pg_stats

The view pg_stats provides access to the information stored in the pg_statistic catalog. This view allows access only to rows of pg_statistic that correspond to tables the user has permission to read, and therefore it is safe to allow public read access to this view.

pg_stats is also designed to present the information in a more readable format than the underlying catalog — at the cost that its schema must be extended whenever new slot types are defined for pg_statistic.

Table 54.93. pg_stats Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing table
tablename name (references pg_class .relname) Name of table
attname name (references pg_attribute .attname) Name of column described by this row
inherited bool

Column Type Description
If true, this row includes inheritance child columns, not just the values in the specified table
`null_frac` `float4` Fraction of column entries that are null
`avg_width` `int4` Average width in bytes of column's entries
`n_distinct` `float4` If greater than zero, the estimated number of distinct values in the column. If less than zero, the negative of the number of distinct values divided by the number of rows. (The negated form is used when `ANALYZE` believes that the number of distinct values is likely to increase as the table grows; the positive form is used when the column seems to have a fixed number of possible values.) For example, -1 indicates a unique column in which the number of distinct values is the same as the number of rows.
`most_common_vals` `anyarray` A list of the most common values in the column. (Null if no values seem to be more common than any others.)
`most_common_freqs` `float4[]` A list of the frequencies of the most common values, i.e., number of occurrences of each divided by total number of rows. (Null when `most_common_vals` is.)
`histogram_bounds` `anyarray` A list of values that divide the column's values into groups of approximately equal population. The values in `most_common_vals`, if present, are omitted from this histogram calculation. (This column is null if the column data type does not have a < operator or if the `most_common_vals` list accounts for the entire population.)
`correlation` `float4` Statistical correlation between physical row ordering and logical ordering of the column values. This ranges from -1 to +1. When the value is near -1 or +1, an index scan on the column will be estimated to be cheaper than when it is near zero, due to reduction of random access to the disk. (This column is null if the column data type does not have a < operator.)
`most_common_elems` `anyarray` A list of non-null element values most often appearing within values of the column. (Null for scalar types.)
`most_common_elem_freqs` `float4[]` A list of the frequencies of the most common element values, i.e., the fraction of rows containing at least one instance of the given value. Two or three additional values follow the per-element frequencies; these are the minimum and maximum of the preceding per-element frequencies, and optionally the frequency of null elements. (Null when `most_common_elems` is.)
`elem_count_histogram` `float4[]` A histogram of the counts of distinct non-null element values within the values of the column, followed by the average number of distinct non-null elements. (Null for scalar types.)

The maximum number of entries in the array fields can be controlled on a column-by-column basis using the `ALTER TABLE SET STATISTICS` command, or globally by setting the default_statistics_target runtime parameter.

54.93. pg_stats_ext

The view `pg_stats_ext` provides access to information about each extended statistics object in the database, combining information stored in the `pg_statistic_ext` and `pg_statistic_ext_data` catalogs. This view allows access only to rows of `pg_statistic_ext` and `pg_statistic_ext_data` that correspond to tables the user owns, and therefore it is safe to allow public read access to this view.

pg_stats_ext is also designed to present the information in a more readable format than the underlying catalogs — at the cost that its schema must be extended whenever new types of extended statistics are added to pg_statistic_ext.

Table 54.94. pg_stats_ext Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing table
tablename name (references pg_class .relname) Name of table
statistics_schemaname name (references pg_namespace .nspname) Name of schema containing extended statistics object
statistics_name name (references pg_statistic_ext .stxname) Name of extended statistics object
statistics_owner name (references pg_authid .rolname) Owner of the extended statistics object
attnames name[] (references pg_attribute .attname) Names of the columns included in the extended statistics object
exprs text[] Expressions included in the extended statistics object
kinds char[] Types of extended statistics object enabled for this record
n_distinct pg_ndistinct N-distinct counts for combinations of column values. If greater than zero, the estimated number of distinct values in the combination. If less than zero, the negative of the number of distinct values divided by the number of rows. (The negated form is used when ANALYZE believes that the number of distinct values is likely to increase as the table grows; the positive form is used when the column seems to have a fixed number of possible values.) For example, -1 indicates a unique combination of columns in which the number of distinct combinations is the same as the number of rows.
dependencies pg_dependencies Functional dependency statistics
most_common_vals text[] A list of the most common combinations of values in the columns. (Null if no combinations seem to be more common than any others.)
most_common_val_nulls bool[] A list of NULL flags for the most common combinations of values. (Null when most_common_vals is.)
most_common_freqs float8[] A list of the frequencies of the most common combinations, i.e., number of occurrences of each divided by total number of rows. (Null when most_common_vals is.)
most_common_base_freqs float8[] A list of the base frequencies of the most common combinations, i.e., product of per-value frequencies. (Null when most_common_vals is.)

The maximum number of entries in the array fields can be controlled on a column-by-column basis using the ALTER TABLE SET STATISTICS command, or globally by setting the default_statistics_target runtime parameter.

54.94. pg_stats_ext_exprs

The view pg_stats_ext_exprs provides access to information about all expressions included in extended statistics objects, combining information stored in the pg_statistic_ext and pg_statistic_ext_data catalogs. This view allows access only to rows of pg_statistic_ext and pg_statistic_ext_data that correspond to tables the user owns, and therefore it is safe to allow public read access to this view.

pg_stats_ext_exprs is also designed to present the information in a more readable format than the underlying catalogs — at the cost that its schema must be extended whenever the structure of statistics in pg_statistic_ext changes.

Table 54.95. pg_stats_ext_exprs Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing table
tablename name (references pg_class .relname) Name of table the statistics object is defined on
statistics_schemaname name (references pg_namespace .nspname) Name of schema containing extended statistics object
statistics_name name (references pg_statistic_ext .stxname) Name of extended statistics object
statistics_owner name (references pg_authid .rolname) Owner of the extended statistics object
expr text Expression included in the extended statistics object
null_frac float4 Fraction of expression entries that are null
avg_width int4 Average width in bytes of expression's entries
n_distinct float4 If greater than zero, the estimated number of distinct values in the expression. If less than zero, the negative of the number of distinct values divided by the number of rows. (The negated form is used when ANALYZE believes that the number of distinct values is likely to increase as the table grows; the positive form is used when the expression seems to have a fixed number of possible values.) For example, -1 indicates a unique expression in which the number of distinct values is the same as the number of rows.
most_common_vals anyarray A list of the most common values in the expression. (Null if no values seem to be more common than any others.)
most_common_freqs float4[] A list of the frequencies of the most common values, i.e., number of occurrences of each divided by total number of rows. (Null when most_common_vals is.)
histogram_bounds anyarray A list of values that divide the expression's values into groups of approximately equal population. The values in most_common_vals , if present, are omitted from this histogram calculation. (This expression is null if the expression data type does not have a < operator or if the most_common_vals list accounts for the entire population.)
correlation float4 Statistical correlation between physical row ordering and logical ordering of the expression values. This ranges from -1 to +1. When the value is near -1 or +1, an index scan on the expression will be estimated to be cheaper than when it is near zero, due to reduction of random access to the disk. (This expression is null if the expression's data type does not have a < operator.)

Column Type Description
most_common_elems anyarray A list of non-null element values most often appearing within values of the expression. (Null for scalar types.)
most_common_elem_freqs float4[] A list of the frequencies of the most common element values, i.e., the fraction of rows containing at least one instance of the given value. Two or three additional values follow the per-element frequencies; these are the minimum and maximum of the preceding per-element frequencies, and optionally the frequency of null elements. (Null when most_common_elems is.)
elem_count_histogram float4[] A histogram of the counts of distinct non-null element values within the values of the expression, followed by the average number of distinct non-null elements. (Null for scalar types.)

The maximum number of entries in the array fields can be controlled on a column-by-column basis using the ALTER TABLE SET STATISTICS command, or globally by setting the default_statistics_target runtime parameter.

54.95. pg_tables

The view pg_tables provides access to useful information about each table in the database.

Table 54.96. pg_tables Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing table
tablename name (references pg_class .relname) Name of table
tableowner name (references pg_authid .rolname) Name of table's owner
tablespace name (references pg_tablespace .spcname) Name of tablespace containing table (null if default for database)
hasindexes bool (references pg_class .relhasindex) True if table has (or recently had) any indexes
hasrules bool (references pg_class .relhasrules) True if table has (or once had) rules
hastriggers bool (references pg_class .relhastriggers) True if table has (or once had) triggers
rowsecurity bool (references pg_class .relrowsecurity) True if row security is enabled on the table

54.96. pg_timezone_abbrevs

The view pg_timezone_abbrevs provides a list of time zone abbreviations that are currently recognized by the datetime input routines. The contents of this view change when the timezone_abbreviations runtime parameter is modified.

Table 54.97. pg_timezone_abbrevs Columns

Column Type Description
abbrev text

Column Type Description
Time zone abbreviation
`utc_offset interval` Offset from UTC (positive means east of Greenwich)
`is_dst bool` True if this is a daylight-savings abbreviation

While most timezone abbreviations represent fixed offsets from UTC, there are some that have historically varied in value (see Section B.4 for more information). In such cases this view presents their current meaning.

54.97. pg_timezone_names

The view `pg_timezone_names` provides a list of time zone names that are recognized by `SET TIMEZONE`, along with their associated abbreviations, UTC offsets, and daylight-savings status. (Technically, Postgres Pro does not use UTC because leap seconds are not handled.) Unlike the abbreviations shown in `pg_timezone_abbrevs`, many of these names imply a set of daylight-savings transition date rules. Therefore, the associated information changes across local DST boundaries. The displayed information is computed based on the current value of `CURRENT_TIMESTAMP`.

Table 54.98. `pg_timezone_names` Columns

Column Type Description
`name text` Time zone name
`abbrev text` Time zone abbreviation
`utc_offset interval` Offset from UTC (positive means east of Greenwich)
`is_dst bool` True if currently observing daylight savings

54.98. pg_user

The view `pg_user` provides access to information about database users. This is simply a publicly readable view of `pg_shadow` that blanks out the password field.

Table 54.99. `pg_user` Columns

Column Type Description
`usename name` User name
`usesysid oid` ID of this user
`usecreatedb bool` User can create databases
`usesuper bool` User is a superuser
`userepl bool` User can initiate streaming replication and put the system in and out of backup mode.

Column Type Description
usebypassrls bool User bypasses every row-level security policy, see Section 5.8 for more information.
passwd text Not the password (always reads as ********)
valuntil timestamptz Password expiry time (only used for password authentication)
useconfig text[] Session defaults for run-time configuration variables

54.99. pg_user_mappings

The view pg_user_mappings provides access to information about user mappings. This is essentially a publicly readable view of pg_user_mapping that leaves out the options field if the user has no rights to use it.

Table 54.100. pg_user_mappings Columns

Column Type Description
umid oid (references pg_user_mapping .oid) OID of the user mapping
srvid oid (references pg_foreign_server .oid) The OID of the foreign server that contains this mapping
srvname name (references pg_foreign_server .srvname) Name of the foreign server
umuser oid (references pg_authid .oid) OID of the local role being mapped, or zero if the user mapping is public
usename name Name of the local user to be mapped
umoptions text[] User mapping specific options, as “keyword=value” strings

To protect password information stored as a user mapping option, the umoptions column will read as null unless one of the following applies:

- current user is the user being mapped, and owns the server or holds USAGE privilege on it
- current user is the server owner and mapping is for PUBLIC
- current user is a superuser

54.100. pg_views

The view pg_views provides access to useful information about each view in the database.

Table 54.101. pg_views Columns

Column Type Description
schemaname name (references pg_namespace .nspname) Name of schema containing view
viewname name (references pg_class .relname) Name of view

Column Type Description
viewowner name (references pg_authid .rolname) Name of view's owner
definition text View definition (a reconstructed SELECT query)

Chapter 55. Frontend/Backend Protocol

Postgres Pro uses a message-based protocol for communication between frontends and backends (clients and servers). The protocol is supported over TCP/IP and also over Unix-domain sockets. Port number 5432 has been registered with IANA as the customary TCP port number for servers supporting this protocol, but in practice any non-privileged port number can be used.

This document describes version 3.0 of the protocol, implemented in PostgreSQL 7.4 and later. For descriptions of the earlier protocol versions, see previous releases of the PostgreSQL documentation. A single server can support multiple protocol versions. The initial startup-request message tells the server which protocol version the client is attempting to use. If the major version requested by the client is not supported by the server, the connection will be rejected (for example, this would occur if the client requested protocol version 4.0, which does not exist as of this writing). If the minor version requested by the client is not supported by the server (e.g., the client requests version 3.1, but the server supports only 3.0), the server may either reject the connection or may respond with a NegotiateProtocolVersion message containing the highest minor protocol version which it supports. The client may then choose either to continue with the connection using the specified protocol version or to abort the connection.

In order to serve multiple clients efficiently, the server launches a new “backend” process for each client. In the current implementation, a new child process is created immediately after an incoming connection is detected. This is transparent to the protocol, however. For purposes of the protocol, the terms “backend” and “server” are interchangeable; likewise “frontend” and “client” are interchangeable.

55.1. Overview

The protocol has separate phases for startup and normal operation. In the startup phase, the frontend opens a connection to the server and authenticates itself to the satisfaction of the server. (This might involve a single message, or multiple messages depending on the authentication method being used.) If all goes well, the server then sends status information to the frontend, and finally enters normal operation. Except for the initial startup-request message, this part of the protocol is driven by the server.

During normal operation, the frontend sends queries and other commands to the backend, and the backend sends back query results and other responses. There are a few cases (such as `NOTIFY`) wherein the backend will send unsolicited messages, but for the most part this portion of a session is driven by frontend requests.

Termination of the session is normally by frontend choice, but can be forced by the backend in certain cases. In any case, when the backend closes the connection, it will roll back any open (incomplete) transaction before exiting.

Within normal operation, SQL commands can be executed through either of two sub-protocols. In the “simple query” protocol, the frontend just sends a textual query string, which is parsed and immediately executed by the backend. In the “extended query” protocol, processing of queries is separated into multiple steps: parsing, binding of parameter values, and execution. This offers flexibility and performance benefits, at the cost of extra complexity.

Normal operation has additional sub-protocols for special operations such as `COPY`.

55.1.1. Messaging Overview

All communication is through a stream of messages. The first byte of a message identifies the message type, and the next four bytes specify the length of the rest of the message (this length count includes itself, but not the message-type byte). The remaining contents of the message are determined by the message type. For historical reasons, the very first message sent by the client (the startup message) has no initial message-type byte.

To avoid losing synchronization with the message stream, both servers and clients typically read an entire message into a buffer (using the byte count) before attempting to process its contents. This allows easy recovery if an error is detected while processing the contents. In extreme situations (such as not

having enough memory to buffer the message), the receiver can use the byte count to determine how much input to skip before it resumes reading messages.

Conversely, both servers and clients must take care never to send an incomplete message. This is commonly done by marshaling the entire message in a buffer before beginning to send it. If a communications failure occurs partway through sending or receiving a message, the only sensible response is to abandon the connection, since there is little hope of recovering message-boundary synchronization.

55.1.2. Extended Query Overview

In the extended-query protocol, execution of SQL commands is divided into multiple steps. The state retained between steps is represented by two types of objects: *prepared statements* and *portals*. A prepared statement represents the result of parsing and semantic analysis of a textual query string. A prepared statement is not in itself ready to execute, because it might lack specific values for *parameters*. A portal represents a ready-to-execute or already-partially-executed statement, with any missing parameter values filled in. (For `SELECT` statements, a portal is equivalent to an open cursor, but we choose to use a different term since cursors don't handle non-`SELECT` statements.)

The overall execution cycle consists of a *parse* step, which creates a prepared statement from a textual query string; a *bind* step, which creates a portal given a prepared statement and values for any needed parameters; and an *execute* step that runs a portal's query. In the case of a query that returns rows (`SELECT`, `SHOW`, etc), the execute step can be told to fetch only a limited number of rows, so that multiple execute steps might be needed to complete the operation.

The backend can keep track of multiple prepared statements and portals (but note that these exist only within a session, and are never shared across sessions). Existing prepared statements and portals are referenced by names assigned when they were created. In addition, an “unnamed” prepared statement and portal exist. Although these behave largely the same as named objects, operations on them are optimized for the case of executing a query only once and then discarding it, whereas operations on named objects are optimized on the expectation of multiple uses.

55.1.3. Formats and Format Codes

Data of a particular data type might be transmitted in any of several different *formats*. As of PostgreSQL 7.4 the only supported formats are “text” and “binary”, but the protocol makes provision for future extensions. The desired format for any value is specified by a *format code*. Clients can specify a format code for each transmitted parameter value and for each column of a query result. Text has format code zero, binary has format code one, and all other format codes are reserved for future definition.

The text representation of values is whatever strings are produced and accepted by the input/output conversion functions for the particular data type. In the transmitted representation, there is no trailing null character; the frontend must add one to received values if it wants to process them as C strings. (The text format does not allow embedded nulls, by the way.)

Binary representations for integers use network byte order (most significant byte first). For other data types consult the documentation to learn about the binary representation. Keep in mind that binary representations for complex data types might change across server versions; the text format is usually the more portable choice.

55.2. Message Flow

This section describes the message flow and the semantics of each message type. (Details of the exact representation of each message appear in Section 55.7.) There are several different sub-protocols depending on the state of the connection: start-up, query, function call, `COPY`, and termination. There are also special provisions for asynchronous operations (including notification responses and command cancellation), which can occur at any time after the start-up phase.

55.2.1. Start-up

To begin a session, a frontend opens a connection to the server and sends a startup message. This message includes the names of the user and of the database the user wants to connect to; it also identifies the

particular protocol version to be used. (Optionally, the startup message can include additional settings for run-time parameters.) The server then uses this information and the contents of its configuration files (such as `pg_hba.conf`) to determine whether the connection is provisionally acceptable, and what additional authentication is required (if any).

The server then sends an appropriate authentication request message, to which the frontend must reply with an appropriate authentication response message (such as a password). For all authentication methods except GSSAPI, SSPI and SASL, there is at most one request and one response. In some methods, no response at all is needed from the frontend, and so no authentication request occurs. For GSSAPI, SSPI and SASL, multiple exchanges of packets may be needed to complete the authentication.

The authentication cycle ends with the server either rejecting the connection attempt (ErrorResponse), or sending AuthenticationOk.

The possible messages from the server in this phase are:

ErrorResponse

The connection attempt has been rejected. The server then immediately closes the connection.

AuthenticationOk

The authentication exchange is successfully completed.

AuthenticationKerberosV5

The frontend must now take part in a Kerberos V5 authentication dialog (not described here, part of the Kerberos specification) with the server. If this is successful, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse. This is no longer supported.

AuthenticationCleartextPassword

The frontend must now send a PasswordMessage containing the password in clear-text form. If this is the correct password, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse.

AuthenticationMD5Password

The frontend must now send a PasswordMessage containing the password (with user name) encrypted via MD5, then encrypted again using the 4-byte random salt specified in the AuthenticationMD5Password message. If this is the correct password, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse. The actual PasswordMessage can be computed in SQL as `concat('md5', md5(concat(md5(concat(password, username)), random-salt)))`. (Keep in mind the `md5()` function returns its result as a hex string.)

AuthenticationSCMCredential

This response is only possible for local Unix-domain connections on platforms that support SCM credential messages. The frontend must issue an SCM credential message and then send a single data byte. (The contents of the data byte are uninteresting; it's only used to ensure that the server waits long enough to receive the credential message.) If the credential is acceptable, the server responds with an AuthenticationOk, otherwise it responds with an ErrorResponse. (This message type is only issued by pre-9.1 servers. It may eventually be removed from the protocol specification.)

AuthenticationGSS

The frontend must now initiate a GSSAPI negotiation. The frontend will send a GSSResponse message with the first part of the GSSAPI data stream in response to this. If further messages are needed, the server will respond with AuthenticationGSSContinue.

AuthenticationSSPI

The frontend must now initiate an SSPI negotiation. The frontend will send a GSSResponse with the first part of the SSPI data stream in response to this. If further messages are needed, the server will respond with AuthenticationGSSContinue.

AuthenticationGSSContinue

This message contains the response data from the previous step of GSSAPI or SSPI negotiation (AuthenticationGSS, AuthenticationSSPI or a previous AuthenticationGSSContinue). If the GSSAPI or SSPI data in this message indicates more data is needed to complete the authentication, the frontend must send that data as another GSSResponse message. If GSSAPI or SSPI authentication is completed by this message, the server will next send AuthenticationOk to indicate successful authentication or ErrorResponse to indicate failure.

AuthenticationSASL

The frontend must now initiate a SASL negotiation, using one of the SASL mechanisms listed in the message. The frontend will send a SASLInitialResponse with the name of the selected mechanism, and the first part of the SASL data stream in response to this. If further messages are needed, the server will respond with AuthenticationSASLContinue. See Section 55.3 for details.

AuthenticationSASLContinue

This message contains challenge data from the previous step of SASL negotiation (AuthenticationSASL, or a previous AuthenticationSASLContinue). The frontend must respond with a SASLResponse message.

AuthenticationSASLFinal

SASL authentication has completed with additional mechanism-specific data for the client. The server will next send AuthenticationOk to indicate successful authentication, or an ErrorResponse to indicate failure. This message is sent only if the SASL mechanism specifies additional data to be sent from server to client at completion.

NegotiateProtocolVersion

The server does not support the minor protocol version requested by the client, but does support an earlier version of the protocol; this message indicates the highest supported minor version. This message will also be sent if the client requested unsupported protocol options (i.e., beginning with `_pq_`.) in the startup packet. This message will be followed by an ErrorResponse or a message indicating the success or failure of authentication.

If the frontend does not support the authentication method requested by the server, then it should immediately close the connection.

After having received AuthenticationOk, the frontend must wait for further messages from the server. In this phase a backend process is being started, and the frontend is just an interested bystander. It is still possible for the startup attempt to fail (ErrorResponse) or the server to decline support for the requested minor protocol version (NegotiateProtocolVersion), but in the normal case the backend will send some ParameterStatus messages, BackendKeyData, and finally ReadyForQuery.

During this phase the backend will attempt to apply any additional run-time parameter settings that were given in the startup message. If successful, these values become session defaults. An error causes ErrorResponse and exit.

The possible messages from the backend in this phase are:

BackendKeyData

This message provides secret-key data that the frontend must save if it wants to be able to issue cancel requests later. The frontend should not respond to this message, but should continue listening for a ReadyForQuery message.

ParameterStatus

This message informs the frontend about the current (initial) setting of backend parameters, such as client_encoding or DateStyle. The frontend can ignore this message, or record the settings for its future use; see Section 55.2.7 for more details. The frontend should not respond to this message, but should continue listening for a ReadyForQuery message.

ReadyForQuery

Start-up is completed. The frontend can now issue commands.

ErrorResponse

Start-up failed. The connection is closed after sending this message.

NoticeResponse

A warning message has been issued. The frontend should display the message but continue listening for ReadyForQuery or ErrorResponse.

The ReadyForQuery message is the same one that the backend will issue after each command cycle. Depending on the coding needs of the frontend, it is reasonable to consider ReadyForQuery as starting a command cycle, or to consider ReadyForQuery as ending the start-up phase and each subsequent command cycle.

55.2.2. Simple Query

A simple query cycle is initiated by the frontend sending a Query message to the backend. The message includes an SQL command (or commands) expressed as a text string. The backend then sends one or more response messages depending on the contents of the query command string, and finally a ReadyForQuery response message. ReadyForQuery informs the frontend that it can safely send a new command. (It is not actually necessary for the frontend to wait for ReadyForQuery before issuing another command, but the frontend must then take responsibility for figuring out what happens if the earlier command fails and already-issued later commands succeed.)

The possible response messages from the backend are:

CommandComplete

An SQL command completed normally.

CopyInResponse

The backend is ready to copy data from the frontend to a table; see Section 55.2.6.

CopyOutResponse

The backend is ready to copy data from a table to the frontend; see Section 55.2.6.

RowDescription

Indicates that rows are about to be returned in response to a `SELECT`, `FETCH`, etc query. The contents of this message describe the column layout of the rows. This will be followed by a DataRow message for each row being returned to the frontend.

DataRow

One of the set of rows returned by a `SELECT`, `FETCH`, etc query.

EmptyQueryResponse

An empty query string was recognized.

ErrorResponse

An error has occurred.

ReadyForQuery

Processing of the query string is complete. A separate message is sent to indicate this because the query string might contain multiple SQL commands. (CommandComplete marks the end of processing one SQL command, not the whole string.) ReadyForQuery will always be sent, whether processing terminates successfully or with an error.

NoticeResponse

A warning message has been issued in relation to the query. Notices are in addition to other responses, i.e., the backend will continue processing the command.

The response to a SELECT query (or other queries that return row sets, such as EXPLAIN or SHOW) normally consists of RowDescription, zero or more DataRow messages, and then CommandComplete. COPY to or from the frontend invokes special protocol as described in Section 55.2.6. All other query types normally produce only a CommandComplete message.

Since a query string could contain several queries (separated by semicolons), there might be several such response sequences before the backend finishes processing the query string. ReadyForQuery is issued when the entire string has been processed and the backend is ready to accept a new query string.

If a completely empty (no contents other than whitespace) query string is received, the response is EmptyQueryResponse followed by ReadyForQuery.

In the event of an error, ErrorResponse is issued followed by ReadyForQuery. All further processing of the query string is aborted by ErrorResponse (even if more queries remained in it). Note that this might occur partway through the sequence of messages generated by an individual query.

In simple Query mode, the format of retrieved values is always text, except when the given command is a FETCH from a cursor declared with the BINARY option. In that case, the retrieved values are in binary format. The format codes given in the RowDescription message tell which format is being used.

A frontend must be prepared to accept ErrorResponse and NoticeResponse messages whenever it is expecting any other type of message. See also Section 55.2.7 concerning messages that the backend might generate due to outside events.

Recommended practice is to code frontends in a state-machine style that will accept any message type at any time that it could make sense, rather than wiring in assumptions about the exact sequence of messages.

55.2.2.1. Multiple Statements in a Simple Query

When a simple Query message contains more than one SQL statement (separated by semicolons), those statements are executed as a single transaction, unless explicit transaction control commands are included to force a different behavior. For example, if the message contains

```
INSERT INTO mytable VALUES(1);
SELECT 1/0;
INSERT INTO mytable VALUES(2);
```

then the divide-by-zero failure in the SELECT will force rollback of the first INSERT. Furthermore, because execution of the message is abandoned at the first error, the second INSERT is never attempted at all.

If instead the message contains

```
BEGIN;
INSERT INTO mytable VALUES(1);
COMMIT;
INSERT INTO mytable VALUES(2);
SELECT 1/0;
```

then the first INSERT is committed by the explicit COMMIT command. The second INSERT and the SELECT are still treated as a single transaction, so that the divide-by-zero failure will roll back the second INSERT, but not the first one.

This behavior is implemented by running the statements in a multi-statement Query message in an *implicit transaction block* unless there is some explicit transaction block for them to run in. The main difference between an implicit transaction block and a regular one is that an implicit block is closed automatically at the end of the Query message, either by an implicit commit if there was no error, or an

implicit rollback if there was an error. This is similar to the implicit commit or rollback that happens for a statement executed by itself (when not in a transaction block).

If the session is already in a transaction block, as a result of a BEGIN in some previous message, then the Query message simply continues that transaction block, whether the message contains one statement or several. However, if the Query message contains a COMMIT or ROLLBACK closing the existing transaction block, then any following statements are executed in an implicit transaction block. Conversely, if a BEGIN appears in a multi-statement Query message, then it starts a regular transaction block that will only be terminated by an explicit COMMIT or ROLLBACK, whether that appears in this Query message or a later one. If the BEGIN follows some statements that were executed as an implicit transaction block, those statements are not immediately committed; in effect, they are retroactively included into the new regular transaction block.

A COMMIT or ROLLBACK appearing in an implicit transaction block is executed as normal, closing the implicit block; however, a warning will be issued since a COMMIT or ROLLBACK without a previous BEGIN might represent a mistake. If more statements follow, a new implicit transaction block will be started for them.

Savepoints are not allowed in an implicit transaction block, since they would conflict with the behavior of automatically closing the block upon any error.

Remember that, regardless of any transaction control commands that may be present, execution of the Query message stops at the first error. Thus for example given

```
BEGIN;
SELECT 1/0;
ROLLBACK;
```

in a single Query message, the session will be left inside a failed regular transaction block, since the ROLLBACK is not reached after the divide-by-zero error. Another ROLLBACK will be needed to restore the session to a usable state.

Another behavior of note is that initial lexical and syntactic analysis is done on the entire query string before any of it is executed. Thus simple errors (such as a misspelled keyword) in later statements can prevent execution of any of the statements. This is normally invisible to users since the statements would all roll back anyway when done as an implicit transaction block. However, it can be visible when attempting to do multiple transactions within a multi-statement Query. For instance, if a typo turned our previous example into

```
BEGIN;
INSERT INTO mytable VALUES(1);
COMMIT;
INSERT INTO mytable VALUES(2);
SELCT 1/0;
```

then none of the statements would get run, resulting in the visible difference that the first INSERT is not committed. Errors detected at semantic analysis or later, such as a misspelled table or column name, do not have this effect.

55.2.3. Extended Query

The extended query protocol breaks down the above-described simple query protocol into multiple steps. The results of preparatory steps can be re-used multiple times for improved efficiency. Furthermore, additional features are available, such as the possibility of supplying data values as separate parameters instead of having to insert them directly into a query string.

In the extended protocol, the frontend first sends a Parse message, which contains a textual query string, optionally some information about data types of parameter placeholders, and the name of a destination prepared-statement object (an empty string selects the unnamed prepared statement). The response is either ParseComplete or ErrorResponse. Parameter data types can be specified by OID; if not given, the parser attempts to infer the data types in the same way as it would do for untyped literal string constants.

> **Note**
>
> A parameter data type can be left unspecified by setting it to zero, or by making the array of parameter type OIDs shorter than the number of parameter symbols (`$n`) used in the query string. Another special case is that a parameter's type can be specified as `void` (that is, the OID of the `void` pseudo-type). This is meant to allow parameter symbols to be used for function parameters that are actually OUT parameters. Ordinarily there is no context in which a `void` parameter could be used, but if such a parameter symbol appears in a function's parameter list, it is effectively ignored. For example, a function call such as `foo($1,$2,$3,$4)` could match a function with two IN and two OUT arguments, if `$3` and `$4` are specified as having type `void`.

> **Note**
>
> The query string contained in a Parse message cannot include more than one SQL statement; else a syntax error is reported. This restriction does not exist in the simple-query protocol, but it does exist in the extended protocol, because allowing prepared statements or portals to contain multiple commands would complicate the protocol unduly.

If successfully created, a named prepared-statement object lasts till the end of the current session, unless explicitly destroyed. An unnamed prepared statement lasts only until the next Parse statement specifying the unnamed statement as destination is issued. (Note that a simple Query message also destroys the unnamed statement.) Named prepared statements must be explicitly closed before they can be redefined by another Parse message, but this is not required for the unnamed statement. Named prepared statements can also be created and accessed at the SQL command level, using `PREPARE` and `EXECUTE`.

Once a prepared statement exists, it can be readied for execution using a Bind message. The Bind message gives the name of the source prepared statement (empty string denotes the unnamed prepared statement), the name of the destination portal (empty string denotes the unnamed portal), and the values to use for any parameter placeholders present in the prepared statement. The supplied parameter set must match those needed by the prepared statement. (If you declared any `void` parameters in the Parse message, pass NULL values for them in the Bind message.) Bind also specifies the format to use for any data returned by the query; the format can be specified overall, or per-column. The response is either BindComplete or ErrorResponse.

> **Note**
>
> The choice between text and binary output is determined by the format codes given in Bind, regardless of the SQL command involved. The `BINARY` attribute in cursor declarations is irrelevant when using extended query protocol.

Query planning typically occurs when the Bind message is processed. If the prepared statement has no parameters, or is executed repeatedly, the server might save the created plan and re-use it during subsequent Bind messages for the same prepared statement. However, it will do so only if it finds that a generic plan can be created that is not much less efficient than a plan that depends on the specific parameter values supplied. This happens transparently so far as the protocol is concerned.

If successfully created, a named portal object lasts till the end of the current transaction, unless explicitly destroyed. An unnamed portal is destroyed at the end of the transaction, or as soon as the next Bind statement specifying the unnamed portal as destination is issued. (Note that a simple Query message also destroys the unnamed portal.) Named portals must be explicitly closed before they can be redefined by another Bind message, but this is not required for the unnamed portal. Named portals can also be created and accessed at the SQL command level, using `DECLARE CURSOR` and `FETCH`.

Once a portal exists, it can be executed using an Execute message. The Execute message specifies the portal name (empty string denotes the unnamed portal) and a maximum result-row count (zero meaning “fetch all rows”). The result-row count is only meaningful for portals containing commands that return row sets; in other cases the command is always executed to completion, and the row count is ignored. The possible responses to Execute are the same as those described above for queries issued via simple query protocol, except that Execute doesn't cause ReadyForQuery or RowDescription to be issued.

If Execute terminates before completing the execution of a portal (due to reaching a nonzero result-row count), it will send a PortalSuspended message; the appearance of this message tells the frontend that another Execute should be issued against the same portal to complete the operation. The CommandComplete message indicating completion of the source SQL command is not sent until the portal's execution is completed. Therefore, an Execute phase is always terminated by the appearance of exactly one of these messages: CommandComplete, EmptyQueryResponse (if the portal was created from an empty query string), ErrorResponse, or PortalSuspended.

At completion of each series of extended-query messages, the frontend should issue a Sync message. This parameterless message causes the backend to close the current transaction if it's not inside a `BEGIN`/`COMMIT` transaction block (“close” meaning to commit if no error, or roll back if error). Then a ReadyForQuery response is issued. The purpose of Sync is to provide a resynchronization point for error recovery. When an error is detected while processing any extended-query message, the backend issues ErrorResponse, then reads and discards messages until a Sync is reached, then issues ReadyForQuery and returns to normal message processing. (But note that no skipping occurs if an error is detected *while* processing Sync — this ensures that there is one and only one ReadyForQuery sent for each Sync.)

> **Note**
>
> Sync does not cause a transaction block opened with `BEGIN` to be closed. It is possible to detect this situation since the ReadyForQuery message includes transaction status information.

In addition to these fundamental, required operations, there are several optional operations that can be used with extended-query protocol.

The Describe message (portal variant) specifies the name of an existing portal (or an empty string for the unnamed portal). The response is a RowDescription message describing the rows that will be returned by executing the portal; or a NoData message if the portal does not contain a query that will return rows; or ErrorResponse if there is no such portal.

The Describe message (statement variant) specifies the name of an existing prepared statement (or an empty string for the unnamed prepared statement). The response is a ParameterDescription message describing the parameters needed by the statement, followed by a RowDescription message describing the rows that will be returned when the statement is eventually executed (or a NoData message if the statement will not return rows). ErrorResponse is issued if there is no such prepared statement. Note that since Bind has not yet been issued, the formats to be used for returned columns are not yet known to the backend; the format code fields in the RowDescription message will be zeroes in this case.

> **Tip**
>
> In most scenarios the frontend should issue one or the other variant of Describe before issuing Execute, to ensure that it knows how to interpret the results it will get back.

The Close message closes an existing prepared statement or portal and releases resources. It is not an error to issue Close against a nonexistent statement or portal name. The response is normally CloseComplete, but could be ErrorResponse if some difficulty is encountered while releasing resources. Note that closing a prepared statement implicitly closes any open portals that were constructed from that statement.

The Flush message does not cause any specific output to be generated, but forces the backend to deliver any data pending in its output buffers. A Flush must be sent after any extended-query command except

Sync, if the frontend wishes to examine the results of that command before issuing more commands. Without Flush, messages returned by the backend will be combined into the minimum possible number of packets to minimize network overhead.

> **Note**
>
> The simple Query message is approximately equivalent to the series Parse, Bind, portal Describe, Execute, Close, Sync, using the unnamed prepared statement and portal objects and no parameters. One difference is that it will accept multiple SQL statements in the query string, automatically performing the bind/describe/execute sequence for each one in succession. Another difference is that it will not return ParseComplete, BindComplete, CloseComplete, or NoData messages.

55.2.4. Pipelining

Use of the extended query protocol allows *pipelining*, which means sending a series of queries without waiting for earlier ones to complete. This reduces the number of network round trips needed to complete a given series of operations. However, the user must carefully consider the required behavior if one of the steps fails, since later queries will already be in flight to the server.

One way to deal with that is to make the whole query series be a single transaction, that is wrap it in `BEGIN` ... `COMMIT`. However, this does not help if one wishes for some of the commands to commit independently of others.

The extended query protocol provides another way to manage this concern, which is to omit sending Sync messages between steps that are dependent. Since, after an error, the backend will skip command messages until it finds Sync, this allows later commands in a pipeline to be skipped automatically when an earlier one fails, without the client having to manage that explicitly with `BEGIN` and `COMMIT`. Independently-committable segments of the pipeline can be separated by Sync messages.

If the client has not issued an explicit `BEGIN`, then each Sync ordinarily causes an implicit `COMMIT` if the preceding step(s) succeeded, or an implicit `ROLLBACK` if they failed. However, there are a few DDL commands (such as `CREATE DATABASE`) that cannot be executed inside a transaction block. If one of these is executed in a pipeline, it will fail unless it is the first command in the pipeline. Furthermore, upon success it will force an immediate commit to preserve database consistency. Thus a Sync immediately following one of these commands has no effect except to respond with ReadyForQuery.

When using this method, completion of the pipeline must be determined by counting ReadyForQuery messages and waiting for that to reach the number of Syncs sent. Counting command completion responses is unreliable, since some of the commands may be skipped and thus not produce a completion message.

55.2.5. Function Call

The Function Call sub-protocol allows the client to request a direct call of any function that exists in the database's `pg_proc` system catalog. The client must have execute permission for the function.

> **Note**
>
> The Function Call sub-protocol is a legacy feature that is probably best avoided in new code. Similar results can be accomplished by setting up a prepared statement that does `SELECT function($1, ...)`. The Function Call cycle can then be replaced with Bind/Execute.

A Function Call cycle is initiated by the frontend sending a FunctionCall message to the backend. The backend then sends one or more response messages depending on the results of the function call, and finally a ReadyForQuery response message. ReadyForQuery informs the frontend that it can safely send a new query or function call.

The possible response messages from the backend are:

ErrorResponse

An error has occurred.

FunctionCallResponse

The function call was completed and returned the result given in the message. (Note that the Function Call protocol can only handle a single scalar result, not a row type or set of results.)

ReadyForQuery

Processing of the function call is complete. ReadyForQuery will always be sent, whether processing terminates successfully or with an error.

NoticeResponse

A warning message has been issued in relation to the function call. Notices are in addition to other responses, i.e., the backend will continue processing the command.

55.2.6. COPY Operations

The `COPY` command allows high-speed bulk data transfer to or from the server. Copy-in and copy-out operations each switch the connection into a distinct sub-protocol, which lasts until the operation is completed.

Copy-in mode (data transfer to the server) is initiated when the backend executes a `COPY FROM STDIN` SQL statement. The backend sends a CopyInResponse message to the frontend. The frontend should then send zero or more CopyData messages, forming a stream of input data. (The message boundaries are not required to have anything to do with row boundaries, although that is often a reasonable choice.) The frontend can terminate the copy-in mode by sending either a CopyDone message (allowing successful termination) or a CopyFail message (which will cause the `COPY` SQL statement to fail with an error). The backend then reverts to the command-processing mode it was in before the `COPY` started, which will be either simple or extended query protocol. It will next send either CommandComplete (if successful) or ErrorResponse (if not).

In the event of a backend-detected error during copy-in mode (including receipt of a CopyFail message), the backend will issue an ErrorResponse message. If the `COPY` command was issued via an extended-query message, the backend will now discard frontend messages until a Sync message is received, then it will issue ReadyForQuery and return to normal processing. If the `COPY` command was issued in a simple Query message, the rest of that message is discarded and ReadyForQuery is issued. In either case, any subsequent CopyData, CopyDone, or CopyFail messages issued by the frontend will simply be dropped.

The backend will ignore Flush and Sync messages received during copy-in mode. Receipt of any other non-copy message type constitutes an error that will abort the copy-in state as described above. (The exception for Flush and Sync is for the convenience of client libraries that always send Flush or Sync after an Execute message, without checking whether the command to be executed is a `COPY FROM STDIN`.)

Copy-out mode (data transfer from the server) is initiated when the backend executes a `COPY TO STDOUT` SQL statement. The backend sends a CopyOutResponse message to the frontend, followed by zero or more CopyData messages (always one per row), followed by CopyDone. The backend then reverts to the command-processing mode it was in before the `COPY` started, and sends CommandComplete. The frontend cannot abort the transfer (except by closing the connection or issuing a Cancel request), but it can discard unwanted CopyData and CopyDone messages.

In the event of a backend-detected error during copy-out mode, the backend will issue an ErrorResponse message and revert to normal processing. The frontend should treat receipt of ErrorResponse as terminating the copy-out mode.

It is possible for NoticeResponse and ParameterStatus messages to be interspersed between CopyData messages; frontends must handle these cases, and should be prepared for other asynchronous message types as well (see Section 55.2.7). Otherwise, any message type other than CopyData or CopyDone may be treated as terminating copy-out mode.

There is another Copy-related mode called copy-both, which allows high-speed bulk data transfer to *and* from the server. Copy-both mode is initiated when a backend in walsender mode executes a `START_REPLICATION` statement. The backend sends a CopyBothResponse message to the frontend. Both the backend and the frontend may then send CopyData messages until either end sends a CopyDone message. After the client sends a CopyDone message, the connection goes from copy-both mode to copy-out mode, and the client may not send any more CopyData messages. Similarly, when the server sends a CopyDone message, the connection goes into copy-in mode, and the server may not send any more CopyData messages. After both sides have sent a CopyDone message, the copy mode is terminated, and the backend reverts to the command-processing mode. In the event of a backend-detected error during copy-both mode, the backend will issue an ErrorResponse message, discard frontend messages until a Sync message is received, and then issue ReadyForQuery and return to normal processing. The frontend should treat receipt of ErrorResponse as terminating the copy in both directions; no CopyDone should be sent in this case. See Section 55.4 for more information on the subprotocol transmitted over copy-both mode.

The CopyInResponse, CopyOutResponse and CopyBothResponse messages include fields that inform the frontend of the number of columns per row and the format codes being used for each column. (As of the present implementation, all columns in a given `COPY` operation will use the same format, but the message design does not assume this.)

55.2.7. Asynchronous Operations

There are several cases in which the backend will send messages that are not specifically prompted by the frontend's command stream. Frontends must be prepared to deal with these messages at any time, even when not engaged in a query. At minimum, one should check for these cases before beginning to read a query response.

It is possible for NoticeResponse messages to be generated due to outside activity; for example, if the database administrator commands a “fast” database shutdown, the backend will send a NoticeResponse indicating this fact before closing the connection. Accordingly, frontends should always be prepared to accept and display NoticeResponse messages, even when the connection is nominally idle.

ParameterStatus messages will be generated whenever the active value changes for any of the parameters the backend believes the frontend should know about. Most commonly this occurs in response to a `SET` SQL command executed by the frontend, and this case is effectively synchronous — but it is also possible for parameter status changes to occur because the administrator changed a configuration file and then sent the SIGHUP signal to the server. Also, if a `SET` command is rolled back, an appropriate ParameterStatus message will be generated to report the current effective value.

At present there is a hard-wired set of parameters for which ParameterStatus will be generated: they are `server_version`, `server_encoding`, `client_encoding`, `application_name`, `default_transaction_read_only`, `in_hot_standby`, `is_superuser`, `session_authorization`, `DateStyle`, `IntervalStyle`, `TimeZone`, `integer_datetimes`, and `standard_conforming_strings`. (`server_encoding`, `TimeZone`, and `integer_datetimes` were not reported by releases before 8.0; `standard_conforming_strings` was not reported by releases before 8.1; `IntervalStyle` was not reported by releases before 8.4; `application_name` was not reported by releases before 9.0; `default_transaction_read_only` and `in_hot_standby` were not reported by releases before 14.) Note that `server_version`, `server_encoding` and `integer_datetimes` are pseudo-parameters that cannot change after startup. This set might change in the future, or even become configurable. Accordingly, a frontend should simply ignore ParameterStatus for parameters that it does not understand or care about.

If a frontend issues a `LISTEN` command, then the backend will send a NotificationResponse message (not to be confused with NoticeResponse!) whenever a `NOTIFY` command is executed for the same channel name.

> **Note**
>
> At present, NotificationResponse can only be sent outside a transaction, and thus it will not occur in the middle of a command-response series, though it might occur just before ReadyForQuery.

It is unwise to design frontend logic that assumes that, however. Good practice is to be able to accept NotificationResponse at any point in the protocol.

55.2.8. Canceling Requests in Progress

During the processing of a query, the frontend might request cancellation of the query. The cancel request is not sent directly on the open connection to the backend for reasons of implementation efficiency: we don't want to have the backend constantly checking for new input from the frontend during query processing. Cancel requests should be relatively infrequent, so we make them slightly cumbersome in order to avoid a penalty in the normal case.

To issue a cancel request, the frontend opens a new connection to the server and sends a CancelRequest message, rather than the StartupMessage message that would ordinarily be sent across a new connection. The server will process this request and then close the connection. For security reasons, no direct reply is made to the cancel request message.

A CancelRequest message will be ignored unless it contains the same key data (PID and secret key) passed to the frontend during connection start-up. If the request matches the PID and secret key for a currently executing backend, the processing of the current query is aborted. (In the existing implementation, this is done by sending a special signal to the backend process that is processing the query.)

The cancellation signal might or might not have any effect — for example, if it arrives after the backend has finished processing the query, then it will have no effect. If the cancellation is effective, it results in the current command being terminated early with an error message.

The upshot of all this is that for reasons of both security and efficiency, the frontend has no direct way to tell whether a cancel request has succeeded. It must continue to wait for the backend to respond to the query. Issuing a cancel simply improves the odds that the current query will finish soon, and improves the odds that it will fail with an error message instead of succeeding.

Since the cancel request is sent across a new connection to the server and not across the regular frontend/backend communication link, it is possible for the cancel request to be issued by any process, not just the frontend whose query is to be canceled. This might provide additional flexibility when building multiple-process applications. It also introduces a security risk, in that unauthorized persons might try to cancel queries. The security risk is addressed by requiring a dynamically generated secret key to be supplied in cancel requests.

55.2.9. Termination

The normal, graceful termination procedure is that the frontend sends a Terminate message and immediately closes the connection. On receipt of this message, the backend closes the connection and terminates.

In rare cases (such as an administrator-commanded database shutdown) the backend might disconnect without any frontend request to do so. In such cases the backend will attempt to send an error or notice message giving the reason for the disconnection before it closes the connection.

Other termination scenarios arise from various failure cases, such as core dump at one end or the other, loss of the communications link, loss of message-boundary synchronization, etc. If either frontend or backend sees an unexpected closure of the connection, it should clean up and terminate. The frontend has the option of launching a new backend by recontacting the server if it doesn't want to terminate itself. Closing the connection is also advisable if an unrecognizable message type is received, since this probably indicates loss of message-boundary sync.

For either normal or abnormal termination, any open transaction is rolled back, not committed. One should note however that if a frontend disconnects while a non-`SELECT` query is being processed, the backend will probably finish the query before noticing the disconnection. If the query is outside any transaction block (`BEGIN` ... `COMMIT` sequence) then its results might be committed before the disconnection is recognized.

55.2.10. SSL Session Encryption

If Postgres Pro was built with SSL support, frontend/backend communications can be encrypted using SSL. This provides communication security in environments where attackers might be able to capture the session traffic. For more information on encrypting Postgres Pro sessions with SSL, see Section 18.9.

To initiate an SSL-encrypted connection, the frontend initially sends an SSLRequest message rather than a StartupMessage. The server then responds with a single byte containing `S` or `N`, indicating that it is willing or unwilling to perform SSL, respectively. The frontend might close the connection at this point if it is dissatisfied with the response. To continue after `S`, perform an SSL startup handshake (not described here, part of the SSL specification) with the server. If this is successful, continue with sending the usual StartupMessage. In this case the StartupMessage and all subsequent data will be SSL-encrypted. To continue after `N`, send the usual StartupMessage and proceed without encryption. (Alternatively, it is permissible to issue a GSSENCRequest message after an `N` response to try to use GSSAPI encryption instead of SSL.)

The frontend should also be prepared to handle an ErrorMessage response to SSLRequest from the server. The frontend should not display this error message to the user/application, since the server has not been authenticated (*CVE-2024-10977*). In this case the connection must be closed, but the frontend might choose to open a fresh connection and proceed without requesting SSL.

When SSL encryption can be performed, the server is expected to send only the single `S` byte and then wait for the frontend to initiate an SSL handshake. If additional bytes are available to read at this point, it likely means that a man-in-the-middle is attempting to perform a buffer-stuffing attack (*CVE-2021-23222*). Frontends should be coded either to read exactly one byte from the socket before turning the socket over to their SSL library, or to treat it as a protocol violation if they find they have read additional bytes.

An initial SSLRequest can also be used in a connection that is being opened to send a CancelRequest message.

While the protocol itself does not provide a way for the server to force SSL encryption, the administrator can configure the server to reject unencrypted sessions as a byproduct of authentication checking.

55.2.11. GSSAPI Session Encryption

If Postgres Pro was built with GSSAPI support, frontend/backend communications can be encrypted using GSSAPI. This provides communication security in environments where attackers might be able to capture the session traffic. For more information on encrypting Postgres Pro sessions with GSSAPI, see Section 18.10.

To initiate a GSSAPI-encrypted connection, the frontend initially sends a GSSENCRequest message rather than a StartupMessage. The server then responds with a single byte containing `G` or `N`, indicating that it is willing or unwilling to perform GSSAPI encryption, respectively. The frontend might close the connection at this point if it is dissatisfied with the response. To continue after `G`, using the GSSAPI C bindings as discussed in *RFC 2744* or equivalent, perform a GSSAPI initialization by calling `gss_init_sec_context()` in a loop and sending the result to the server, starting with an empty input and then with each result from the server, until it returns no output. When sending the results of `gss_init_sec_context()` to the server, prepend the length of the message as a four byte integer in network byte order. To continue after `N`, send the usual StartupMessage and proceed without encryption. (Alternatively, it is permissible to issue an SSLRequest message after an `N` response to try to use SSL encryption instead of GSSAPI.)

The frontend should also be prepared to handle an ErrorMessage response to GSSENCRequest from the server. The frontend should not display this error message to the user/application, since the server has not been authenticated (*CVE-2024-10977*). In this case the connection must be closed, but the frontend might choose to open a fresh connection and proceed without requesting GSSAPI encryption.

When GSSAPI encryption can be performed, the server is expected to send only the single `G` byte and then wait for the frontend to initiate a GSSAPI handshake. If additional bytes are available to read at

this point, it likely means that a man-in-the-middle is attempting to perform a buffer-stuffing attack (*CVE-2021-23222*). Frontends should be coded either to read exactly one byte from the socket before turning the socket over to their GSSAPI library, or to treat it as a protocol violation if they find they have read additional bytes.

An initial GSSENCRequest can also be used in a connection that is being opened to send a CancelRequest message.

Once GSSAPI encryption has been successfully established, use `gss_wrap()` to encrypt the usual StartupMessage and all subsequent data, prepending the length of the result from `gss_wrap()` as a four byte integer in network byte order to the actual encrypted payload. Note that the server will only accept encrypted packets from the client which are less than 16kB; `gss_wrap_size_limit()` should be used by the client to determine the size of the unencrypted message which will fit within this limit and larger messages should be broken up into multiple `gss_wrap()` calls. Typical segments are 8kB of unencrypted data, resulting in encrypted packets of slightly larger than 8kB but well within the 16kB maximum. The server can be expected to not send encrypted packets of larger than 16kB to the client.

While the protocol itself does not provide a way for the server to force GSSAPI encryption, the administrator can configure the server to reject unencrypted sessions as a byproduct of authentication checking.

55.3. SASL Authentication

SASL is a framework for authentication in connection-oriented protocols. At the moment, Postgres Pro implements two SASL authentication mechanisms, SCRAM-SHA-256 and SCRAM-SHA-256-PLUS. More might be added in the future. The below steps illustrate how SASL authentication is performed in general, while the next subsection gives more details on SCRAM-SHA-256 and SCRAM-SHA-256-PLUS.

SASL Authentication Message Flow

1. To begin a SASL authentication exchange, the server sends an AuthenticationSASL message. It includes a list of SASL authentication mechanisms that the server can accept, in the server's preferred order.
2. The client selects one of the supported mechanisms from the list, and sends a SASLInitialResponse message to the server. The message includes the name of the selected mechanism, and an optional Initial Client Response, if the selected mechanism uses that.
3. One or more server-challenge and client-response message will follow. Each server-challenge is sent in an AuthenticationSASLContinue message, followed by a response from client in a SASLResponse message. The particulars of the messages are mechanism specific.
4. Finally, when the authentication exchange is completed successfully, the server sends an AuthenticationSASLFinal message, followed immediately by an AuthenticationOk message. The AuthenticationSASLFinal contains additional server-to-client data, whose content is particular to the selected authentication mechanism. If the authentication mechanism doesn't use additional data that's sent at completion, the AuthenticationSASLFinal message is not sent.

On error, the server can abort the authentication at any stage, and send an ErrorMessage.

55.3.1. SCRAM-SHA-256 Authentication

The implemented SASL mechanisms at the moment are `SCRAM-SHA-256` and its variant with channel binding `SCRAM-SHA-256-PLUS`. They are described in detail in *RFC 7677* and *RFC 5802*.

When SCRAM-SHA-256 is used in Postgres Pro, the server will ignore the user name that the client sends in the `client-first-message`. The user name that was already sent in the startup message is used instead. Postgres Pro supports multiple character encodings, while SCRAM dictates UTF-8 to be used for the user name, so it might be impossible to represent the Postgres Pro user name in UTF-8.

The SCRAM specification dictates that the password is also in UTF-8, and is processed with the *SASLprep* algorithm. Postgres Pro, however, does not require UTF-8 to be used for the password. When a user's password is set, it is processed with SASLprep as if it was in UTF-8, regardless of the actual encoding

used. However, if it is not a legal UTF-8 byte sequence, or it contains UTF-8 byte sequences that are prohibited by the SASLprep algorithm, the raw password will be used without SASLprep processing, instead of throwing an error. This allows the password to be normalized when it is in UTF-8, but still allows a non-UTF-8 password to be used, and doesn't require the system to know which encoding the password is in.

Channel binding is supported in Postgres Pro builds with SSL support. The SASL mechanism name for SCRAM with channel binding is `SCRAM-SHA-256-PLUS`. The channel binding type used by Postgres Pro is `tls-server-end-point`.

In SCRAM without channel binding, the server chooses a random number that is transmitted to the client to be mixed with the user-supplied password in the transmitted password hash. While this prevents the password hash from being successfully retransmitted in a later session, it does not prevent a fake server between the real server and client from passing through the server's random value and successfully authenticating.

SCRAM with channel binding prevents such man-in-the-middle attacks by mixing the signature of the server's certificate into the transmitted password hash. While a fake server can retransmit the real server's certificate, it doesn't have access to the private key matching that certificate, and therefore cannot prove it is the owner, causing SSL connection failure.

Example

1. The server sends an AuthenticationSASL message. It includes a list of SASL authentication mechanisms that the server can accept. This will be `SCRAM-SHA-256-PLUS` and `SCRAM-SHA-256` if the server is built with SSL support, or else just the latter.
2. The client responds by sending a SASLInitialResponse message, which indicates the chosen mechanism, `SCRAM-SHA-256` or `SCRAM-SHA-256-PLUS`. (A client is free to choose either mechanism, but for better security it should choose the channel-binding variant if it can support it.) In the Initial Client response field, the message contains the SCRAM `client-first-message`. The `client-first-message` also contains the channel binding type chosen by the client.
3. Server sends an AuthenticationSASLContinue message, with a SCRAM `server-first-message` as the content.
4. Client sends a SASLResponse message, with SCRAM `client-final-message` as the content.
5. Server sends an AuthenticationSASLFinal message, with the SCRAM `server-final-message`, followed immediately by an AuthenticationOk message.

55.4. Streaming Replication Protocol

To initiate streaming replication, the frontend sends the `replication` parameter in the startup message. A Boolean value of `true` (or `on`, `yes`, `1`) tells the backend to go into physical replication walsender mode, wherein a small set of replication commands, shown below, can be issued instead of SQL statements.

Passing `database` as the value for the `replication` parameter instructs the backend to go into logical replication walsender mode, connecting to the database specified in the `dbname` parameter. In logical replication walsender mode, the replication commands shown below as well as normal SQL commands can be issued.

In either physical replication or logical replication walsender mode, only the simple query protocol can be used.

For the purpose of testing replication commands, you can make a replication connection via psql or any other libpq-using tool with a connection string including the `replication` option, e.g.:

```
psql "dbname=postgres replication=database" -c "IDENTIFY_SYSTEM;"
```

However, it is often more useful to use pg_receivewal (for physical replication) or pg_recvlogical (for logical replication).

Replication commands are logged in the server log when log_replication_commands is enabled.

The commands accepted in replication mode are:

`IDENTIFY_SYSTEM`

Requests the server to identify itself. Server replies with a result set of a single row, containing four fields:

`systemid` (`text`)

The unique system identifier identifying the cluster. This can be used to check that the base backup used to initialize the standby came from the same cluster.

`timeline` (`int4`)

Current timeline ID. Also useful to check that the standby is consistent with the primary.

`xlogpos` (`text`)

Current WAL flush location. Useful to get a known location in the write-ahead log where streaming can start.

`dbname` (`text`)

Database connected to or null.

`SHOW` *`name`*

Requests the server to send the current setting of a run-time parameter. This is similar to the SQL command SHOW.

`name`

The name of a run-time parameter. Available parameters are documented in Chapter 19.

`TIMELINE_HISTORY` *`tli`*

Requests the server to send over the timeline history file for timeline *`tli`*. Server replies with a result set of a single row, containing two fields. While the fields are labeled as `text`, they effectively return raw bytes, with no encoding conversion:

`filename` (`text`)

File name of the timeline history file, e.g., `00000002.history`.

`content` (`text`)

Contents of the timeline history file.

`CREATE_REPLICATION_SLOT` *`slot_name`* [`TEMPORARY`] { `PHYSICAL` [`RESERVE_WAL`] | `LOGICAL` *`output_plugin`* [`EXPORT_SNAPSHOT` | `NOEXPORT_SNAPSHOT` | `USE_SNAPSHOT`] }

Create a physical or logical replication slot. See Section 26.2.6 for more about replication slots.

`slot_name`

The name of the slot to create. Must be a valid replication slot name (see Section 26.2.6.1).

`output_plugin`

The name of the output plugin used for logical decoding (see Section 51.6).

`TEMPORARY`

Specify that this replication slot is a temporary one. Temporary slots are not saved to disk and are automatically dropped on error or when the session has finished.

RESERVE_WAL

Specify that this physical replication slot reserves WAL immediately. Otherwise, WAL is only reserved upon connection from a streaming replication client.

EXPORT_SNAPSHOT
NOEXPORT_SNAPSHOT
USE_SNAPSHOT

Decides what to do with the snapshot created during logical slot initialization. EXPORT_SNAPSHOT, which is the default, will export the snapshot for use in other sessions. This option can't be used inside a transaction. USE_SNAPSHOT will use the snapshot for the current transaction executing the command. This option must be used in a transaction, and CREATE_REPLICATION_SLOT must be the first command run in that transaction. Finally, NOEXPORT_SNAPSHOT will just use the snapshot for logical decoding as normal but won't do anything else with it.

In response to this command, the server will send a one-row result set containing the following fields:

slot_name (text)

The name of the newly-created replication slot.

consistent_point (text)

The WAL location at which the slot became consistent. This is the earliest location from which streaming can start on this replication slot.

snapshot_name (text)

The identifier of the snapshot exported by the command. The snapshot is valid until a new command is executed on this connection or the replication connection is closed. Null if the created slot is physical.

output_plugin (text)

The name of the output plugin used by the newly-created replication slot. Null if the created slot is physical.

START_REPLICATION [SLOT *slot_name*] [PHYSICAL] *XXX/XXX* [TIMELINE *tli*]

Instructs server to start streaming WAL, starting at WAL location *XXX/XXX*. If TIMELINE option is specified, streaming starts on timeline *tli*; otherwise, the server's current timeline is selected. The server can reply with an error, for example if the requested section of WAL has already been recycled. On success, the server responds with a CopyBothResponse message, and then starts to stream WAL to the frontend.

If a slot's name is provided via *slot_name*, it will be updated as replication progresses so that the server knows which WAL segments, and if hot_standby_feedback is on which transactions, are still needed by the standby.

If the client requests a timeline that's not the latest but is part of the history of the server, the server will stream all the WAL on that timeline starting from the requested start point up to the point where the server switched to another timeline. If the client requests streaming at exactly the end of an old timeline, the server skips COPY mode entirely.

After streaming all the WAL on a timeline that is not the latest one, the server will end streaming by exiting the COPY mode. When the client acknowledges this by also exiting COPY mode, the server sends a result set with one row and two columns, indicating the next timeline in this server's history. The first column is the next timeline's ID (type int8), and the second column is the WAL location where the switch happened (type text). Usually, the switch position is the end of the WAL that was streamed, but there are corner cases where the server can send some WAL from the old timeline that it has not itself replayed before promoting. Finally, the server sends two CommandComplete

messages (one that ends the CopyData and the other ends the `START_REPLICATION` itself), and is ready to accept a new command.

WAL data is sent as a series of CopyData messages. (This allows other information to be intermixed; in particular the server can send an ErrorResponse message if it encounters a failure after beginning to stream.) The payload of each CopyData message from server to the client contains a message of one of the following formats:

XLogData (B)

Byte1('w')

Identifies the message as WAL data.

Int64

The starting point of the WAL data in this message.

Int64

The current end of WAL on the server.

Int64

The server's system clock at the time of transmission, as microseconds since midnight on 2000-01-01.

Byte*n*

A section of the WAL data stream.

A single WAL record is never split across two XLogData messages. When a WAL record crosses a WAL page boundary, and is therefore already split using continuation records, it can be split at the page boundary. In other words, the first main WAL record and its continuation records can be sent in different XLogData messages.

Primary keepalive message (B)

Byte1('k')

Identifies the message as a sender keepalive.

Int64

The current end of WAL on the server.

Int64

The server's system clock at the time of transmission, as microseconds since midnight on 2000-01-01.

Byte1

1 means that the client should reply to this message as soon as possible, to avoid a timeout disconnect. 0 otherwise.

The receiving process can send replies back to the sender at any time, using one of the following message formats (also in the payload of a CopyData message):

Standby status update (F)

Byte1('r')

Identifies the message as a receiver status update.

Int64

The location of the last WAL byte + 1 received and written to disk in the standby.

Int64

The location of the last WAL byte + 1 flushed to disk in the standby.

Int64

The location of the last WAL byte + 1 applied in the standby.

Int64

The client's system clock at the time of transmission, as microseconds since midnight on 2000-01-01.

Byte1

If 1, the client requests the server to reply to this message immediately. This can be used to ping the server, to test if the connection is still healthy.

Hot Standby feedback message (F)

Byte1('h')

Identifies the message as a Hot Standby feedback message.

Int64

The client's system clock at the time of transmission, as microseconds since midnight on 2000-01-01.

Int32

The standby's current global xmin, excluding the catalog_xmin from any replication slots. If both this value and the following catalog_xmin are 0 this is treated as a notification that Hot Standby feedback will no longer be sent on this connection. Later non-zero messages may reinitiate the feedback mechanism.

Int32

The epoch of the global xmin xid on the standby.

Int32

The lowest catalog_xmin of any replication slots on the standby. Set to 0 if no catalog_xmin exists on the standby or if hot standby feedback is being disabled.

Int32

The epoch of the catalog_xmin xid on the standby.

`START_REPLICATION SLOT` *`slot_name`* `LOGICAL` *`XXX/XXX`* [(*`option_name`* [*`option_value`*] [, ...])]

Instructs server to start streaming WAL for logical replication, starting at WAL location *`XXX/XXX`*. The server can reply with an error, for example if the requested section of WAL has already been recycled. On success, server responds with a CopyBothResponse message, and then starts to stream WAL to the frontend.

The messages inside the CopyBothResponse messages are of the same format documented for `START_REPLICATION ... PHYSICAL`, including two CommandComplete messages.

The output plugin associated with the selected slot is used to process the output for streaming.

`SLOT` *`slot_name`*

The name of the slot to stream changes from. This parameter is required, and must correspond to an existing logical replication slot created with `CREATE_REPLICATION_SLOT` in `LOGICAL` mode.

`XXX/XXX`

The WAL location to begin streaming at.

option_name

The name of an option passed to the slot's logical decoding output plugin. See Section 55.5 for options that are accepted by the standard (pgoutput) plugin.

option_value

Optional value, in the form of a string constant, associated with the specified option.

DROP_REPLICATION_SLOT *slot_name* [WAIT]

Drops a replication slot, freeing any reserved server-side resources.

slot_name

The name of the slot to drop.

WAIT

This option causes the command to wait if the slot is active until it becomes inactive, instead of the default behavior of raising an error.

BASE_BACKUP [LABEL '*label*'] [PROGRESS] [FAST] [WAL] [NOWAIT] [MAX_RATE *rate*] [TABLESPACE_MAP] [NOVERIFY_CHECKSUMS] [MANIFEST *manifest_option*] [MANIFEST_CHECKSUMS *checksum_algorithm*]

Instructs the server to start streaming a base backup. The system will automatically be put in backup mode before the backup is started, and taken out of it when the backup is complete. The following options are accepted:

LABEL '*label*'

Sets the label of the backup. If none is specified, a backup label of base backup will be used. The quoting rules for the label are the same as a standard SQL string with standard_conforming_strings turned on.

PROGRESS

Request information required to generate a progress report. This will send back an approximate size in the header of each tablespace, which can be used to calculate how far along the stream is done. This is calculated by enumerating all the file sizes once before the transfer is even started, and might as such have a negative impact on the performance. In particular, it might take longer before the first data is streamed. Since the database files can change during the backup, the size is only approximate and might both grow and shrink between the time of approximation and the sending of the actual files.

FAST

Request a fast checkpoint.

WAL

Include the necessary WAL segments in the backup. This will include all the files between start and stop backup in the pg_wal directory of the base directory tar file.

NOWAIT

By default, the backup will wait until the last required WAL segment has been archived, or emit a warning if log archiving is not enabled. Specifying NOWAIT disables both the waiting and the warning, leaving the client responsible for ensuring the required log is available.

MAX_RATE *rate*

Limit (throttle) the maximum amount of data transferred from server to client per unit of time. The expected unit is kilobytes per second. If this option is specified, the value must either be equal to zero or it must fall within the range from 32 kB through 1 GB (inclusive). If zero is passed or the option is not specified, no restriction is imposed on the transfer.

TABLESPACE_MAP

Include information about symbolic links present in the directory pg_tblspc in a file named tablespace_map. The tablespace map file includes each symbolic link name as it exists in the directory pg_tblspc/ and the full path of that symbolic link.

NOVERIFY_CHECKSUMS

By default, checksums are verified during a base backup if they are enabled. Specifying NOVERIFY_CHECKSUMS disables this verification.

MANIFEST *manifest_option*

When this option is specified with a value of yes or force-encode, a backup manifest is created and sent along with the backup. The manifest is a list of every file present in the backup with the exception of any WAL files that may be included. It also stores the size, last modification time, and optionally a checksum for each file. A value of force-encode forces all filenames to be hex-encoded; otherwise, this type of encoding is performed only for files whose names are non-UTF8 octet sequences. force-encode is intended primarily for testing purposes, to be sure that clients which read the backup manifest can handle this case. For compatibility with previous releases, the default is MANIFEST 'no'.

MANIFEST_CHECKSUMS *checksum_algorithm*

Specifies the checksum algorithm that should be applied to each file included in the backup manifest. Currently, the available algorithms are NONE, CRC32C, SHA224, SHA256, SHA384, and SHA512. The default is CRC32C.

When the backup is started, the server will first send two ordinary result sets, followed by one or more CopyOutResponse results.

The first ordinary result set contains the starting position of the backup, in a single row with two columns. The first column contains the start position given in XLogRecPtr format, and the second column contains the corresponding timeline ID.

The second ordinary result set has one row for each tablespace. The fields in this row are:

spcoid (oid)

The OID of the tablespace, or null if it's the base directory.

spclocation (text)

The full path of the tablespace directory, or null if it's the base directory.

size (int8)

The approximate size of the tablespace, in kilobytes (1024 bytes), if progress report has been requested; otherwise it's null.

After the second regular result set, one or more CopyOutResponse results will be sent, one for the main data directory and one for each additional tablespace other than pg_default and pg_global. The data in the CopyOutResponse results will be a tar format (following the “ustar interchange format” specified in the POSIX 1003.1-2008 standard) dump of the tablespace contents, except that the two trailing blocks of zeroes specified in the standard are omitted. After the tar data is complete, and if a backup manifest was requested, another CopyOutResponse result is sent, containing the manifest data for the current base backup. In any case, a final ordinary result set will be sent, containing the WAL end position of the backup, in the same format as the start position.

The tar archive for the data directory and each tablespace will contain all files in the directories, regardless of whether they are Postgres Pro files or other files added to the same directory. The only excluded files are:

- postmaster.pid

- `postmaster.opts`
- `pg_internal.init` (found in multiple directories)
- Various temporary files and directories created during the operation of the Postgres Pro server, such as any file or directory beginning with `pgsql_tmp` and temporary relations.
- Unlogged relations, except for the init fork which is required to recreate the (empty) unlogged relation on recovery.
- `pg_wal`, including subdirectories. If the backup is run with WAL files included, a synthesized version of `pg_wal` will be included, but it will only contain the files necessary for the backup to work, not the rest of the contents.
- `pg_dynshmem`, `pg_notify`, `pg_replslot`, `pg_serial`, `pg_snapshots`, `pg_stat_tmp`, and `pg_subtrans` are copied as empty directories (even if they are symbolic links).
- Files other than regular files and directories, such as symbolic links (other than for the directories listed above) and special device files, are skipped. (Symbolic links in `pg_tblspc` are maintained.)

Owner, group, and file mode are set if the underlying file system on the server supports it.

55.5. Logical Streaming Replication Protocol

This section describes the logical replication protocol, which is the message flow started by the `START_REPLICATION SLOT` *`slot_name`* `LOGICAL` replication command.

The logical streaming replication protocol builds on the primitives of the physical streaming replication protocol.

PostgreSQL logical decoding supports output plugins. `pgoutput` is the standard one used for the built-in logical replication.

55.5.1. Logical Streaming Replication Parameters

Using the `START_REPLICATION` command, `pgoutput` accepts the following options:

proto_version

Protocol version. Currently versions `1` and `2` are supported. A valid version is required. The version `2` is supported only for server version 14 and above, and it allows streaming of large in-progress transactions.

publication_names

Comma separated list of publication names for which to subscribe (receive changes). The individual publication names are treated as standard objects names and can be quoted the same as needed. At least one publication name is required.

binary

Boolean option to use binary transfer mode. Binary mode is faster than the text mode but slightly less robust.

messages

Boolean option to enable sending the messages that are written by `pg_logical_emit_message`.

streaming

Boolean option to enable streaming of in-progress transactions. Minimum protocol version 2 is required to turn it on.

55.5.2. Logical Replication Protocol Messages

The individual protocol messages are discussed in the following subsections. Individual messages are described in Section 55.9.

All top-level protocol messages begin with a message type byte. While represented in code as a character, this is a signed byte with no associated encoding.

Since the streaming replication protocol supplies a message length there is no need for top-level protocol messages to embed a length in their header.

55.5.3. Logical Replication Protocol Message Flow

With the exception of the `START_REPLICATION` command and the replay progress messages, all information flows only from the backend to the frontend.

The logical replication protocol sends individual transactions one by one. This means that all messages between a pair of Begin and Commit messages belong to the same transaction. It also sends changes of large in-progress transactions between a pair of Stream Start and Stream Stop messages. The last stream of such a transaction contains Stream Commit or Stream Abort message.

Every sent transaction contains zero or more DML messages (Insert, Update, Delete). In case of a cascaded setup it can also contain Origin messages. The origin message indicates that the transaction originated on different replication node. Since a replication node in the scope of logical replication protocol can be pretty much anything, the only identifier is the origin name. It's downstream's responsibility to handle this as needed (if needed). The Origin message is always sent before any DML messages in the transaction.

Every DML message contains a relation OID, identifying the publisher's relation that was acted on. Before the first DML message for a given relation OID, a Relation message will be sent, describing the schema of that relation. Subsequently, a new Relation message will be sent if the relation's definition has changed since the last Relation message was sent for it. (The protocol assumes that the client is capable of remembering this metadata for as many relations as needed.)

Relation messages identify column types by their OIDs. In the case of a built-in type, it is assumed that the client can look up that type OID locally, so no additional data is needed. For a non-built-in type OID, a Type message will be sent before the Relation message, to provide the type name associated with that OID. Thus, a client that needs to specifically identify the types of relation columns should cache the contents of Type messages, and first consult that cache to see if the type OID is defined there. If not, look up the type OID locally.

55.6. Message Data Types

This section describes the base data types used in messages.

Int*n*(*i*)

An *n*-bit integer in network byte order (most significant byte first). If *i* is specified it is the exact value that will appear, otherwise the value is variable. Eg. Int16, Int32(42).

Int*n*[*k*]

An array of *k* *n*-bit integers, each in network byte order. The array length *k* is always determined by an earlier field in the message. Eg. Int16[M].

String(*s*)

A null-terminated string (C-style string). There is no specific length limitation on strings. If *s* is specified it is the exact value that will appear, otherwise the value is variable. Eg. String, String("user").

> **Note**
>
> *There is no predefined limit* on the length of a string that can be returned by the backend. Good coding strategy for a frontend is to use an expandable buffer so that anything that fits in memory can be accepted. If that's not feasible, read the full string and discard trailing characters that don't fit into your fixed-size buffer.

Byte*n*(*c*)

Exactly *n* bytes. If the field width *n* is not a constant, it is always determinable from an earlier field in the message. If *c* is specified it is the exact value. Eg. Byte2, Byte1('\n').

55.7. Message Formats

This section describes the detailed format of each message. Each is marked to indicate that it can be sent by a frontend (F), a backend (B), or both (F & B). Notice that although each message includes a byte count at the beginning, the message format is defined so that the message end can be found without reference to the byte count. This aids validity checking. (The CopyData message is an exception, because it forms part of a data stream; the contents of any individual CopyData message cannot be interpretable on their own.)

AuthenticationOk (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(8)

Length of message contents in bytes, including self.

Int32(0)

Specifies that the authentication was successful.

AuthenticationKerberosV5 (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(8)

Length of message contents in bytes, including self.

Int32(2)

Specifies that Kerberos V5 authentication is required.

AuthenticationCleartextPassword (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(8)

Length of message contents in bytes, including self.

Int32(3)

Specifies that a clear-text password is required.

AuthenticationMD5Password (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(12)

Length of message contents in bytes, including self.

Int32(5)

Specifies that an MD5-encrypted password is required.

Byte4

The salt to use when encrypting the password.

AuthenticationSCMCredential (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(8)

Length of message contents in bytes, including self.

Int32(6)

Specifies that an SCM credentials message is required.

AuthenticationGSS (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(8)

Length of message contents in bytes, including self.

Int32(7)

Specifies that GSSAPI authentication is required.

AuthenticationGSSContinue (B)

Byte1('R')

Identifies the message as an authentication request.

Int32

Length of message contents in bytes, including self.

Int32(8)

Specifies that this message contains GSSAPI or SSPI data.

Byte*n*

GSSAPI or SSPI authentication data.

AuthenticationSSPI (B)

Byte1('R')

Identifies the message as an authentication request.

Int32(8)

Length of message contents in bytes, including self.

Int32(9)

Specifies that SSPI authentication is required.

AuthenticationSASL (B)

Byte1('R')

Identifies the message as an authentication request.

Int32

Length of message contents in bytes, including self.

Int32(10)

Specifies that SASL authentication is required.

The message body is a list of SASL authentication mechanisms, in the server's order of preference. A zero byte is required as terminator after the last authentication mechanism name. For each mechanism, there is the following:

String

Name of a SASL authentication mechanism.

AuthenticationSASLContinue (B)

Byte1('R')

Identifies the message as an authentication request.

Int32

Length of message contents in bytes, including self.

Int32(11)

Specifies that this message contains a SASL challenge.

Byte*n*

SASL data, specific to the SASL mechanism being used.

AuthenticationSASLFinal (B)

Byte1('R')

Identifies the message as an authentication request.

Int32

Length of message contents in bytes, including self.

Int32(12)

Specifies that SASL authentication has completed.

Byte*n*

SASL outcome "additional data", specific to the SASL mechanism being used.

BackendKeyData (B)

Byte1('K')

Identifies the message as cancellation key data. The frontend must save these values if it wishes to be able to issue CancelRequest messages later.

Int32(12)

Length of message contents in bytes, including self.

Int32

The process ID of this backend.

Int32

The secret key of this backend.

Bind (F)

Byte1('B')

Identifies the message as a Bind command.

Int32

Length of message contents in bytes, including self.

String

The name of the destination portal (an empty string selects the unnamed portal).

String

The name of the source prepared statement (an empty string selects the unnamed prepared statement).

Int16

The number of parameter format codes that follow (denoted *C* below). This can be zero to indicate that there are no parameters or that the parameters all use the default format (text); or one, in which case the specified format code is applied to all parameters; or it can equal the actual number of parameters.

Int16[*C*]

The parameter format codes. Each must presently be zero (text) or one (binary).

Int16

The number of parameter values that follow (possibly zero). This must match the number of parameters needed by the query.

Next, the following pair of fields appear for each parameter:

Int32

The length of the parameter value, in bytes (this count does not include itself). Can be zero. As a special case, -1 indicates a NULL parameter value. No value bytes follow in the NULL case.

Byte*n*

The value of the parameter, in the format indicated by the associated format code. *n* is the above length.

After the last parameter, the following fields appear:

Int16

The number of result-column format codes that follow (denoted *R* below). This can be zero to indicate that there are no result columns or that the result columns should all use the default format (text); or one, in which case the specified format code is applied to all result columns (if any); or it can equal the actual number of result columns of the query.

Int16[*R*]

The result-column format codes. Each must presently be zero (text) or one (binary).

BindComplete (B)

Byte1('2')

Identifies the message as a Bind-complete indicator.

Int32(4)

Length of message contents in bytes, including self.

CancelRequest (F)

Int32(16)

Length of message contents in bytes, including self.

Int32(80877102)

The cancel request code. The value is chosen to contain `1234` in the most significant 16 bits, and `5678` in the least significant 16 bits. (To avoid confusion, this code must not be the same as any protocol version number.)

Int32

The process ID of the target backend.

Int32

The secret key for the target backend.

Close (F)

Byte1('C')

Identifies the message as a Close command.

Int32

Length of message contents in bytes, including self.

Byte1

'`S`' to close a prepared statement; or '`P`' to close a portal.

String

The name of the prepared statement or portal to close (an empty string selects the unnamed prepared statement or portal).

CloseComplete (B)

Byte1('3')

Identifies the message as a Close-complete indicator.

Int32(4)

Length of message contents in bytes, including self.

CommandComplete (B)

Byte1('C')

Identifies the message as a command-completed response.

Int32

Length of message contents in bytes, including self.

String

The command tag. This is usually a single word that identifies which SQL command was completed.

For an `INSERT` command, the tag is `INSERT` *`oid rows`*, where *`rows`* is the number of rows inserted. *`oid`* used to be the object ID of the inserted row if *`rows`* was 1 and the target table had OIDs, but OIDs system columns are not supported anymore; therefore *`oid`* is always 0.

For a DELETE command, the tag is DELETE *rows* where *rows* is the number of rows deleted.

For an UPDATE command, the tag is UPDATE *rows* where *rows* is the number of rows updated.

For a SELECT or CREATE TABLE AS command, the tag is SELECT *rows* where *rows* is the number of rows retrieved.

For a MOVE command, the tag is MOVE *rows* where *rows* is the number of rows the cursor's position has been changed by.

For a FETCH command, the tag is FETCH *rows* where *rows* is the number of rows that have been retrieved from the cursor.

For a COPY command, the tag is COPY *rows* where *rows* is the number of rows copied. (Note: the row count appears only in PostgreSQL 8.2 and later.)

CopyData (F & B)

Byte1('d')

Identifies the message as COPY data.

Int32

Length of message contents in bytes, including self.

Byte*n*

Data that forms part of a COPY data stream. Messages sent from the backend will always correspond to single data rows, but messages sent by frontends might divide the data stream arbitrarily.

CopyDone (F & B)

Byte1('c')

Identifies the message as a COPY-complete indicator.

Int32(4)

Length of message contents in bytes, including self.

CopyFail (F)

Byte1('f')

Identifies the message as a COPY-failure indicator.

Int32

Length of message contents in bytes, including self.

String

An error message to report as the cause of failure.

CopyInResponse (B)

Byte1('G')

Identifies the message as a Start Copy In response. The frontend must now send copy-in data (if not prepared to do so, send a CopyFail message).

Int32

Length of message contents in bytes, including self.

Int8

0 indicates the overall `COPY` format is textual (rows separated by newlines, columns separated by separator characters, etc). 1 indicates the overall copy format is binary (similar to DataRow format). See COPY for more information.

Int16

The number of columns in the data to be copied (denoted *N* below).

Int16[*N*]

The format codes to be used for each column. Each must presently be zero (text) or one (binary). All must be zero if the overall copy format is textual.

CopyOutResponse (B)

Byte1('H')

Identifies the message as a Start Copy Out response. This message will be followed by copy-out data.

Int32

Length of message contents in bytes, including self.

Int8

0 indicates the overall `COPY` format is textual (rows separated by newlines, columns separated by separator characters, etc). 1 indicates the overall copy format is binary (similar to DataRow format). See COPY for more information.

Int16

The number of columns in the data to be copied (denoted *N* below).

Int16[*N*]

The format codes to be used for each column. Each must presently be zero (text) or one (binary). All must be zero if the overall copy format is textual.

CopyBothResponse (B)

Byte1('W')

Identifies the message as a Start Copy Both response. This message is used only for Streaming Replication.

Int32

Length of message contents in bytes, including self.

Int8

0 indicates the overall `COPY` format is textual (rows separated by newlines, columns separated by separator characters, etc). 1 indicates the overall copy format is binary (similar to DataRow format). See COPY for more information.

Int16

The number of columns in the data to be copied (denoted *N* below).

Int16[*N*]

The format codes to be used for each column. Each must presently be zero (text) or one (binary). All must be zero if the overall copy format is textual.

DataRow (B)

Byte1('D')

Identifies the message as a data row.

Int32

Length of message contents in bytes, including self.

Int16

The number of column values that follow (possibly zero).

Next, the following pair of fields appear for each column:

Int32

The length of the column value, in bytes (this count does not include itself). Can be zero. As a special case, -1 indicates a NULL column value. No value bytes follow in the NULL case.

Byte*n*

The value of the column, in the format indicated by the associated format code. *n* is the above length.

Describe (F)

Byte1('D')

Identifies the message as a Describe command.

Int32

Length of message contents in bytes, including self.

Byte1

'`S`' to describe a prepared statement; or '`P`' to describe a portal.

String

The name of the prepared statement or portal to describe (an empty string selects the unnamed prepared statement or portal).

EmptyQueryResponse (B)

Byte1('I')

Identifies the message as a response to an empty query string. (This substitutes for CommandComplete.)

Int32(4)

Length of message contents in bytes, including self.

ErrorResponse (B)

Byte1('E')

Identifies the message as an error.

Int32

Length of message contents in bytes, including self.

The message body consists of one or more identified fields, followed by a zero byte as a terminator. Fields can appear in any order. For each field there is the following:

Byte1

A code identifying the field type; if zero, this is the message terminator and no string follows. The presently defined field types are listed in Section 55.8. Since more field types might be added in future, frontends should silently ignore fields of unrecognized type.

String

The field value.

Execute (F)

Byte1('E')

Identifies the message as an Execute command.

Int32

Length of message contents in bytes, including self.

String

The name of the portal to execute (an empty string selects the unnamed portal).

Int32

Maximum number of rows to return, if portal contains a query that returns rows (ignored otherwise). Zero denotes “no limit”.

Flush (F)

Byte1('H')

Identifies the message as a Flush command.

Int32(4)

Length of message contents in bytes, including self.

FunctionCall (F)

Byte1('F')

Identifies the message as a function call.

Int32

Length of message contents in bytes, including self.

Int32

Specifies the object ID of the function to call.

Int16

The number of argument format codes that follow (denoted C below). This can be zero to indicate that there are no arguments or that the arguments all use the default format (text); or one, in which case the specified format code is applied to all arguments; or it can equal the actual number of arguments.

Int16[C]

The argument format codes. Each must presently be zero (text) or one (binary).

Int16

Specifies the number of arguments being supplied to the function.

Next, the following pair of fields appear for each argument:

Int32

The length of the argument value, in bytes (this count does not include itself). Can be zero. As a special case, -1 indicates a NULL argument value. No value bytes follow in the NULL case.

Byte*n*

The value of the argument, in the format indicated by the associated format code. *n* is the above length.

After the last argument, the following field appears:

Int16

The format code for the function result. Must presently be zero (text) or one (binary).

FunctionCallResponse (B)

Byte1('V')

Identifies the message as a function call result.

Int32

Length of message contents in bytes, including self.

Int32

The length of the function result value, in bytes (this count does not include itself). Can be zero. As a special case, -1 indicates a NULL function result. No value bytes follow in the NULL case.

Byte*n*

The value of the function result, in the format indicated by the associated format code. *n* is the above length.

GSSENCRequest (F)

Int32(8)

Length of message contents in bytes, including self.

Int32(80877104)

The GSSAPI Encryption request code. The value is chosen to contain `1234` in the most significant 16 bits, and `5680` in the least significant 16 bits. (To avoid confusion, this code must not be the same as any protocol version number.)

GSSResponse (F)

Byte1('p')

Identifies the message as a GSSAPI or SSPI response. Note that this is also used for SASL and password response messages. The exact message type can be deduced from the context.

Int32

Length of message contents in bytes, including self.

Byte*n*

GSSAPI/SSPI specific message data.

NegotiateProtocolVersion (B)

Byte1('v')

Identifies the message as a protocol version negotiation message.

Int32

Length of message contents in bytes, including self.

Int32

Newest minor protocol version supported by the server for the major protocol version requested by the client.

Int32

Number of protocol options not recognized by the server.

Then, for protocol option not recognized by the server, there is the following:

String

The option name.

NoData (B)

Byte1('n')

Identifies the message as a no-data indicator.

Int32(4)

Length of message contents in bytes, including self.

NoticeResponse (B)

Byte1('N')

Identifies the message as a notice.

Int32

Length of message contents in bytes, including self.

The message body consists of one or more identified fields, followed by a zero byte as a terminator. Fields can appear in any order. For each field there is the following:

Byte1

A code identifying the field type; if zero, this is the message terminator and no string follows. The presently defined field types are listed in Section 55.8. Since more field types might be added in future, frontends should silently ignore fields of unrecognized type.

String

The field value.

NotificationResponse (B)

Byte1('A')

Identifies the message as a notification response.

Int32

Length of message contents in bytes, including self.

Int32

The process ID of the notifying backend process.

String

The name of the channel that the notify has been raised on.

String

The “payload” string passed from the notifying process.

ParameterDescription (B)

Byte1('t')

Identifies the message as a parameter description.

Int32

Length of message contents in bytes, including self.

Int16

The number of parameters used by the statement (can be zero).

Then, for each parameter, there is the following:

Int32

Specifies the object ID of the parameter data type.

ParameterStatus (B)

Byte1('S')

Identifies the message as a run-time parameter status report.

Int32

Length of message contents in bytes, including self.

String

The name of the run-time parameter being reported.

String

The current value of the parameter.

Parse (F)

Byte1('P')

Identifies the message as a Parse command.

Int32

Length of message contents in bytes, including self.

String

The name of the destination prepared statement (an empty string selects the unnamed prepared statement).

String

The query string to be parsed.

Int16

The number of parameter data types specified (can be zero). Note that this is not an indication of the number of parameters that might appear in the query string, only the number that the frontend wants to prespecify types for.

Then, for each parameter, there is the following:

Int32

Specifies the object ID of the parameter data type. Placing a zero here is equivalent to leaving the type unspecified.

ParseComplete (B)

Byte1('1')

Identifies the message as a Parse-complete indicator.

Int32(4)

Length of message contents in bytes, including self.

PasswordMessage (F)

Byte1('p')

Identifies the message as a password response. Note that this is also used for GSSAPI, SSPI and SASL response messages. The exact message type can be deduced from the context.

Int32

Length of message contents in bytes, including self.

String

The password (encrypted, if requested).

PortalSuspended (B)

Byte1('s')

Identifies the message as a portal-suspended indicator. Note this only appears if an Execute message's row-count limit was reached.

Int32(4)

Length of message contents in bytes, including self.

Query (F)

Byte1('Q')

Identifies the message as a simple query.

Int32

Length of message contents in bytes, including self.

String

The query string itself.

ReadyForQuery (B)

Byte1('Z')

Identifies the message type. ReadyForQuery is sent whenever the backend is ready for a new query cycle.

Int32(5)

Length of message contents in bytes, including self.

Byte1

Current backend transaction status indicator. Possible values are '`I`' if idle (not in a transaction block); '`T`' if in a transaction block; or '`E`' if in a failed transaction block (queries will be rejected until block is ended).

RowDescription (B)

Byte1('T')

Identifies the message as a row description.

Int32

Length of message contents in bytes, including self.

Int16

Specifies the number of fields in a row (can be zero).

Then, for each field, there is the following:

String

The field name.

Int32

If the field can be identified as a column of a specific table, the object ID of the table; otherwise zero.

Int16

If the field can be identified as a column of a specific table, the attribute number of the column; otherwise zero.

Int32

The object ID of the field's data type.

Int16

The data type size (see `pg_type.typlen`). Note that negative values denote variable-width types.

Int32

The type modifier (see `pg_attribute.atttypmod`). The meaning of the modifier is type-specific.

Int16

The format code being used for the field. Currently will be zero (text) or one (binary). In a RowDescription returned from the statement variant of Describe, the format code is not yet known and will always be zero.

SASLInitialResponse (F)

Byte1('p')

Identifies the message as an initial SASL response. Note that this is also used for GSSAPI, SSPI and password response messages. The exact message type is deduced from the context.

Int32

Length of message contents in bytes, including self.

String

Name of the SASL authentication mechanism that the client selected.

Int32

Length of SASL mechanism specific "Initial Client Response" that follows, or -1 if there is no Initial Response.

Byte*n*

SASL mechanism specific "Initial Response".

SASLResponse (F)

Byte1('p')

Identifies the message as a SASL response. Note that this is also used for GSSAPI, SSPI and password response messages. The exact message type can be deduced from the context.

Int32

Length of message contents in bytes, including self.

Byte*n*

SASL mechanism specific message data.

SSLRequest (F)

Int32(8)

Length of message contents in bytes, including self.

Int32(80877103)

The SSL request code. The value is chosen to contain `1234` in the most significant 16 bits, and `5679` in the least significant 16 bits. (To avoid confusion, this code must not be the same as any protocol version number.)

StartupMessage (F)

Int32

Length of message contents in bytes, including self.

Int32(196608)

The protocol version number. The most significant 16 bits are the major version number (3 for the protocol described here). The least significant 16 bits are the minor version number (0 for the protocol described here).

The protocol version number is followed by one or more pairs of parameter name and value strings. A zero byte is required as a terminator after the last name/value pair. Parameters can appear in any order. `user` is required, others are optional. Each parameter is specified as:

String

The parameter name. Currently recognized names are:

`user`

The database user name to connect as. Required; there is no default.

`database`

The database to connect to. Defaults to the user name.

`options`

Command-line arguments for the backend. (This is deprecated in favor of setting individual run-time parameters.) Spaces within this string are considered to separate arguments, unless escaped with a backslash (`\`); write `\\` to represent a literal backslash.

`replication`

Used to connect in streaming replication mode, where a small set of replication commands can be issued instead of SQL statements. Value can be `true`, `false`, or `database`, and the default is `false`. See Section 55.4 for details.

In addition to the above, other parameters may be listed. Parameter names beginning with `_pq_`. are reserved for use as protocol extensions, while others are treated as run-time parameters to

be set at backend start time. Such settings will be applied during backend start (after parsing the command-line arguments if any) and will act as session defaults.

String

The parameter value.

Sync (F)

Byte1('S')

Identifies the message as a Sync command.

Int32(4)

Length of message contents in bytes, including self.

Terminate (F)

Byte1('X')

Identifies the message as a termination.

Int32(4)

Length of message contents in bytes, including self.

55.8. Error and Notice Message Fields

This section describes the fields that can appear in ErrorResponse and NoticeResponse messages. Each field type has a single-byte identification token. Note that any given field type should appear at most once per message.

`S`

Severity: the field contents are `ERROR`, `FATAL`, or `PANIC` (in an error message), or `WARNING`, `NOTICE`, `DEBUG`, `INFO`, or `LOG` (in a notice message), or a localized translation of one of these. Always present.

`V`

Severity: the field contents are `ERROR`, `FATAL`, or `PANIC` (in an error message), or `WARNING`, `NOTICE`, `DEBUG`, `INFO`, or `LOG` (in a notice message). This is identical to the `S` field except that the contents are never localized. This is present only in messages generated by Postgres Pro versions 9.6 and later.

`C`

Code: the SQLSTATE code for the error (see Appendix A). Not localizable. Always present.

`M`

Message: the primary human-readable error message. This should be accurate but terse (typically one line). Always present.

`D`

Detail: an optional secondary error message carrying more detail about the problem. Might run to multiple lines.

`H`

Hint: an optional suggestion what to do about the problem. This is intended to differ from Detail in that it offers advice (potentially inappropriate) rather than hard facts. Might run to multiple lines.

`P`

Position: the field value is a decimal ASCII integer, indicating an error cursor position as an index into the original query string. The first character has index 1, and positions are measured in characters not bytes.

`p`

Internal position: this is defined the same as the `P` field, but it is used when the cursor position refers to an internally generated command rather than the one submitted by the client. The `q` field will always appear when this field appears.

`q`

Internal query: the text of a failed internally-generated command. This could be, for example, an SQL query issued by a PL/pgSQL function.

`W`

Where: an indication of the context in which the error occurred. Presently this includes a call stack traceback of active procedural language functions and internally-generated queries. The trace is one entry per line, most recent first.

`s`

Schema name: if the error was associated with a specific database object, the name of the schema containing that object, if any.

`t`

Table name: if the error was associated with a specific table, the name of the table. (Refer to the schema name field for the name of the table's schema.)

`c`

Column name: if the error was associated with a specific table column, the name of the column. (Refer to the schema and table name fields to identify the table.)

`d`

Data type name: if the error was associated with a specific data type, the name of the data type. (Refer to the schema name field for the name of the data type's schema.)

`n`

Constraint name: if the error was associated with a specific constraint, the name of the constraint. Refer to fields listed above for the associated table or domain. (For this purpose, indexes are treated as constraints, even if they weren't created with constraint syntax.)

`F`

File: the file name of the source-code location where the error was reported.

`L`

Line: the line number of the source-code location where the error was reported.

`R`

Routine: the name of the source-code routine reporting the error.

> **Note**
>
> The fields for schema name, table name, column name, data type name, and constraint name are supplied only for a limited number of error types; see Appendix A. Frontends should not assume that the presence of any of these fields guarantees the presence of another field. Core error sources observe the interrelationships noted above, but user-defined functions may use these fields in other ways. In the same vein, clients should not assume that these fields denote contemporary objects in the current database.

The client is responsible for formatting displayed information to meet its needs; in particular it should break long lines as needed. Newline characters appearing in the error message fields should be treated as paragraph breaks, not line breaks.

55.9. Logical Replication Message Formats

This section describes the detailed format of each logical replication message. These messages are returned either by the replication slot SQL interface or are sent by a walsender. In case of a walsender they are encapsulated inside the replication protocol WAL messages as described in Section 55.4 and generally obey same message flow as physical replication.

Begin

Byte1('B')

Identifies the message as a begin message.

Int64

The final LSN of the transaction.

Int64

Commit timestamp of the transaction. The value is in number of microseconds since Postgres Pro epoch (2000-01-01).

Int64

Xid of the transaction.

Message

Byte1('M')

Identifies the message as a logical decoding message.

Int64

Xid of the transaction (only present for streamed transactions). This field is available since protocol version 2.

Int8

Flags; Either 0 for no flags or 1 if the logical decoding message is transactional.

Int64

The LSN of the logical decoding message.

String

The prefix of the logical decoding message.

Int32

Length of the content.

Byte$n$

The content of the logical decoding message.

Commit

Byte1('C')

Identifies the message as a commit message.

Int8

Flags; currently unused (must be 0).

Int64

The LSN of the commit.

Int64

The end LSN of the transaction.

Int64

Commit timestamp of the transaction. The value is in number of microseconds since Postgres Pro epoch (2000-01-01).

Origin

Byte1('O')

Identifies the message as an origin message.

Int64

The LSN of the commit on the origin server.

String

Name of the origin.

Note that there can be multiple Origin messages inside a single transaction.

Relation

Byte1('R')

Identifies the message as a relation message.

Int64

Xid of the transaction (only present for streamed transactions). This field is available since protocol version 2.

Int32

ID of the relation.

String

Namespace (empty string for `pg_catalog`).

String

Relation name.

Int8

Replica identity setting for the relation (same as `relreplident` in `pg_class`).

Int16

Number of columns.

Next, the following message part appears for each column (except generated columns):

Int8

Flags for the column. Currently can be either 0 for no flags or 1 which marks the column as part of the key.

String

Name of the column.

Int32

ID of the column's data type.

Int32

Type modifier of the column (`atttypmod`).

Type

Byte1('Y')

Identifies the message as a type message.

Int64

Xid of the transaction (only present for streamed transactions). This field is available since protocol version 2.

Int32

ID of the data type.

String

Namespace (empty string for `pg_catalog`).

String

Name of the data type.

Insert

Byte1('I')

Identifies the message as an insert message.

Int64

Xid of the transaction (only present for streamed transactions). This field is available since protocol version 2.

Int32

ID of the relation corresponding to the ID in the relation message.

Byte1('N')

Identifies the following TupleData message as a new tuple.

TupleData

TupleData message part representing the contents of new tuple.

Update

Byte1('U')

Identifies the message as an update message.

Int64

Xid of the transaction (only present for streamed transactions). This field is available since protocol version 2.

Int32

ID of the relation corresponding to the ID in the relation message.

Byte1('K')

Identifies the following TupleData submessage as a key. This field is optional and is only present if the update changed data in any of the column(s) that are part of the REPLICA IDENTITY index.

Byte1('O')

Identifies the following TupleData submessage as an old tuple. This field is optional and is only present if table in which the update happened has REPLICA IDENTITY set to FULL.

TupleData

TupleData message part representing the contents of the old tuple or primary key. Only present if the previous 'O' or 'K' part is present.

Byte1('N')

Identifies the following TupleData message as a new tuple.

TupleData

TupleData message part representing the contents of a new tuple.

The Update message may contain either a 'K' message part or an 'O' message part or neither of them, but never both of them.

Delete

Byte1('D')

Identifies the message as a delete message.

Int64

Xid of the transaction (only present for streamed transactions). This field is available since protocol version 2.

Int32

ID of the relation corresponding to the ID in the relation message.

Byte1('K')

Identifies the following TupleData submessage as a key. This field is present if the table in which the delete has happened uses an index as REPLICA IDENTITY.

Byte1('O')

Identifies the following TupleData message as an old tuple. This field is present if the table in which the delete happened has REPLICA IDENTITY set to FULL.

TupleData

TupleData message part representing the contents of the old tuple or primary key, depending on the previous field.

The Delete message may contain either a 'K' message part or an 'O' message part, but never both of them.

Truncate

Byte1('T')

Identifies the message as a truncate message.

Int64

Xid of the transaction (only present for streamed transactions). This field is available since protocol version 2.

Int32

Number of relations

Int8

Option bits for `TRUNCATE`: 1 for `CASCADE`, 2 for `RESTART IDENTITY`

Int32

ID of the relation corresponding to the ID in the relation message. This field is repeated for each relation.

The following messages (Stream Start, Stream Stop, Stream Commit, and Stream Abort) are available since protocol version 2.

Stream Start

Byte1('S')

Identifies the message as a stream start message.

Int64

Xid of the transaction.

Int8

A value of 1 indicates this is the first stream segment for this XID, 0 for any other stream segment.

Stream Stop

Byte1('E')

Identifies the message as a stream stop message.

Stream Commit

Byte1('c')

Identifies the message as a stream commit message.

Int64

Xid of the transaction.

Int8

Flags; currently unused (must be 0).

Int64

The LSN of the commit.

Int64

The end LSN of the transaction.

Int64

Commit timestamp of the transaction. The value is in number of microseconds since PostgreSQL epoch (2000-01-01).

Stream Abort

Byte1('A')

Identifies the message as a stream abort message.

Int64

Xid of the transaction.

Int64

Xid of the subtransaction (will be same as xid of the transaction for top-level transactions).

The following message parts are shared by the above messages.

TupleData

Int16

Number of columns.

Next, one of the following submessages appears for each column (except generated columns):

Byte1('n')

Identifies the data as NULL value.

Or

Byte1('u')

Identifies unchanged TOASTed value (the actual value is not sent).

Or

Byte1('t')

Identifies the data as text formatted value.

Or

Byte1('b')

Identifies the data as binary formatted value.

Int32

Length of the column value.

Byte*n*

The value of the column, either in binary or in text format. (As specified in the preceding format byte). *n* is the above length.

55.10. Summary of Changes since Protocol 2.0

This section provides a quick checklist of changes, for the benefit of developers trying to update existing client libraries to protocol 3.0.

The initial startup packet uses a flexible list-of-strings format instead of a fixed format. Notice that session default values for run-time parameters can now be specified directly in the startup packet. (Actually, you could do that before using the `options` field, but given the limited width of `options` and the lack of any way to quote whitespace in the values, it wasn't a very safe technique.)

All messages now have a length count immediately following the message type byte (except for startup packets, which have no type byte). Also note that PasswordMessage now has a type byte.

ErrorResponse and NoticeResponse ('`E`' and '`N`') messages now contain multiple fields, from which the client code can assemble an error message of the desired level of verbosity. Note that individual fields will typically not end with a newline, whereas the single string sent in the older protocol always did.

The ReadyForQuery ('`Z`') message includes a transaction status indicator.

The distinction between BinaryRow and DataRow message types is gone; the single DataRow message type serves for returning data in all formats. Note that the layout of DataRow has changed to make it easier to parse. Also, the representation of binary values has changed: it is no longer directly tied to the server's internal representation.

There is a new “extended query” sub-protocol, which adds the frontend message types Parse, Bind, Execute, Describe, Close, Flush, and Sync, and the backend message types ParseComplete, BindComplete, PortalSuspended, ParameterDescription, NoData, and CloseComplete. Existing clients do not have to concern themselves with this sub-protocol, but making use of it might allow improvements in performance or functionality.

`COPY` data is now encapsulated into CopyData and CopyDone messages. There is a well-defined way to recover from errors during `COPY`. The special “`\.`” last line is not needed anymore, and is not sent during `COPY OUT`. (It is still recognized as a terminator during `COPY IN`, but its use is deprecated and will eventually be removed.) Binary `COPY` is supported. The CopyInResponse and CopyOutResponse messages include fields indicating the number of columns and the format of each column.

The layout of FunctionCall and FunctionCallResponse messages has changed. FunctionCall can now support passing NULL arguments to functions. It also can handle passing parameters and retrieving results in either text or binary format. There is no longer any reason to consider FunctionCall a potential security hole, since it does not offer direct access to internal server data representations.

The backend sends ParameterStatus ('`S`') messages during connection startup for all parameters it considers interesting to the client library. Subsequently, a ParameterStatus message is sent whenever the active value changes for any of these parameters.

The RowDescription ('`T`') message carries new table OID and column number fields for each column of the described row. It also shows the format code for each column.

The CursorResponse ('`P`') message is no longer generated by the backend.

The NotificationResponse ('`A`') message has an additional string field, which can carry a “payload” string passed from the `NOTIFY` event sender.

The EmptyQueryResponse ('`I`') message used to include an empty string parameter; this has been removed.

Chapter 56. Writing a Procedural Language Handler

All calls to functions that are written in a language other than the current “version 1” interface for compiled languages (this includes functions in user-defined procedural languages and functions written in SQL) go through a *call handler* function for the specific language. It is the responsibility of the call handler to execute the function in a meaningful way, such as by interpreting the supplied source text. This chapter outlines how a new procedural language's call handler can be written.

The call handler for a procedural language is a “normal” function that must be written in a compiled language such as C, using the version-1 interface, and registered with Postgres Pro as taking no arguments and returning the type `language_handler`. This special pseudo-type identifies the function as a call handler and prevents it from being called directly in SQL commands. For more details on C language calling conventions and dynamic loading, see Section 40.10.

The call handler is called in the same way as any other function: It receives a pointer to a `FunctionCallInfoBaseData struct` containing argument values and information about the called function, and it is expected to return a `Datum` result (and possibly set the `isnull` field of the `FunctionCallInfoBaseData` structure, if it wishes to return an SQL null result). The difference between a call handler and an ordinary callee function is that the `flinfo->fn_oid` field of the `FunctionCallInfoBaseData` structure will contain the OID of the actual function to be called, not of the call handler itself. The call handler must use this field to determine which function to execute. Also, the passed argument list has been set up according to the declaration of the target function, not of the call handler.

It's up to the call handler to fetch the entry of the function from the `pg_proc` system catalog and to analyze the argument and return types of the called function. The `AS` clause from the `CREATE FUNCTION` command for the function will be found in the `prosrc` column of the `pg_proc` row. This is commonly source text in the procedural language, but in theory it could be something else, such as a path name to a file, or anything else that tells the call handler what to do in detail.

Often, the same function is called many times per SQL statement. A call handler can avoid repeated lookups of information about the called function by using the `flinfo->fn_extra` field. This will initially be `NULL`, but can be set by the call handler to point at information about the called function. On subsequent calls, if `flinfo->fn_extra` is already non-`NULL` then it can be used and the information lookup step skipped. The call handler must make sure that `flinfo->fn_extra` is made to point at memory that will live at least until the end of the current query, since an `FmgrInfo` data structure could be kept that long. One way to do this is to allocate the extra data in the memory context specified by `flinfo->fn_mcxt`; such data will normally have the same lifespan as the `FmgrInfo` itself. But the handler could also choose to use a longer-lived memory context so that it can cache function definition information across queries.

When a procedural-language function is invoked as a trigger, no arguments are passed in the usual way, but the `FunctionCallInfoBaseData`'s `context` field points at a `TriggerData` structure, rather than being `NULL` as it is in a plain function call. A language handler should provide mechanisms for procedural-language functions to get at the trigger information.

Although providing a call handler is sufficient to create a minimal procedural language, there are two other functions that can optionally be provided to make the language more convenient to use. These are a *validator* and an *inline handler*. A validator can be provided to allow language-specific checking to be done during CREATE FUNCTION. An inline handler can be provided to allow the language to support anonymous code blocks executed via the DO command.

If a validator is provided by a procedural language, it must be declared as a function taking a single parameter of type `oid`. The validator's result is ignored, so it is customarily declared to return `void`. The validator will be called at the end of a `CREATE FUNCTION` command that has created or updated a function written in the procedural language. The passed-in OID is the OID of the function's `pg_proc` row. The validator must fetch this row in the usual way, and do whatever checking is appropriate. First, call `CheckFunctionValidatorAccess()` to diagnose explicit calls to the validator that the user could not

achieve through `CREATE FUNCTION`. Typical checks then include verifying that the function's argument and result types are supported by the language, and that the function's body is syntactically correct in the language. If the validator finds the function to be okay, it should just return. If it finds an error, it should report that via the normal `ereport()` error reporting mechanism. Throwing an error will force a transaction rollback and thus prevent the incorrect function definition from being committed.

Validator functions should typically honor the check_function_bodies parameter: if it is turned off then any expensive or context-sensitive checking should be skipped. If the language provides for code execution at compilation time, the validator must suppress checks that would induce such execution. In particular, this parameter is turned off by pg_dump so that it can load procedural language functions without worrying about side effects or dependencies of the function bodies on other database objects. (Because of this requirement, the call handler should avoid assuming that the validator has fully checked the function. The point of having a validator is not to let the call handler omit checks, but to notify the user immediately if there are obvious errors in a `CREATE FUNCTION` command.) While the choice of exactly what to check is mostly left to the discretion of the validator function, note that the core `CREATE FUNCTION` code only executes `SET` clauses attached to a function when `check_function_bodies` is on. Therefore, checks whose results might be affected by GUC parameters definitely should be skipped when `check_function_bodies` is off, to avoid false failures when restoring a dump.

If an inline handler is provided by a procedural language, it must be declared as a function taking a single parameter of type `internal`. The inline handler's result is ignored, so it is customarily declared to return `void`. The inline handler will be called when a `DO` statement is executed specifying the procedural language. The parameter actually passed is a pointer to an `InlineCodeBlock` struct, which contains information about the `DO` statement's parameters, in particular the text of the anonymous code block to be executed. The inline handler should execute this code and return.

It's recommended that you wrap all these function declarations, as well as the `CREATE LANGUAGE` command itself, into an *extension* so that a simple `CREATE EXTENSION` command is sufficient to install the language. See Section 40.17 for information about writing extensions.

The procedural languages included in the standard distribution are good references when trying to write your own language handler. The CREATE LANGUAGE reference page has some useful details.

Chapter 57. Writing a Foreign Data Wrapper

All operations on a foreign table are handled through its foreign data wrapper, which consists of a set of functions that the core server calls. The foreign data wrapper is responsible for fetching data from the remote data source and returning it to the Postgres Pro executor. If updating foreign tables is to be supported, the wrapper must handle that, too. This chapter outlines how to write a new foreign data wrapper.

The foreign data wrappers included in the standard distribution are good references when trying to write your own. Look into the `contrib` subdirectory of the source tree. The CREATE FOREIGN DATA WRAPPER reference page also has some useful details.

> **Note**
>
> The SQL standard specifies an interface for writing foreign data wrappers. However, Postgres Pro does not implement that API, because the effort to accommodate it into Postgres Pro would be large, and the standard API hasn't gained wide adoption anyway.

57.1. Foreign Data Wrapper Functions

The FDW author needs to implement a handler function, and optionally a validator function. Both functions must be written in a compiled language such as C, using the version-1 interface. For details on C language calling conventions and dynamic loading, see Section 40.10.

The handler function simply returns a struct of function pointers to callback functions that will be called by the planner, executor, and various maintenance commands. Most of the effort in writing an FDW is in implementing these callback functions. The handler function must be registered with Postgres Pro as taking no arguments and returning the special pseudo-type `fdw_handler`. The callback functions are plain C functions and are not visible or callable at the SQL level. The callback functions are described in Section 57.2.

The validator function is responsible for validating options given in `CREATE` and `ALTER` commands for its foreign data wrapper, as well as foreign servers, user mappings, and foreign tables using the wrapper. The validator function must be registered as taking two arguments, a text array containing the options to be validated, and an OID representing the type of object the options are associated with. The latter corresponds to the OID of the system catalog the object would be stored in, one of:

- `AttributeRelationId`
- `ForeignDataWrapperRelationId`
- `ForeignServerRelationId`
- `ForeignTableRelationId`
- `UserMappingRelationId`

If no validator function is supplied, options are not checked at object creation time or object alteration time.

57.2. Foreign Data Wrapper Callback Routines

The FDW handler function returns a palloc'd `FdwRoutine` struct containing pointers to the callback functions described below. The scan-related functions are required, the rest are optional.

The `FdwRoutine` struct type is declared in *src/include/foreign/fdwapi.h*, which see for additional details.

57.2.1. FDW Routines for Scanning Foreign Tables

```
void
GetForeignRelSize(PlannerInfo *root,
```

```
                RelOptInfo *baserel,
                Oid foreigntableid);
```

Obtain relation size estimates for a foreign table. This is called at the beginning of planning for a query that scans a foreign table. `root` is the planner's global information about the query; `baserel` is the planner's information about this table; and `foreigntableid` is the `pg_class` OID of the foreign table. (`foreigntableid` could be obtained from the planner data structures, but it's passed explicitly to save effort.)

This function should update `baserel->rows` to be the expected number of rows returned by the table scan, after accounting for the filtering done by the restriction quals. The initial value of `baserel->rows` is just a constant default estimate, which should be replaced if at all possible. The function may also choose to update `baserel->width` if it can compute a better estimate of the average result row width. (The initial value is based on column data types and on column average-width values measured by the last `ANALYZE`.) Also, this function may update `baserel->tuples` if it can compute a better estimate of the foreign table's total row count. (The initial value is from `pg_class.reltuples` which represents the total row count seen by the last `ANALYZE`; it will be `-1` if no `ANALYZE` has been done on this foreign table.)

See Section 57.4 for additional information.

```
void
GetForeignPaths(PlannerInfo *root,
                RelOptInfo *baserel,
                Oid foreigntableid);
```

Create possible access paths for a scan on a foreign table. This is called during query planning. The parameters are the same as for `GetForeignRelSize`, which has already been called.

This function must generate at least one access path (`ForeignPath` node) for a scan on the foreign table and must call `add_path` to add each such path to `baserel->pathlist`. It's recommended to use `create_foreignscan_path` to build the `ForeignPath` nodes. The function can generate multiple access paths, e.g., a path which has valid `pathkeys` to represent a pre-sorted result. Each access path must contain cost estimates, and can contain any FDW-private information that is needed to identify the specific scan method intended.

See Section 57.4 for additional information.

```
ForeignScan *
GetForeignPlan(PlannerInfo *root,
               RelOptInfo *baserel,
               Oid foreigntableid,
               ForeignPath *best_path,
               List *tlist,
               List *scan_clauses,
               Plan *outer_plan);
```

Create a `ForeignScan` plan node from the selected foreign access path. This is called at the end of query planning. The parameters are as for `GetForeignRelSize`, plus the selected `ForeignPath` (previously produced by `GetForeignPaths`, `GetForeignJoinPaths`, or `GetForeignUpperPaths`), the target list to be emitted by the plan node, the restriction clauses to be enforced by the plan node, and the outer subplan of the `ForeignScan`, which is used for rechecks performed by `RecheckForeignScan`. (If the path is for a join rather than a base relation, `foreigntableid` is `InvalidOid`.)

This function must create and return a `ForeignScan` plan node; it's recommended to use `make_foreignscan` to build the `ForeignScan` node.

See Section 57.4 for additional information.

```
void
BeginForeignScan(ForeignScanState *node,
                 int eflags);
```

Begin executing a foreign scan. This is called during executor startup. It should perform any initialization needed before the scan can start, but not start executing the actual scan (that should be done upon the first call to `IterateForeignScan`). The `ForeignScanState` node has already been created, but its `fdw_state` field is still NULL. Information about the table to scan is accessible through the `ForeignScanState` node (in particular, from the underlying `ForeignScan` plan node, which contains any FDW-private information provided by `GetForeignPlan`). `eflags` contains flag bits describing the executor's operating mode for this plan node.

Note that when `(eflags & EXEC_FLAG_EXPLAIN_ONLY)` is true, this function should not perform any externally-visible actions; it should only do the minimum required to make the node state valid for `ExplainForeignScan` and `EndForeignScan`.

```
TupleTableSlot *
IterateForeignScan(ForeignScanState *node);
```

Fetch one row from the foreign source, returning it in a tuple table slot (the node's `ScanTupleSlot` should be used for this purpose). Return NULL if no more rows are available. The tuple table slot infrastructure allows either a physical or virtual tuple to be returned; in most cases the latter choice is preferable from a performance standpoint. Note that this is called in a short-lived memory context that will be reset between invocations. Create a memory context in `BeginForeignScan` if you need longer-lived storage, or use the `es_query_cxt` of the node's `EState`.

The rows returned must match the `fdw_scan_tlist` target list if one was supplied, otherwise they must match the row type of the foreign table being scanned. If you choose to optimize away fetching columns that are not needed, you should insert nulls in those column positions, or else generate a `fdw_scan_tlist` list with those columns omitted.

Note that Postgres Pro's executor doesn't care whether the rows returned violate any constraints that were defined on the foreign table — but the planner does care, and may optimize queries incorrectly if there are rows visible in the foreign table that do not satisfy a declared constraint. If a constraint is violated when the user has declared that the constraint should hold true, it may be appropriate to raise an error (just as you would need to do in the case of a data type mismatch).

```
void
ReScanForeignScan(ForeignScanState *node);
```

Restart the scan from the beginning. Note that any parameters the scan depends on may have changed value, so the new scan does not necessarily return exactly the same rows.

```
void
EndForeignScan(ForeignScanState *node);
```

End the scan and release resources. It is normally not important to release palloc'd memory, but for example open files and connections to remote servers should be cleaned up.

57.2.2. FDW Routines for Scanning Foreign Joins

If an FDW supports performing foreign joins remotely (rather than by fetching both tables' data and doing the join locally), it should provide this callback function:

```
void
GetForeignJoinPaths(PlannerInfo *root,
                    RelOptInfo *joinrel,
                    RelOptInfo *outerrel,
                    RelOptInfo *innerrel,
                    JoinType jointype,
                    JoinPathExtraData *extra);
```

Create possible access paths for a join of two (or more) foreign tables that all belong to the same foreign server. This optional function is called during query planning. As with `GetForeignPaths`, this function should generate `ForeignPath` path(s) for the supplied `joinrel` (use `create_foreign_join_path` to build

them), and call `add_path` to add these paths to the set of paths considered for the join. But unlike `GetForeignPaths`, it is not necessary that this function succeed in creating at least one path, since paths involving local joining are always possible.

Note that this function will be invoked repeatedly for the same join relation, with different combinations of inner and outer relations; it is the responsibility of the FDW to minimize duplicated work.

If a `ForeignPath` path is chosen for the join, it will represent the entire join process; paths generated for the component tables and subsidiary joins will not be used. Subsequent processing of the join path proceeds much as it does for a path scanning a single foreign table. One difference is that the `scanrelid` of the resulting `ForeignScan` plan node should be set to zero, since there is no single relation that it represents; instead, the `fs_relids` field of the `ForeignScan` node represents the set of relations that were joined. (The latter field is set up automatically by the core planner code, and need not be filled by the FDW.) Another difference is that, because the column list for a remote join cannot be found from the system catalogs, the FDW must fill `fdw_scan_tlist` with an appropriate list of `TargetEntry` nodes, representing the set of columns it will supply at run time in the tuples it returns.

See Section 57.4 for additional information.

57.2.3. FDW Routines for Planning Post-Scan/Join Processing

If an FDW supports performing remote post-scan/join processing, such as remote aggregation, it should provide this callback function:

```
void
GetForeignUpperPaths(PlannerInfo *root,
                     UpperRelationKind stage,
                     RelOptInfo *input_rel,
                     RelOptInfo *output_rel,
                     void *extra);
```

Create possible access paths for *upper relation* processing, which is the planner's term for all post-scan/join query processing, such as aggregation, window functions, sorting, and table updates. This optional function is called during query planning. Currently, it is called only if all base relation(s) involved in the query belong to the same FDW. This function should generate `ForeignPath` path(s) for any post-scan/join processing that the FDW knows how to perform remotely (use `create_foreign_upper_path` to build them), and call `add_path` to add these paths to the indicated upper relation. As with `GetForeignJoinPaths`, it is not necessary that this function succeed in creating any paths, since paths involving local processing are always possible.

The `stage` parameter identifies which post-scan/join step is currently being considered. `output_rel` is the upper relation that should receive paths representing computation of this step, and `input_rel` is the relation representing the input to this step. The `extra` parameter provides additional details, currently, it is set only for `UPPERREL_PARTIAL_GROUP_AGG` or `UPPERREL_GROUP_AGG`, in which case it points to a `GroupPathExtraData` structure; or for `UPPERREL_FINAL`, in which case it points to a `FinalPathExtraData` structure. (Note that `ForeignPath` paths added to `output_rel` would typically not have any direct dependency on paths of the `input_rel`, since their processing is expected to be done externally. However, examining paths previously generated for the previous processing step can be useful to avoid redundant planning work.)

See Section 57.4 for additional information.

57.2.4. FDW Routines for Updating Foreign Tables

If an FDW supports writable foreign tables, it should provide some or all of the following callback functions depending on the needs and capabilities of the FDW:

```
void
AddForeignUpdateTargets(PlannerInfo *root,
                        Index rtindex,
```

```
                         RangeTblEntry *target_rte,
                         Relation target_relation);
```

UPDATE and DELETE operations are performed against rows previously fetched by the table-scanning functions. The FDW may need extra information, such as a row ID or the values of primary-key columns, to ensure that it can identify the exact row to update or delete. To support that, this function can add extra hidden, or "junk", target columns to the list of columns that are to be retrieved from the foreign table during an UPDATE or DELETE.

To do that, construct a Var representing an extra value you need, and pass it to add_row_identity_var, along with a name for the junk column. (You can do this more than once if several columns are needed.) You must choose a distinct junk column name for each different Var you need, except that Vars that are identical except for the varno field can and should share a column name. The core system uses the junk column names tableoid for a table's tableoid column, ctid or ctid*N* for ctid, wholerow for a whole-row Var marked with vartype = RECORD, and wholerow*N* for a whole-row Var with vartype equal to the table's declared row type. Re-use these names when you can (the planner will combine duplicate requests for identical junk columns). If you need another kind of junk column besides these, it might be wise to choose a name prefixed with your extension name, to avoid conflicts against other FDWs.

If the AddForeignUpdateTargets pointer is set to NULL, no extra target expressions are added. (This will make it impossible to implement DELETE operations, though UPDATE may still be feasible if the FDW relies on an unchanging primary key to identify rows.)

```
List *
PlanForeignModify(PlannerInfo *root,
                  ModifyTable *plan,
                  Index resultRelation,
                  int subplan_index);
```

Perform any additional planning actions needed for an insert, update, or delete on a foreign table. This function generates the FDW-private information that will be attached to the ModifyTable plan node that performs the update action. This private information must have the form of a List, and will be delivered to BeginForeignModify during the execution stage.

root is the planner's global information about the query. plan is the ModifyTable plan node, which is complete except for the fdwPrivLists field. resultRelation identifies the target foreign table by its range table index. subplan_index identifies which target of the ModifyTable plan node this is, counting from zero; use this if you want to index into per-target-relation substructures of the plan node.

See Section 57.4 for additional information.

If the PlanForeignModify pointer is set to NULL, no additional plan-time actions are taken, and the fdw_private list delivered to BeginForeignModify will be NIL.

```
void
BeginForeignModify(ModifyTableState *mtstate,
                   ResultRelInfo *rinfo,
                   List *fdw_private,
                   int subplan_index,
                   int eflags);
```

Begin executing a foreign table modification operation. This routine is called during executor startup. It should perform any initialization needed prior to the actual table modifications. Subsequently, ExecForeignInsert/ExecForeignBatchInsert, ExecForeignUpdate or ExecForeignDelete will be called for tuple(s) to be inserted, updated, or deleted.

mtstate is the overall state of the ModifyTable plan node being executed; global data about the plan and execution state is available via this structure. rinfo is the ResultRelInfo struct describing the target foreign table. (The ri_FdwState field of ResultRelInfo is available for the FDW to store any private state it needs for this operation.) fdw_private contains the private data generated by PlanForeignModify, if

any. subplan_index identifies which target of the ModifyTable plan node this is. eflags contains flag bits describing the executor's operating mode for this plan node.

Note that when (eflags & EXEC_FLAG_EXPLAIN_ONLY) is true, this function should not perform any externally-visible actions; it should only do the minimum required to make the node state valid for ExplainForeignModify and EndForeignModify.

If the BeginForeignModify pointer is set to NULL, no action is taken during executor startup.

```
TupleTableSlot *
ExecForeignInsert(EState *estate,
                  ResultRelInfo *rinfo,
                  TupleTableSlot *slot,
                  TupleTableSlot *planSlot);
```

Insert one tuple into the foreign table. estate is global execution state for the query. rinfo is the ResultRelInfo struct describing the target foreign table. slot contains the tuple to be inserted; it will match the row-type definition of the foreign table. planSlot contains the tuple that was generated by the ModifyTable plan node's subplan; it differs from slot in possibly containing additional “junk” columns. (The planSlot is typically of little interest for INSERT cases, but is provided for completeness.)

The return value is either a slot containing the data that was actually inserted (this might differ from the data supplied, for example as a result of trigger actions), or NULL if no row was actually inserted (again, typically as a result of triggers). The passed-in slot can be re-used for this purpose.

The data in the returned slot is used only if the INSERT statement has a RETURNING clause or involves a view WITH CHECK OPTION; or if the foreign table has an AFTER ROW trigger. Triggers require all columns, but the FDW could choose to optimize away returning some or all columns depending on the contents of the RETURNING clause or WITH CHECK OPTION constraints. Regardless, some slot must be returned to indicate success, or the query's reported row count will be wrong.

If the ExecForeignInsert pointer is set to NULL, attempts to insert into the foreign table will fail with an error message.

Note that this function is also called when inserting routed tuples into a foreign-table partition or executing COPY FROM on a foreign table, in which case it is called in a different way than it is in the INSERT case. See the callback functions described below that allow the FDW to support that.

```
TupleTableSlot **
ExecForeignBatchInsert(EState *estate,
                       ResultRelInfo *rinfo,
                       TupleTableSlot **slots,
                       TupleTableSlot **planSlots,
                       int *numSlots);
```

Insert multiple tuples in bulk into the foreign table. The parameters are the same for ExecForeignInsert except slots and planSlots contain multiple tuples and *numSlots specifies the number of tuples in those arrays.

The return value is an array of slots containing the data that was actually inserted (this might differ from the data supplied, for example as a result of trigger actions.) The passed-in slots can be re-used for this purpose. The number of successfully inserted tuples is returned in *numSlots.

The data in the returned slot is used only if the INSERT statement involves a view WITH CHECK OPTION; or if the foreign table has an AFTER ROW trigger. Triggers require all columns, but the FDW could choose to optimize away returning some or all columns depending on the contents of the WITH CHECK OPTION constraints.

If the ExecForeignBatchInsert or GetForeignModifyBatchSize pointer is set to NULL, attempts to insert into the foreign table will use ExecForeignInsert. This function is not used if the INSERT has the RETURNING clause.

Note that this function is also called when inserting routed tuples into a foreign-table partition. See the callback functions described below that allow the FDW to support that.

```
int
GetForeignModifyBatchSize(ResultRelInfo *rinfo);
```

Report the maximum number of tuples that a single ExecForeignBatchInsert call can handle for the specified foreign table. The executor passes at most the given number of tuples to ExecForeignBatchInsert. rinfo is the ResultRelInfo struct describing the target foreign table. The FDW is expected to provide a foreign server and/or foreign table option for the user to set this value, or some hard-coded value.

If the ExecForeignBatchInsert or GetForeignModifyBatchSize pointer is set to NULL, attempts to insert into the foreign table will use ExecForeignInsert.

```
TupleTableSlot *
ExecForeignUpdate(EState *estate,
                  ResultRelInfo *rinfo,
                  TupleTableSlot *slot,
                  TupleTableSlot *planSlot);
```

Update one tuple in the foreign table. estate is global execution state for the query. rinfo is the ResultRelInfo struct describing the target foreign table. slot contains the new data for the tuple; it will match the row-type definition of the foreign table. planSlot contains the tuple that was generated by the ModifyTable plan node's subplan. Unlike slot, this tuple contains only the new values for columns changed by the query, so do not rely on attribute numbers of the foreign table to index into planSlot. Also, planSlot typically contains additional "junk" columns. In particular, any junk columns that were requested by AddForeignUpdateTargets will be available from this slot.

The return value is either a slot containing the row as it was actually updated (this might differ from the data supplied, for example as a result of trigger actions), or NULL if no row was actually updated (again, typically as a result of triggers). The passed-in slot can be re-used for this purpose.

The data in the returned slot is used only if the UPDATE statement has a RETURNING clause or involves a view WITH CHECK OPTION; or if the foreign table has an AFTER ROW trigger. Triggers require all columns, but the FDW could choose to optimize away returning some or all columns depending on the contents of the RETURNING clause or WITH CHECK OPTION constraints. Regardless, some slot must be returned to indicate success, or the query's reported row count will be wrong.

If the ExecForeignUpdate pointer is set to NULL, attempts to update the foreign table will fail with an error message.

```
TupleTableSlot *
ExecForeignDelete(EState *estate,
                  ResultRelInfo *rinfo,
                  TupleTableSlot *slot,
                  TupleTableSlot *planSlot);
```

Delete one tuple from the foreign table. estate is global execution state for the query. rinfo is the ResultRelInfo struct describing the target foreign table. slot contains nothing useful upon call, but can be used to hold the returned tuple. planSlot contains the tuple that was generated by the ModifyTable plan node's subplan; in particular, it will carry any junk columns that were requested by AddForeignUpdateTargets. The junk column(s) must be used to identify the tuple to be deleted.

The return value is either a slot containing the row that was deleted, or NULL if no row was deleted (typically as a result of triggers). The passed-in slot can be used to hold the tuple to be returned.

The data in the returned slot is used only if the DELETE query has a RETURNING clause or the foreign table has an AFTER ROW trigger. Triggers require all columns, but the FDW could choose to optimize away returning some or all columns depending on the contents of the RETURNING clause. Regardless, some slot must be returned to indicate success, or the query's reported row count will be wrong.

If the ExecForeignDelete pointer is set to NULL, attempts to delete from the foreign table will fail with an error message.

```
void
EndForeignModify(EState *estate,
                 ResultRelInfo *rinfo);
```

End the table update and release resources. It is normally not important to release palloc'd memory, but for example open files and connections to remote servers should be cleaned up.

If the EndForeignModify pointer is set to NULL, no action is taken during executor shutdown.

Tuples inserted into a partitioned table by INSERT or COPY FROM are routed to partitions. If an FDW supports routable foreign-table partitions, it should also provide the following callback functions. These functions are also called when COPY FROM is executed on a foreign table.

```
void
BeginForeignInsert(ModifyTableState *mtstate,
                   ResultRelInfo *rinfo);
```

Begin executing an insert operation on a foreign table. This routine is called right before the first tuple is inserted into the foreign table in both cases when it is the partition chosen for tuple routing and the target specified in a COPY FROM command. It should perform any initialization needed prior to the actual insertion. Subsequently, ExecForeignInsert or ExecForeignBatchInsert will be called for tuple(s) to be inserted into the foreign table.

mtstate is the overall state of the ModifyTable plan node being executed; global data about the plan and execution state is available via this structure. rinfo is the ResultRelInfo struct describing the target foreign table. (The ri_FdwState field of ResultRelInfo is available for the FDW to store any private state it needs for this operation.)

When this is called by a COPY FROM command, the plan-related global data in mtstate is not provided and the planSlot parameter of ExecForeignInsert subsequently called for each inserted tuple is NULL, whether the foreign table is the partition chosen for tuple routing or the target specified in the command.

If the BeginForeignInsert pointer is set to NULL, no action is taken for the initialization.

Note that if the FDW does not support routable foreign-table partitions and/or executing COPY FROM on foreign tables, this function or ExecForeignInsert/ExecForeignBatchInsert subsequently called must throw error as needed.

```
void
EndForeignInsert(EState *estate,
                 ResultRelInfo *rinfo);
```

End the insert operation and release resources. It is normally not important to release palloc'd memory, but for example open files and connections to remote servers should be cleaned up.

If the EndForeignInsert pointer is set to NULL, no action is taken for the termination.

```
int
IsForeignRelUpdatable(Relation rel);
```

Report which update operations the specified foreign table supports. The return value should be a bit mask of rule event numbers indicating which operations are supported by the foreign table, using the CmdType enumeration; that is, (1 << CMD_UPDATE) = 4 for UPDATE, (1 << CMD_INSERT) = 8 for INSERT, and (1 << CMD_DELETE) = 16 for DELETE.

If the IsForeignRelUpdatable pointer is set to NULL, foreign tables are assumed to be insertable, updatable, or deletable if the FDW provides ExecForeignInsert, ExecForeignUpdate, or ExecForeignDelete respectively. This function is only needed if the FDW supports some tables that are updatable and some that are not. (Even then, it's permissible to throw an error in the execution routine instead

of checking in this function. However, this function is used to determine updatability for display in the information_schema views.)

Some inserts, updates, and deletes to foreign tables can be optimized by implementing an alternative set of interfaces. The ordinary interfaces for inserts, updates, and deletes fetch rows from the remote server and then modify those rows one at a time. In some cases, this row-by-row approach is necessary, but it can be inefficient. If it is possible for the foreign server to determine which rows should be modified without actually retrieving them, and if there are no local structures which would affect the operation (row-level local triggers, stored generated columns, or WITH CHECK OPTION constraints from parent views), then it is possible to arrange things so that the entire operation is performed on the remote server. The interfaces described below make this possible.

```
bool
PlanDirectModify(PlannerInfo *root,
                 ModifyTable *plan,
                 Index resultRelation,
                 int subplan_index);
```

Decide whether it is safe to execute a direct modification on the remote server. If so, return true after performing planning actions needed for that. Otherwise, return false. This optional function is called during query planning. If this function succeeds, BeginDirectModify, IterateDirectModify and EndDirectModify will be called at the execution stage, instead. Otherwise, the table modification will be executed using the table-updating functions described above. The parameters are the same as for PlanForeignModify.

To execute the direct modification on the remote server, this function must rewrite the target subplan with a ForeignScan plan node that executes the direct modification on the remote server. The operation and resultRelation fields of the ForeignScan must be set appropriately. operation must be set to the CmdType enumeration corresponding to the statement kind (that is, CMD_UPDATE for UPDATE, CMD_INSERT for INSERT, and CMD_DELETE for DELETE), and the resultRelation argument must be copied to the resultRelation field.

See Section 57.4 for additional information.

If the PlanDirectModify pointer is set to NULL, no attempts to execute a direct modification on the remote server are taken.

```
void
BeginDirectModify(ForeignScanState *node,
                  int eflags);
```

Prepare to execute a direct modification on the remote server. This is called during executor startup. It should perform any initialization needed prior to the direct modification (that should be done upon the first call to IterateDirectModify). The ForeignScanState node has already been created, but its fdw_state field is still NULL. Information about the table to modify is accessible through the ForeignScanState node (in particular, from the underlying ForeignScan plan node, which contains any FDW-private information provided by PlanDirectModify). eflags contains flag bits describing the executor's operating mode for this plan node.

Note that when (eflags & EXEC_FLAG_EXPLAIN_ONLY) is true, this function should not perform any externally-visible actions; it should only do the minimum required to make the node state valid for ExplainDirectModify and EndDirectModify.

If the BeginDirectModify pointer is set to NULL, no attempts to execute a direct modification on the remote server are taken.

```
TupleTableSlot *
IterateDirectModify(ForeignScanState *node);
```

When the INSERT, UPDATE or DELETE query doesn't have a RETURNING clause, just return NULL after a direct modification on the remote server. When the query has the clause, fetch one result containing the

data needed for the RETURNING calculation, returning it in a tuple table slot (the node's ScanTupleSlot should be used for this purpose). The data that was actually inserted, updated or deleted must be stored in node->resultRelInfo->ri_projectReturning->pi_exprContext->ecxt_scantuple. Return NULL if no more rows are available. Note that this is called in a short-lived memory context that will be reset between invocations. Create a memory context in BeginDirectModify if you need longer-lived storage, or use the es_query_cxt of the node's EState.

The rows returned must match the fdw_scan_tlist target list if one was supplied, otherwise they must match the row type of the foreign table being updated. If you choose to optimize away fetching columns that are not needed for the RETURNING calculation, you should insert nulls in those column positions, or else generate a fdw_scan_tlist list with those columns omitted.

Whether the query has the clause or not, the query's reported row count must be incremented by the FDW itself. When the query doesn't have the clause, the FDW must also increment the row count for the ForeignScanState node in the EXPLAIN ANALYZE case.

If the IterateDirectModify pointer is set to NULL, no attempts to execute a direct modification on the remote server are taken.

```
void
EndDirectModify(ForeignScanState *node);
```

Clean up following a direct modification on the remote server. It is normally not important to release palloc'd memory, but for example open files and connections to the remote server should be cleaned up.

If the EndDirectModify pointer is set to NULL, no attempts to execute a direct modification on the remote server are taken.

57.2.5. FDW Routines for TRUNCATE

```
void
ExecForeignTruncate(List *rels,
                    DropBehavior behavior,
                    bool restart_seqs);
```

Truncate foreign tables. This function is called when TRUNCATE is executed on a foreign table. rels is a list of Relation data structures of foreign tables to truncate.

behavior is either DROP_RESTRICT or DROP_CASCADE indicating that the RESTRICT or CASCADE option was requested in the original TRUNCATE command, respectively.

If restart_seqs is true, the original TRUNCATE command requested the RESTART IDENTITY behavior, otherwise the CONTINUE IDENTITY behavior was requested.

Note that the ONLY options specified in the original TRUNCATE command are not passed to ExecForeign-Truncate. This behavior is similar to the callback functions of SELECT, UPDATE and DELETE on a foreign table.

ExecForeignTruncate is invoked once per foreign server for which foreign tables are to be truncated. This means that all foreign tables included in rels must belong to the same server.

If the ExecForeignTruncate pointer is set to NULL, attempts to truncate foreign tables will fail with an error message.

57.2.6. FDW Routines for Row Locking

If an FDW wishes to support *late row locking* (as described in Section 57.5), it must provide the following callback functions:

```
RowMarkType
GetForeignRowMarkType(RangeTblEntry *rte,
```

```
                                LockClauseStrength strength);
```

Report which row-marking option to use for a foreign table. `rte` is the `RangeTblEntry` node for the table and `strength` describes the lock strength requested by the relevant `FOR UPDATE/SHARE` clause, if any. The result must be a member of the `RowMarkType` enum type.

This function is called during query planning for each foreign table that appears in an `UPDATE`, `DELETE`, or `SELECT FOR UPDATE/SHARE` query and is not the target of `UPDATE` or `DELETE`.

If the `GetForeignRowMarkType` pointer is set to `NULL`, the `ROW_MARK_COPY` option is always used. (This implies that `RefetchForeignRow` will never be called, so it need not be provided either.)

See Section 57.5 for more information.

```
void
RefetchForeignRow(EState *estate,
                  ExecRowMark *erm,
                  Datum rowid,
                  TupleTableSlot *slot,
                  bool *updated);
```

Re-fetch one tuple slot from the foreign table, after locking it if required. `estate` is global execution state for the query. `erm` is the `ExecRowMark` struct describing the target foreign table and the row lock type (if any) to acquire. `rowid` identifies the tuple to be fetched. `slot` contains nothing useful upon call, but can be used to hold the returned tuple. `updated` is an output parameter.

This function should store the tuple into the provided slot, or clear it if the row lock couldn't be obtained. The row lock type to acquire is defined by `erm->markType`, which is the value previously returned by `GetForeignRowMarkType`. (`ROW_MARK_REFERENCE` means to just re-fetch the tuple without acquiring any lock, and `ROW_MARK_COPY` will never be seen by this routine.)

In addition, `*updated` should be set to `true` if what was fetched was an updated version of the tuple rather than the same version previously obtained. (If the FDW cannot be sure about this, always returning `true` is recommended.)

Note that by default, failure to acquire a row lock should result in raising an error; returning with an empty slot is only appropriate if the `SKIP LOCKED` option is specified by `erm->waitPolicy`.

The `rowid` is the `ctid` value previously read for the row to be re-fetched. Although the `rowid` value is passed as a `Datum`, it can currently only be a `tid`. The function API is chosen in hopes that it may be possible to allow other data types for row IDs in future.

If the `RefetchForeignRow` pointer is set to `NULL`, attempts to re-fetch rows will fail with an error message.

See Section 57.5 for more information.

```
bool
RecheckForeignScan(ForeignScanState *node,
                   TupleTableSlot *slot);
```

Recheck that a previously-returned tuple still matches the relevant scan and join qualifiers, and possibly provide a modified version of the tuple. For foreign data wrappers which do not perform join pushdown, it will typically be more convenient to set this to `NULL` and instead set `fdw_recheck_quals` appropriately. When outer joins are pushed down, however, it isn't sufficient to reapply the checks relevant to all the base tables to the result tuple, even if all needed attributes are present, because failure to match some qualifier might result in some attributes going to NULL, rather than in no tuple being returned. `RecheckForeignScan` can recheck qualifiers and return true if they are still satisfied and false otherwise, but it can also store a replacement tuple into the supplied slot.

To implement join pushdown, a foreign data wrapper will typically construct an alternative local join plan which is used only for rechecks; this will become the outer subplan of the `ForeignScan`. When a recheck

is required, this subplan can be executed and the resulting tuple can be stored in the slot. This plan need not be efficient since no base table will return more than one row; for example, it may implement all joins as nested loops. The function `GetExistingLocalJoinPath` may be used to search existing paths for a suitable local join path, which can be used as the alternative local join plan. `GetExistingLocalJoinPath` searches for an unparameterized path in the path list of the specified join relation. (If it does not find such a path, it returns NULL, in which case a foreign data wrapper may build the local path by itself or may choose not to create access paths for that join.)

57.2.7. FDW Routines for `EXPLAIN`

```
void
ExplainForeignScan(ForeignScanState *node,
                   ExplainState *es);
```

Print additional `EXPLAIN` output for a foreign table scan. This function can call `ExplainPropertyText` and related functions to add fields to the `EXPLAIN` output. The flag fields in `es` can be used to determine what to print, and the state of the `ForeignScanState` node can be inspected to provide run-time statistics in the `EXPLAIN ANALYZE` case.

If the `ExplainForeignScan` pointer is set to `NULL`, no additional information is printed during `EXPLAIN`.

```
void
ExplainForeignModify(ModifyTableState *mtstate,
                     ResultRelInfo *rinfo,
                     List *fdw_private,
                     int subplan_index,
                     struct ExplainState *es);
```

Print additional `EXPLAIN` output for a foreign table update. This function can call `ExplainPropertyText` and related functions to add fields to the `EXPLAIN` output. The flag fields in `es` can be used to determine what to print, and the state of the `ModifyTableState` node can be inspected to provide run-time statistics in the `EXPLAIN ANALYZE` case. The first four arguments are the same as for `BeginForeignModify`.

If the `ExplainForeignModify` pointer is set to `NULL`, no additional information is printed during `EXPLAIN`.

```
void
ExplainDirectModify(ForeignScanState *node,
                    ExplainState *es);
```

Print additional `EXPLAIN` output for a direct modification on the remote server. This function can call `ExplainPropertyText` and related functions to add fields to the `EXPLAIN` output. The flag fields in `es` can be used to determine what to print, and the state of the `ForeignScanState` node can be inspected to provide run-time statistics in the `EXPLAIN ANALYZE` case.

If the `ExplainDirectModify` pointer is set to `NULL`, no additional information is printed during `EXPLAIN`.

57.2.8. FDW Routines for `ANALYZE`

```
bool
AnalyzeForeignTable(Relation relation,
                    AcquireSampleRowsFunc *func,
                    BlockNumber *totalpages);
```

This function is called when ANALYZE is executed on a foreign table. If the FDW can collect statistics for this foreign table, it should return `true`, and provide a pointer to a function that will collect sample rows from the table in *`func`*, plus the estimated size of the table in pages in *`totalpages`*. Otherwise, return `false`.

If the FDW does not support collecting statistics for any tables, the `AnalyzeForeignTable` pointer can be set to `NULL`.

If provided, the sample collection function must have the signature

```
int
AcquireSampleRowsFunc(Relation relation,
                      int elevel,
                      HeapTuple *rows,
                      int targrows,
                      double *totalrows,
                      double *totaldeadrows);
```

A random sample of up to *targrows* rows should be collected from the table and stored into the caller-provided *rows* array. The actual number of rows collected must be returned. In addition, store estimates of the total numbers of live and dead rows in the table into the output parameters *totalrows* and *totaldeadrows*. (Set *totaldeadrows* to zero if the FDW does not have any concept of dead rows.)

57.2.9. FDW Routines for `IMPORT FOREIGN SCHEMA`

```
List *
ImportForeignSchema(ImportForeignSchemaStmt *stmt, Oid serverOid);
```

Obtain a list of foreign table creation commands. This function is called when executing IMPORT FOREIGN SCHEMA, and is passed the parse tree for that statement, as well as the OID of the foreign server to use. It should return a list of C strings, each of which must contain a CREATE FOREIGN TABLE command. These strings will be parsed and executed by the core server.

Within the `ImportForeignSchemaStmt` struct, `remote_schema` is the name of the remote schema from which tables are to be imported. `list_type` identifies how to filter table names: `FDW_IMPORT_SCHEMA_ALL` means that all tables in the remote schema should be imported (in this case `table_list` is empty), `FDW_IMPORT_SCHEMA_LIMIT_TO` means to include only tables listed in `table_list`, and `FDW_IMPORT_SCHEMA_EXCEPT` means to exclude the tables listed in `table_list`. `options` is a list of options used for the import process. The meanings of the options are up to the FDW. For example, an FDW could use an option to define whether the `NOT NULL` attributes of columns should be imported. These options need not have anything to do with those supported by the FDW as database object options.

The FDW may ignore the `local_schema` field of the `ImportForeignSchemaStmt`, because the core server will automatically insert that name into the parsed `CREATE FOREIGN TABLE` commands.

The FDW does not have to concern itself with implementing the filtering specified by `list_type` and `table_list`, either, as the core server will automatically skip any returned commands for tables excluded according to those options. However, it's often useful to avoid the work of creating commands for excluded tables in the first place. The function `IsImportableForeignTable()` may be useful to test whether a given foreign-table name will pass the filter.

If the FDW does not support importing table definitions, the `ImportForeignSchema` pointer can be set to `NULL`.

57.2.10. FDW Routines for Parallel Execution

A `ForeignScan` node can, optionally, support parallel execution. A parallel `ForeignScan` will be executed in multiple processes and must return each row exactly once across all cooperating processes. To do this, processes can coordinate through fixed-size chunks of dynamic shared memory. This shared memory is not guaranteed to be mapped at the same address in every process, so it must not contain pointers. The following functions are all optional, but most are required if parallel execution is to be supported.

```
bool
IsForeignScanParallelSafe(PlannerInfo *root, RelOptInfo *rel,
                          RangeTblEntry *rte);
```

Test whether a scan can be performed within a parallel worker. This function will only be called when the planner believes that a parallel plan might be possible, and should return true if it is safe for that scan to run within a parallel worker. This will generally not be the case if the remote data source has transaction semantics, unless the worker's connection to the data can somehow be made to share the same transaction context as the leader.

If this function is not defined, it is assumed that the scan must take place within the parallel leader. Note that returning true does not mean that the scan itself can be done in parallel, only that the scan can be performed within a parallel worker. Therefore, it can be useful to define this method even when parallel execution is not supported.

```
Size
EstimateDSMForeignScan(ForeignScanState *node, ParallelContext *pcxt);
```

Estimate the amount of dynamic shared memory that will be required for parallel operation. This may be higher than the amount that will actually be used, but it must not be lower. The return value is in bytes. This function is optional, and can be omitted if not needed; but if it is omitted, the next three functions must be omitted as well, because no shared memory will be allocated for the FDW's use.

```
void
InitializeDSMForeignScan(ForeignScanState *node, ParallelContext *pcxt,
                         void *coordinate);
```

Initialize the dynamic shared memory that will be required for parallel operation. `coordinate` points to a shared memory area of size equal to the return value of `EstimateDSMForeignScan`. This function is optional, and can be omitted if not needed.

```
void
ReInitializeDSMForeignScan(ForeignScanState *node, ParallelContext *pcxt,
                           void *coordinate);
```

Re-initialize the dynamic shared memory required for parallel operation when the foreign-scan plan node is about to be re-scanned. This function is optional, and can be omitted if not needed. Recommended practice is that this function reset only shared state, while the `ReScanForeignScan` function resets only local state. Currently, this function will be called before `ReScanForeignScan`, but it's best not to rely on that ordering.

```
void
InitializeWorkerForeignScan(ForeignScanState *node, shm_toc *toc,
                            void *coordinate);
```

Initialize a parallel worker's local state based on the shared state set up by the leader during `InitializeDSMForeignScan`. This function is optional, and can be omitted if not needed.

```
void
ShutdownForeignScan(ForeignScanState *node);
```

Release resources when it is anticipated the node will not be executed to completion. This is not called in all cases; sometimes, `EndForeignScan` may be called without this function having been called first. Since the DSM segment used by parallel query is destroyed just after this callback is invoked, foreign data wrappers that wish to take some action before the DSM segment goes away should implement this method.

57.2.11. FDW Routines for Asynchronous Execution

A `ForeignScan` node can, optionally, support asynchronous execution. The following functions are all optional, but are all required if asynchronous execution is to be supported.

```
bool
IsForeignPathAsyncCapable(ForeignPath *path);
```

Test whether a given `ForeignPath` path can scan the underlying foreign relation asynchronously. This function will only be called at the end of query planning when the given path is a direct child of an `AppendPath` path and when the planner believes that asynchronous execution improves performance, and should return true if the given path is able to scan the foreign relation asynchronously.

If this function is not defined, it is assumed that the given path scans the foreign relation using `IterateForeignScan`. (This implies that the callback functions described below will never be called, so they need not be provided either.)

```
void
ForeignAsyncRequest(AsyncRequest *areq);
```

Produce one tuple asynchronously from the `ForeignScan` node. `areq` is the `AsyncRequest` struct describing the `ForeignScan` node and the parent `Append` node that requested the tuple from it. This function should store the tuple into the slot specified by `areq->result`, and set `areq->request_complete` to `true`; or if it needs to wait on an event external to the core server such as network I/O, and cannot produce any tuple immediately, set the flag to `false`, and set `areq->callback_pending` to `true` for the `ForeignScan` node to get a callback from the callback functions described below. If no more tuples are available, set the slot to NULL or an empty slot, and the `areq->request_complete` flag to `true`. It's recommended to use `ExecAsyncRequestDone` or `ExecAsyncRequestPending` to set the output parameters in the `areq`.

```
void
ForeignAsyncConfigureWait(AsyncRequest *areq);
```

Configure a file descriptor event for which the `ForeignScan` node wishes to wait. This function will only be called when the `ForeignScan` node has the `areq->callback_pending` flag set, and should add the event to the `as_eventset` of the parent `Append` node described by the `areq`. When the file descriptor event occurs, `ForeignAsyncNotify` will be called.

```
void
ForeignAsyncNotify(AsyncRequest *areq);
```

Process a relevant event that has occurred, then produce one tuple asynchronously from the `ForeignScan` node. This function should set the output parameters in the `areq` in the same way as `ForeignAsyncRequest`.

57.2.12. FDW Routines for Reparameterization of Paths

```
List *
ReparameterizeForeignPathByChild(PlannerInfo *root, List *fdw_private,
                                 RelOptInfo *child_rel);
```

This function is called while converting a path parameterized by the top-most parent of the given child relation `child_rel` to be parameterized by the child relation. The function is used to reparameterize any paths or translate any expression nodes saved in the given `fdw_private` member of a `ForeignPath`. The callback may use `reparameterize_path_by_child`, `adjust_appendrel_attrs` or `adjust_appendrel_attrs_multilevel` as required.

57.3. Foreign Data Wrapper Helper Functions

Several helper functions are exported from the core server so that authors of foreign data wrappers can get easy access to attributes of FDW-related objects, such as FDW options. To use any of these functions, you need to include the header file *foreign/foreign.h* in your source file. That header also defines the struct types that are returned by these functions.

```
ForeignDataWrapper *
GetForeignDataWrapperExtended(Oid fdwid, bits16 flags);
```

This function returns a `ForeignDataWrapper` object for the foreign-data wrapper with the given OID. A `ForeignDataWrapper` object contains properties of the FDW (see `foreign/foreign.h` for details). `flags` is a bitwise-or'd bit mask indicating an extra set of options. It can take the value `FDW_MISSING_OK`, in which case a `NULL` result is returned to the caller instead of an error for an undefined object.

```
ForeignDataWrapper *
GetForeignDataWrapper(Oid fdwid);
```

This function returns a `ForeignDataWrapper` object for the foreign-data wrapper with the given OID. A `ForeignDataWrapper` object contains properties of the FDW (see `foreign/foreign.h` for details).

```
ForeignServer *
GetForeignServerExtended(Oid serverid, bits16 flags);
```

This function returns a `ForeignServer` object for the foreign server with the given OID. A `ForeignServer` object contains properties of the server (see `foreign/foreign.h` for details). `flags` is a bitwise-or'd bit mask indicating an extra set of options. It can take the value `FSV_MISSING_OK`, in which case a `NULL` result is returned to the caller instead of an error for an undefined object.

```
ForeignServer *
GetForeignServer(Oid serverid);
```

This function returns a `ForeignServer` object for the foreign server with the given OID. A `ForeignServer` object contains properties of the server (see `foreign/foreign.h` for details).

```
UserMapping *
GetUserMapping(Oid userid, Oid serverid);
```

This function returns a `UserMapping` object for the user mapping of the given role on the given server. (If there is no mapping for the specific user, it will return the mapping for `PUBLIC`, or throw error if there is none.) A `UserMapping` object contains properties of the user mapping (see `foreign/foreign.h` for details).

```
ForeignTable *
GetForeignTable(Oid relid);
```

This function returns a `ForeignTable` object for the foreign table with the given OID. A `ForeignTable` object contains properties of the foreign table (see `foreign/foreign.h` for details).

```
List *
GetForeignColumnOptions(Oid relid, AttrNumber attnum);
```

This function returns the per-column FDW options for the column with the given foreign table OID and attribute number, in the form of a list of `DefElem`. NIL is returned if the column has no options.

Some object types have name-based lookup functions in addition to the OID-based ones:

```
ForeignDataWrapper *
GetForeignDataWrapperByName(const char *name, bool missing_ok);
```

This function returns a `ForeignDataWrapper` object for the foreign-data wrapper with the given name. If the wrapper is not found, return NULL if missing_ok is true, otherwise raise an error.

```
ForeignServer *
GetForeignServerByName(const char *name, bool missing_ok);
```

This function returns a `ForeignServer` object for the foreign server with the given name. If the server is not found, return NULL if missing_ok is true, otherwise raise an error.

57.4. Foreign Data Wrapper Query Planning

The FDW callback functions `GetForeignRelSize`, `GetForeignPaths`, `GetForeignPlan`, `PlanForeignModify`, `GetForeignJoinPaths`, `GetForeignUpperPaths`, and `PlanDirectModify` must fit into the workings of the Postgres Pro planner. Here are some notes about what they must do.

The information in `root` and `baserel` can be used to reduce the amount of information that has to be fetched from the foreign table (and therefore reduce the cost). `baserel->baserestrictinfo` is particularly interesting, as it contains restriction quals (`WHERE` clauses) that should be used to filter the rows to be fetched. (The FDW itself is not required to enforce these quals, as the core executor can check them instead.) `baserel->reltarget->exprs` can be used to determine which columns need to be fetched; but note that it only lists columns that have to be emitted by the `ForeignScan` plan node, not columns that are used in qual evaluation but not output by the query.

Various private fields are available for the FDW planning functions to keep information in. Generally, whatever you store in FDW private fields should be palloc'd, so that it will be reclaimed at the end of planning.

`baserel->fdw_private` is a `void` pointer that is available for FDW planning functions to store information relevant to the particular foreign table. The core planner does not touch it except to initialize it to NULL when the `RelOptInfo` node is created. It is useful for passing information forward from `GetForeignRelSize` to `GetForeignPaths` and/or `GetForeignPaths` to `GetForeignPlan`, thereby avoiding recalculation.

`GetForeignPaths` can identify the meaning of different access paths by storing private information in the `fdw_private` field of `ForeignPath` nodes. `fdw_private` is declared as a `List` pointer, but could actually contain anything since the core planner does not touch it. However, best practice is to use a representation that's dumpable by `nodeToString`, for use with debugging support available in the backend.

`GetForeignPlan` can examine the `fdw_private` field of the selected `ForeignPath` node, and can generate `fdw_exprs` and `fdw_private` lists to be placed in the `ForeignScan` plan node, where they will be available at execution time. Both of these lists must be represented in a form that `copyObject` knows how to copy. The `fdw_private` list has no other restrictions and is not interpreted by the core backend in any way. The `fdw_exprs` list, if not NIL, is expected to contain expression trees that are intended to be executed at run time. These trees will undergo post-processing by the planner to make them fully executable.

In `GetForeignPlan`, generally the passed-in target list can be copied into the plan node as-is. The passed `scan_clauses` list contains the same clauses as `baserel->baserestrictinfo`, but may be re-ordered for better execution efficiency. In simple cases the FDW can just strip `RestrictInfo` nodes from the `scan_clauses` list (using `extract_actual_clauses`) and put all the clauses into the plan node's qual list, which means that all the clauses will be checked by the executor at run time. More complex FDWs may be able to check some of the clauses internally, in which case those clauses can be removed from the plan node's qual list so that the executor doesn't waste time rechecking them.

As an example, the FDW might identify some restriction clauses of the form *`foreign_variable = sub_expression`*, which it determines can be executed on the remote server given the locally-evaluated value of the *`sub_expression`*. The actual identification of such a clause should happen during `GetForeignPaths`, since it would affect the cost estimate for the path. The path's `fdw_private` field would probably include a pointer to the identified clause's `RestrictInfo` node. Then `GetForeignPlan` would remove that clause from `scan_clauses`, but add the *`sub_expression`* to `fdw_exprs` to ensure that it gets massaged into executable form. It would probably also put control information into the plan node's `fdw_private` field to tell the execution functions what to do at run time. The query transmitted to the remote server would involve something like `WHERE` *`foreign_variable`* `= $1`, with the parameter value obtained at run time from evaluation of the `fdw_exprs` expression tree.

Any clauses removed from the plan node's qual list must instead be added to `fdw_recheck_quals` or rechecked by `RecheckForeignScan` in order to ensure correct behavior at the `READ COMMITTED` isolation level. When a concurrent update occurs for some other table involved in the query, the executor may need to verify that all of the original quals are still satisfied for the tuple, possibly against a different set of parameter values. Using `fdw_recheck_quals` is typically easier than implementing checks inside `RecheckForeignScan`, but this method will be insufficient when outer joins have been pushed down, since the join tuples in that case might have some fields go to NULL without rejecting the tuple entirely.

Another `ForeignScan` field that can be filled by FDWs is `fdw_scan_tlist`, which describes the tuples returned by the FDW for this plan node. For simple foreign table scans this can be set to `NIL`, implying that the returned tuples have the row type declared for the foreign table. A non-`NIL` value must be a target list (list of `TargetEntry`s) containing Vars and/or expressions representing the returned columns. This might be used, for example, to show that the FDW has omitted some columns that it noticed won't be needed for the query. Also, if the FDW can compute expressions used by the query more cheaply than can be done locally, it could add those expressions to `fdw_scan_tlist`. Note that join plans (created from paths made by `GetForeignJoinPaths`) must always supply `fdw_scan_tlist` to describe the set of columns they will return.

The FDW should always construct at least one path that depends only on the table's restriction clauses. In join queries, it might also choose to construct path(s) that depend on join clauses, for example *`foreign_variable = local_variable`*. Such clauses will not be found in `baserel->baserestrictinfo` but

must be sought in the relation's join lists. A path using such a clause is called a “parameterized path”. It must identify the other relations used in the selected join clause(s) with a suitable value of `param_info`; use `get_baserel_parampathinfo` to compute that value. In `GetForeignPlan`, the *`local_variable`* portion of the join clause would be added to `fdw_exprs`, and then at run time the case works the same as for an ordinary restriction clause.

If an FDW supports remote joins, `GetForeignJoinPaths` should produce `ForeignPath`s for potential remote joins in much the same way as `GetForeignPaths` works for base tables. Information about the intended join can be passed forward to `GetForeignPlan` in the same ways described above. However, `baserestrictinfo` is not relevant for join relations; instead, the relevant join clauses for a particular join are passed to `GetForeignJoinPaths` as a separate parameter (`extra->restrictlist`).

An FDW might additionally support direct execution of some plan actions that are above the level of scans and joins, such as grouping or aggregation. To offer such options, the FDW should generate paths and insert them into the appropriate *upper relation*. For example, a path representing remote aggregation should be inserted into the `UPPERREL_GROUP_AGG` relation, using `add_path`. This path will be compared on a cost basis with local aggregation performed by reading a simple scan path for the foreign relation (note that such a path must also be supplied, else there will be an error at plan time). If the remote-aggregation path wins, which it usually would, it will be converted into a plan in the usual way, by calling `GetForeignPlan`. The recommended place to generate such paths is in the `GetForeignUpperPaths` callback function, which is called for each upper relation (i.e., each post-scan/join processing step), if all the base relations of the query come from the same FDW.

`PlanForeignModify` and the other callbacks described in Section 57.2.4 are designed around the assumption that the foreign relation will be scanned in the usual way and then individual row updates will be driven by a local `ModifyTable` plan node. This approach is necessary for the general case where an update requires reading local tables as well as foreign tables. However, if the operation could be executed entirely by the foreign server, the FDW could generate a path representing that and insert it into the `UPPERREL_FINAL` upper relation, where it would compete against the `ModifyTable` approach. This approach could also be used to implement remote `SELECT FOR UPDATE`, rather than using the row locking callbacks described in Section 57.2.6. Keep in mind that a path inserted into `UPPERREL_FINAL` is responsible for implementing *all* behavior of the query.

When planning an `UPDATE` or `DELETE`, `PlanForeignModify` and `PlanDirectModify` can look up the `RelOptInfo` struct for the foreign table and make use of the `baserel->fdw_private` data previously created by the scan-planning functions. However, in `INSERT` the target table is not scanned so there is no `RelOptInfo` for it. The `List` returned by `PlanForeignModify` has the same restrictions as the `fdw_private` list of a `ForeignScan` plan node, that is it must contain only structures that `copyObject` knows how to copy.

`INSERT` with an `ON CONFLICT` clause does not support specifying the conflict target, as unique constraints or exclusion constraints on remote tables are not locally known. This in turn implies that `ON CONFLICT DO UPDATE` is not supported, since the specification is mandatory there.

57.5. Row Locking in Foreign Data Wrappers

If an FDW's underlying storage mechanism has a concept of locking individual rows to prevent concurrent updates of those rows, it is usually worthwhile for the FDW to perform row-level locking with as close an approximation as practical to the semantics used in ordinary Postgres Pro tables. There are multiple considerations involved in this.

One key decision to be made is whether to perform *early locking* or *late locking*. In early locking, a row is locked when it is first retrieved from the underlying store, while in late locking, the row is locked only when it is known that it needs to be locked. (The difference arises because some rows may be discarded by locally-checked restriction or join conditions.) Early locking is much simpler and avoids extra round trips to a remote store, but it can cause locking of rows that need not have been locked, resulting in reduced concurrency or even unexpected deadlocks. Also, late locking is only possible if the row to be locked can be uniquely re-identified later. Preferably the row identifier should identify a specific version of the row, as Postgres Pro TIDs do.

By default, Postgres Pro ignores locking considerations when interfacing to FDWs, but an FDW can perform early locking without any explicit support from the core code. The API functions described in Section 57.2.6, which were added in Postgres Pro 9.5, allow an FDW to use late locking if it wishes.

An additional consideration is that in `READ COMMITTED` isolation mode, Postgres Pro may need to re-check restriction and join conditions against an updated version of some target tuple. Rechecking join conditions requires re-obtaining copies of the non-target rows that were previously joined to the target tuple. When working with standard Postgres Pro tables, this is done by including the TIDs of the non-target tables in the column list projected through the join, and then re-fetching non-target rows when required. This approach keeps the join data set compact, but it requires inexpensive re-fetch capability, as well as a TID that can uniquely identify the row version to be re-fetched. By default, therefore, the approach used with foreign tables is to include a copy of the entire row fetched from a foreign table in the column list projected through the join. This puts no special demands on the FDW but can result in reduced performance of merge and hash joins. An FDW that is capable of meeting the re-fetch requirements can choose to do it the first way.

For an `UPDATE` or `DELETE` on a foreign table, it is recommended that the `ForeignScan` operation on the target table perform early locking on the rows that it fetches, perhaps via the equivalent of `SELECT FOR UPDATE`. An FDW can detect whether a table is an `UPDATE`/`DELETE` target at plan time by comparing its relid to `root->parse->resultRelation`, or at execution time by using `ExecRelationIsTargetRelation()`. An alternative possibility is to perform late locking within the `ExecForeignUpdate` or `ExecForeignDelete` callback, but no special support is provided for this.

For foreign tables that are specified to be locked by a `SELECT FOR UPDATE/SHARE` command, the `ForeignScan` operation can again perform early locking by fetching tuples with the equivalent of `SELECT FOR UPDATE/SHARE`. To perform late locking instead, provide the callback functions defined in Section 57.2.6. In `GetForeignRowMarkType`, select rowmark option `ROW_MARK_EXCLUSIVE`, `ROW_MARK_NOKEYEXCLUSIVE`, `ROW_MARK_SHARE`, or `ROW_MARK_KEYSHARE` depending on the requested lock strength. (The core code will act the same regardless of which of these four options you choose.) Elsewhere, you can detect whether a foreign table was specified to be locked by this type of command by using `get_plan_rowmark` at plan time, or `ExecFindRowMark` at execution time; you must check not only whether a non-null rowmark struct is returned, but that its `strength` field is not `LCS_NONE`.

Lastly, for foreign tables that are used in an `UPDATE`, `DELETE` or `SELECT FOR UPDATE/SHARE` command but are not specified to be row-locked, you can override the default choice to copy entire rows by having `GetForeignRowMarkType` select option `ROW_MARK_REFERENCE` when it sees lock strength `LCS_NONE`. This will cause `RefetchForeignRow` to be called with that value for `markType`; it should then re-fetch the row without acquiring any new lock. (If you have a `GetForeignRowMarkType` function but don't wish to re-fetch unlocked rows, select option `ROW_MARK_COPY` for `LCS_NONE`.)

Chapter 58. Writing a Table Sampling Method

Postgres Pro's implementation of the `TABLESAMPLE` clause supports custom table sampling methods, in addition to the `BERNOULLI` and `SYSTEM` methods that are required by the SQL standard. The sampling method determines which rows of the table will be selected when the `TABLESAMPLE` clause is used.

At the SQL level, a table sampling method is represented by a single SQL function, typically implemented in C, having the signature

```
method_name(internal) RETURNS tsm_handler
```

The name of the function is the same method name appearing in the `TABLESAMPLE` clause. The `internal` argument is a dummy (always having value zero) that simply serves to prevent this function from being called directly from an SQL command. The result of the function must be a palloc'd struct of type `TsmRoutine`, which contains pointers to support functions for the sampling method. These support functions are plain C functions and are not visible or callable at the SQL level. The support functions are described in Section 58.1.

In addition to function pointers, the `TsmRoutine` struct must provide these additional fields:

`List *parameterTypes`

This is an OID list containing the data type OIDs of the parameter(s) that will be accepted by the `TABLESAMPLE` clause when this sampling method is used. For example, for the built-in methods, this list contains a single item with value `FLOAT4OID`, which represents the sampling percentage. Custom sampling methods can have more or different parameters.

`bool repeatable_across_queries`

If `true`, the sampling method can deliver identical samples across successive queries, if the same parameters and `REPEATABLE` seed value are supplied each time and the table contents have not changed. When this is `false`, the `REPEATABLE` clause is not accepted for use with the sampling method.

`bool repeatable_across_scans`

If `true`, the sampling method can deliver identical samples across successive scans in the same query (assuming unchanging parameters, seed value, and snapshot). When this is `false`, the planner will not select plans that would require scanning the sampled table more than once, since that might result in inconsistent query output.

The table sampling methods included in the standard distribution are good references when trying to write your own. Look into the `contrib` subdirectory for add-on methods.

58.1. Sampling Method Support Functions

The TSM handler function returns a palloc'd `TsmRoutine` struct containing pointers to the support functions described below. Most of the functions are required, but some are optional, and those pointers can be NULL.

```
void
SampleScanGetSampleSize (PlannerInfo *root,
                         RelOptInfo *baserel,
                         List *paramexprs,
                         BlockNumber *pages,
                         double *tuples);
```

This function is called during planning. It must estimate the number of relation pages that will be read during a sample scan, and the number of tuples that will be selected by the scan. (For example, these

might be determined by estimating the sampling fraction, and then multiplying the baserel->pages and baserel->tuples numbers by that, being sure to round the results to integral values.) The paramexprs list holds the expression(s) that are parameters to the TABLESAMPLE clause. It is recommended to use estimate_expression_value() to try to reduce these expressions to constants, if their values are needed for estimation purposes; but the function must provide size estimates even if they cannot be reduced, and it should not fail even if the values appear invalid (remember that they're only estimates of what the run-time values will be). The pages and tuples parameters are outputs.

```
void
InitSampleScan (SampleScanState *node,
                int eflags);
```

Initialize for execution of a SampleScan plan node. This is called during executor startup. It should perform any initialization needed before processing can start. The SampleScanState node has already been created, but its tsm_state field is NULL. The InitSampleScan function can palloc whatever internal state data is needed by the sampling method, and store a pointer to it in node->tsm_state. Information about the table to scan is accessible through other fields of the SampleScanState node (but note that the node->ss.ss_currentScanDesc scan descriptor is not set up yet). eflags contains flag bits describing the executor's operating mode for this plan node.

When (eflags & EXEC_FLAG_EXPLAIN_ONLY) is true, the scan will not actually be performed, so this function should only do the minimum required to make the node state valid for EXPLAIN and EndSampleScan.

This function can be omitted (set the pointer to NULL), in which case BeginSampleScan must perform all initialization needed by the sampling method.

```
void
BeginSampleScan (SampleScanState *node,
                 Datum *params,
                 int nparams,
                 uint32 seed);
```

Begin execution of a sampling scan. This is called just before the first attempt to fetch a tuple, and may be called again if the scan needs to be restarted. Information about the table to scan is accessible through fields of the SampleScanState node (but note that the node->ss.ss_currentScanDesc scan descriptor is not set up yet). The params array, of length nparams, contains the values of the parameters supplied in the TABLESAMPLE clause. These will have the number and types specified in the sampling method's parameterTypes list, and have been checked to not be null. seed contains a seed to use for any random numbers generated within the sampling method; it is either a hash derived from the REPEATABLE value if one was given, or the result of random() if not.

This function may adjust the fields node->use_bulkread and node->use_pagemode. If node->use_bulkread is true, which it is by default, the scan will use a buffer access strategy that encourages recycling buffers after use. It might be reasonable to set this to false if the scan will visit only a small fraction of the table's pages. If node->use_pagemode is true, which it is by default, the scan will perform visibility checking in a single pass for all tuples on each visited page. It might be reasonable to set this to false if the scan will select only a small fraction of the tuples on each visited page. That will result in fewer tuple visibility checks being performed, though each one will be more expensive because it will require more locking.

If the sampling method is marked repeatable_across_scans, it must be able to select the same set of tuples during a rescan as it did originally, that is a fresh call of BeginSampleScan must lead to selecting the same tuples as before (if the TABLESAMPLE parameters and seed don't change).

```
BlockNumber
NextSampleBlock (SampleScanState *node, BlockNumber nblocks);
```

Returns the block number of the next page to be scanned, or InvalidBlockNumber if no pages remain to be scanned.

This function can be omitted (set the pointer to NULL), in which case the core code will perform a sequential scan of the entire relation. Such a scan can use synchronized scanning, so that the sampling method cannot assume that the relation pages are visited in the same order on each scan.

```
OffsetNumber
NextSampleTuple (SampleScanState *node,
                 BlockNumber blockno,
                 OffsetNumber maxoffset);
```

Returns the offset number of the next tuple to be sampled on the specified page, or `InvalidOffsetNumber` if no tuples remain to be sampled. `maxoffset` is the largest offset number in use on the page.

> **Note**
>
> `NextSampleTuple` is not explicitly told which of the offset numbers in the range `1 .. maxoffset` actually contain valid tuples. This is not normally a problem since the core code ignores requests to sample missing or invisible tuples; that should not result in any bias in the sample. However, if necessary, the function can use `node->donetuples` to examine how many of the tuples it returned were valid and visible.

> **Note**
>
> `NextSampleTuple` must *not* assume that `blockno` is the same page number returned by the most recent `NextSampleBlock` call. It was returned by some previous `NextSampleBlock` call, but the core code is allowed to call `NextSampleBlock` in advance of actually scanning pages, so as to support prefetching. It is OK to assume that once sampling of a given page begins, successive `NextSampleTuple` calls all refer to the same page until `InvalidOffsetNumber` is returned.

```
void
EndSampleScan (SampleScanState *node);
```

End the scan and release resources. It is normally not important to release palloc'd memory, but any externally-visible resources should be cleaned up. This function can be omitted (set the pointer to NULL) in the common case where no such resources exist.

Chapter 59. Writing a Custom Scan Provider

Postgres Pro supports a set of experimental facilities which are intended to allow extension modules to add new scan types to the system. Unlike a foreign data wrapper, which is only responsible for knowing how to scan its own foreign tables, a custom scan provider can provide an alternative method of scanning any relation in the system. Typically, the motivation for writing a custom scan provider will be to allow the use of some optimization not supported by the core system, such as caching or some form of hardware acceleration. This chapter outlines how to write a new custom scan provider.

Implementing a new type of custom scan is a three-step process. First, during planning, it is necessary to generate access paths representing a scan using the proposed strategy. Second, if one of those access paths is selected by the planner as the optimal strategy for scanning a particular relation, the access path must be converted to a plan. Finally, it must be possible to execute the plan and generate the same results that would have been generated for any other access path targeting the same relation.

59.1. Creating Custom Scan Paths

A custom scan provider will typically add paths for a base relation by setting the following hook, which is called after the core code has generated all the access paths it can for the relation (except for Gather paths, which are made after this call so that they can use partial paths added by the hook):

```
typedef void (*set_rel_pathlist_hook_type) (PlannerInfo *root,
                                            RelOptInfo *rel,
                                            Index rti,
                                            RangeTblEntry *rte);
extern PGDLLIMPORT set_rel_pathlist_hook_type set_rel_pathlist_hook;
```

Although this hook function can be used to examine, modify, or remove paths generated by the core system, a custom scan provider will typically confine itself to generating `CustomPath` objects and adding them to `rel` using `add_path`. The custom scan provider is responsible for initializing the `CustomPath` object, which is declared like this:

```
typedef struct CustomPath
{
    Path      path;
    uint32    flags;
    List     *custom_paths;
    List     *custom_private;
    const CustomPathMethods *methods;
} CustomPath;
```

`path` must be initialized as for any other path, including the row-count estimate, start and total cost, and sort ordering provided by this path. `flags` is a bit mask, which should include `CUSTOMPATH_SUPPORT_BACKWARD_SCAN` if the custom path can support a backward scan and `CUSTOMPATH_SUPPORT_MARK_RESTORE` if it can support mark and restore. Both capabilities are optional. An optional `custom_paths` is a list of `Path` nodes used by this custom-path node; these will be transformed into `Plan` nodes by planner. `custom_private` can be used to store the custom path's private data. Private data should be stored in a form that can be handled by `nodeToString`, so that debugging routines that attempt to print the custom path will work as designed. `methods` must point to a (usually statically allocated) object implementing the required custom path methods, which are further detailed below.

A custom scan provider can also provide join paths. Just as for base relations, such a path must produce the same output as would normally be produced by the join it replaces. To do this, the join provider should set the following hook, and then within the hook function, create `CustomPath` path(s) for the join relation.

```
typedef void (*set_join_pathlist_hook_type) (PlannerInfo *root,
                                             RelOptInfo *joinrel,
                                             RelOptInfo *outerrel,
                                             RelOptInfo *innerrel,
```

```
                                                JoinType jointype,
                                                JoinPathExtraData *extra);
extern PGDLLIMPORT set_join_pathlist_hook_type set_join_pathlist_hook;
```

This hook will be invoked repeatedly for the same join relation, with different combinations of inner and outer relations; it is the responsibility of the hook to minimize duplicated work.

59.1.1. Custom Scan Path Callbacks

```
Plan *(*PlanCustomPath) (PlannerInfo *root,
                         RelOptInfo *rel,
                         CustomPath *best_path,
                         List *tlist,
                         List *clauses,
                         List *custom_plans);
```

Convert a custom path to a finished plan. The return value will generally be a `CustomScan` object, which the callback must allocate and initialize. See Section 59.2 for more details.

```
List *(*ReparameterizeCustomPathByChild) (PlannerInfo *root,
                                          List *custom_private,
                                          RelOptInfo *child_rel);
```

This callback is called while converting a path parameterized by the top-most parent of the given child relation `child_rel` to be parameterized by the child relation. The callback is used to reparameterize any paths or translate any expression nodes saved in the given `custom_private` member of a `CustomPath`. The callback may use `reparameterize_path_by_child`, `adjust_appendrel_attrs` or `adjust_appendrel_attrs_multilevel` as required.

59.2. Creating Custom Scan Plans

A custom scan is represented in a finished plan tree using the following structure:

```
typedef struct CustomScan
{
    Scan      scan;
    uint32    flags;
    List     *custom_plans;
    List     *custom_exprs;
    List     *custom_private;
    List     *custom_scan_tlist;
    Bitmapset *custom_relids;
    const CustomScanMethods *methods;
} CustomScan;
```

`scan` must be initialized as for any other scan, including estimated costs, target lists, qualifications, and so on. `flags` is a bit mask with the same meaning as in `CustomPath`. `custom_plans` can be used to store child `Plan` nodes. `custom_exprs` should be used to store expression trees that will need to be fixed up by `setrefs.c` and `subselect.c`, while `custom_private` should be used to store other private data that is only used by the custom scan provider itself. `custom_scan_tlist` can be NIL when scanning a base relation, indicating that the custom scan returns scan tuples that match the base relation's row type. Otherwise it is a target list describing the actual scan tuples. `custom_scan_tlist` must be provided for joins, and could be provided for scans if the custom scan provider can compute some non-Var expressions. `custom_relids` is set by the core code to the set of relations (range table indexes) that this scan node handles; except when this scan is replacing a join, it will have only one member. `methods` must point to a (usually statically allocated) object implementing the required custom scan methods, which are further detailed below.

When a `CustomScan` scans a single relation, `scan.scanrelid` must be the range table index of the table to be scanned. When it replaces a join, `scan.scanrelid` should be zero.

Plan trees must be able to be duplicated using `copyObject`, so all the data stored within the "custom" fields must consist of nodes that that function can handle. Furthermore, custom scan providers cannot substitute a larger structure that embeds a `CustomScan` for the structure itself, as would be possible for a `CustomPath` or `CustomScanState`.

59.2.1. Custom Scan Plan Callbacks

```
Node *(*CreateCustomScanState) (CustomScan *cscan);
```

Allocate a `CustomScanState` for this `CustomScan`. The actual allocation will often be larger than required for an ordinary `CustomScanState`, because many providers will wish to embed that as the first field of a larger structure. The value returned must have the node tag and `methods` set appropriately, but other fields should be left as zeroes at this stage; after `ExecInitCustomScan` performs basic initialization, the `BeginCustomScan` callback will be invoked to give the custom scan provider a chance to do whatever else is needed.

59.3. Executing Custom Scans

When a `CustomScan` is executed, its execution state is represented by a `CustomScanState`, which is declared as follows:

```
typedef struct CustomScanState
{
    ScanState ss;
    uint32    flags;
    const CustomExecMethods *methods;
} CustomScanState;
```

`ss` is initialized as for any other scan state, except that if the scan is for a join rather than a base relation, `ss.ss_currentRelation` is left NULL. `flags` is a bit mask with the same meaning as in `CustomPath` and `CustomScan`. `methods` must point to a (usually statically allocated) object implementing the required custom scan state methods, which are further detailed below. Typically, a `CustomScanState`, which need not support `copyObject`, will actually be a larger structure embedding the above as its first member.

59.3.1. Custom Scan Execution Callbacks

```
void (*BeginCustomScan) (CustomScanState *node,
                         EState *estate,
                         int eflags);
```

Complete initialization of the supplied `CustomScanState`. Standard fields have been initialized by `ExecInitCustomScan`, but any private fields should be initialized here.

```
TupleTableSlot *(*ExecCustomScan) (CustomScanState *node);
```

Fetch the next scan tuple. If any tuples remain, it should fill `ps_ResultTupleSlot` with the next tuple in the current scan direction, and then return the tuple slot. If not, `NULL` or an empty slot should be returned.

```
void (*EndCustomScan) (CustomScanState *node);
```

Clean up any private data associated with the `CustomScanState`. This method is required, but it does not need to do anything if there is no associated data or it will be cleaned up automatically.

```
void (*ReScanCustomScan) (CustomScanState *node);
```

Rewind the current scan to the beginning and prepare to rescan the relation.

```
void (*MarkPosCustomScan) (CustomScanState *node);
```

Save the current scan position so that it can subsequently be restored by the `RestrPosCustomScan` callback. This callback is optional, and need only be supplied if the `CUSTOMPATH_SUPPORT_MARK_RESTORE` flag is set.

```
void (*RestrPosCustomScan) (CustomScanState *node);
```

Restore the previous scan position as saved by the `MarkPosCustomScan` callback. This callback is optional, and need only be supplied if the `CUSTOMPATH_SUPPORT_MARK_RESTORE` flag is set.

```
Size (*EstimateDSMCustomScan) (CustomScanState *node,
                               ParallelContext *pcxt);
```

Estimate the amount of dynamic shared memory that will be required for parallel operation. This may be higher than the amount that will actually be used, but it must not be lower. The return value is in bytes. This callback is optional, and need only be supplied if this custom scan provider supports parallel execution.

```
void (*InitializeDSMCustomScan) (CustomScanState *node,
                                 ParallelContext *pcxt,
                                 void *coordinate);
```

Initialize the dynamic shared memory that will be required for parallel operation. `coordinate` points to a shared memory area of size equal to the return value of `EstimateDSMCustomScan`. This callback is optional, and need only be supplied if this custom scan provider supports parallel execution.

```
void (*ReInitializeDSMCustomScan) (CustomScanState *node,
                                   ParallelContext *pcxt,
                                   void *coordinate);
```

Re-initialize the dynamic shared memory required for parallel operation when the custom-scan plan node is about to be re-scanned. This callback is optional, and need only be supplied if this custom scan provider supports parallel execution. Recommended practice is that this callback reset only shared state, while the `ReScanCustomScan` callback resets only local state. Currently, this callback will be called before `ReScanCustomScan`, but it's best not to rely on that ordering.

```
void (*InitializeWorkerCustomScan) (CustomScanState *node,
                                    shm_toc *toc,
                                    void *coordinate);
```

Initialize a parallel worker's local state based on the shared state set up by the leader during `InitializeDSMCustomScan`. This callback is optional, and need only be supplied if this custom scan provider supports parallel execution.

```
void (*ShutdownCustomScan) (CustomScanState *node);
```

Release resources when it is anticipated the node will not be executed to completion. This is not called in all cases; sometimes, `EndCustomScan` may be called without this function having been called first. Since the DSM segment used by parallel query is destroyed just after this callback is invoked, custom scan providers that wish to take some action before the DSM segment goes away should implement this method.

```
void (*ExplainCustomScan) (CustomScanState *node,
                           List *ancestors,
                           ExplainState *es);
```

Output additional information for `EXPLAIN` of a custom-scan plan node. This callback is optional. Common data stored in the `ScanState`, such as the target list and scan relation, will be shown even without this callback, but the callback allows the display of additional, private state.

Chapter 60. Genetic Query Optimizer

Author

Written by Martin Utesch (<utesch@aut.tu-freiberg.de>) for the Institute of Automatic Control at the University of Mining and Technology in Freiberg, Germany.

60.1. Query Handling as a Complex Optimization Problem

Among all relational operators the most difficult one to process and optimize is the *join*. The number of possible query plans grows exponentially with the number of joins in the query. Further optimization effort is caused by the support of a variety of *join methods* (e.g., nested loop, hash join, merge join in Postgres Pro) to process individual joins and a diversity of *indexes* (e.g., B-tree, hash, GiST and GIN in Postgres Pro) as access paths for relations.

The normal Postgres Pro query optimizer performs a *near-exhaustive search* over the space of alternative strategies. This algorithm, first introduced in IBM's System R database, produces a near-optimal join order, but can take an enormous amount of time and memory space when the number of joins in the query grows large. This makes the ordinary Postgres Pro query optimizer inappropriate for queries that join a large number of tables.

The Institute of Automatic Control at the University of Mining and Technology, in Freiberg, Germany, encountered some problems when it wanted to use PostgreSQL as the backend for a decision support knowledge based system for the maintenance of an electrical power grid. The DBMS needed to handle large join queries for the inference machine of the knowledge based system. The number of joins in these queries made using the normal query optimizer infeasible.

In the following we describe the implementation of a *genetic algorithm* to solve the join ordering problem in a manner that is efficient for queries involving large numbers of joins.

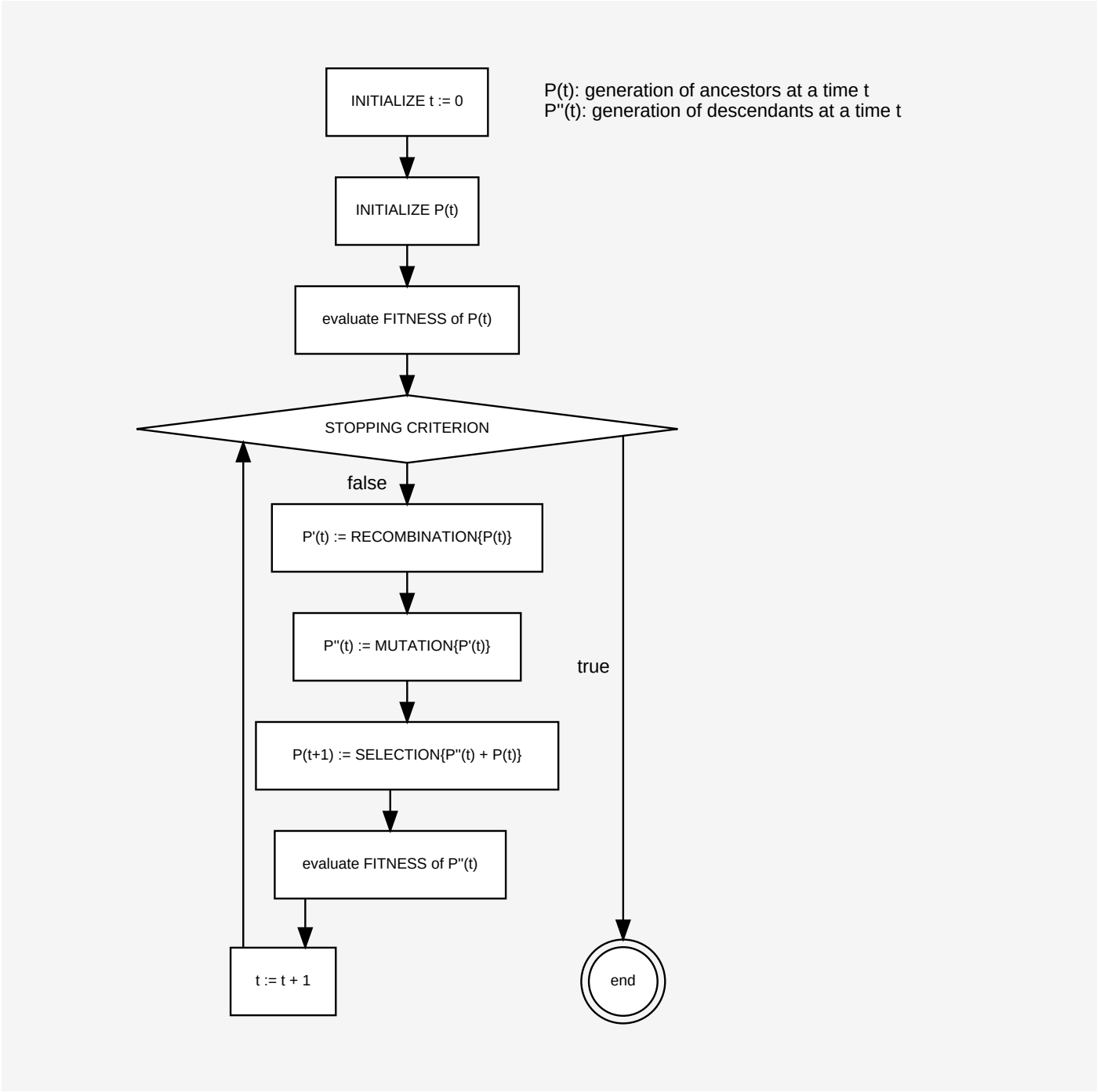
60.2. Genetic Algorithms

The genetic algorithm (GA) is a heuristic optimization method which operates through randomized search. The set of possible solutions for the optimization problem is considered as a *population* of *individuals*. The degree of adaptation of an individual to its environment is specified by its *fitness*.

The coordinates of an individual in the search space are represented by *chromosomes*, in essence a set of character strings. A *gene* is a subsection of a chromosome which encodes the value of a single parameter being optimized. Typical encodings for a gene could be *binary* or *integer*.

Through simulation of the evolutionary operations *recombination*, *mutation*, and *selection* new generations of search points are found that show a higher average fitness than their ancestors. Figure 60.1 illustrates these steps.

Figure 60.1. Structure of a Genetic Algorithm



According to the comp.ai.genetic FAQ it cannot be stressed too strongly that a GA is not a pure random search for a solution to a problem. A GA uses stochastic processes, but the result is distinctly non-random (better than random).

60.3. Genetic Query Optimization (GEQO) in Postgres Pro

The GEQO module approaches the query optimization problem as though it were the well-known traveling salesman problem (TSP). Possible query plans are encoded as integer strings. Each string represents the join order from one relation of the query to the next. For example, the join tree

```
   /\
  /\ 2
 /\ 3
```

```
4  1
```

is encoded by the integer string '4-1-3-2', which means, first join relation '4' and '1', then '3', and then '2', where 1, 2, 3, 4 are relation IDs within the Postgres Pro optimizer.

Specific characteristics of the GEQO implementation in Postgres Pro are:

- Usage of a *steady state* GA (replacement of the least fit individuals in a population, not whole-generational replacement) allows fast convergence towards improved query plans. This is essential for query handling with reasonable time;
- Usage of *edge recombination crossover* which is especially suited to keep edge losses low for the solution of the TSP by means of a GA;
- Mutation as genetic operator is deprecated so that no repair mechanisms are needed to generate legal TSP tours.

Parts of the GEQO module are adapted from D. Whitley's Genitor algorithm.

The GEQO module allows the Postgres Pro query optimizer to support large join queries effectively through non-exhaustive search.

60.3.1. Generating Possible Plans with GEQO

The GEQO planning process uses the standard planner code to generate plans for scans of individual relations. Then join plans are developed using the genetic approach. As shown above, each candidate join plan is represented by a sequence in which to join the base relations. In the initial stage, the GEQO code simply generates some possible join sequences at random. For each join sequence considered, the standard planner code is invoked to estimate the cost of performing the query using that join sequence. (For each step of the join sequence, all three possible join strategies are considered; and all the initially-determined relation scan plans are available. The estimated cost is the cheapest of these possibilities.) Join sequences with lower estimated cost are considered “more fit” than those with higher cost. The genetic algorithm discards the least fit candidates. Then new candidates are generated by combining genes of more-fit candidates — that is, by using randomly-chosen portions of known low-cost join sequences to create new sequences for consideration. This process is repeated until a preset number of join sequences have been considered; then the best one found at any time during the search is used to generate the finished plan.

This process is inherently nondeterministic, because of the randomized choices made during both the initial population selection and subsequent “mutation” of the best candidates. To avoid surprising changes of the selected plan, each run of the GEQO algorithm restarts its random number generator with the current geqo_seed parameter setting. As long as `geqo_seed` and the other GEQO parameters are kept fixed, the same plan will be generated for a given query (and other planner inputs such as statistics). To experiment with different search paths, try changing `geqo_seed`.

60.3.2. Future Implementation Tasks for PostgreSQL GEQO

Work is still needed to improve the genetic algorithm parameter settings. We have to find a compromise for the parameter settings to satisfy two competing demands:

- Optimality of the query plan
- Computing time

In the current implementation, the fitness of each candidate join sequence is estimated by running the standard planner's join selection and cost estimation code from scratch. To the extent that different candidates use similar sub-sequences of joins, a great deal of work will be repeated. This could be made significantly faster by retaining cost estimates for sub-joins. The problem is to avoid expending unreasonable amounts of memory on retaining that state.

At a more basic level, it is not clear that solving query optimization with a GA algorithm designed for TSP is appropriate. In the TSP case, the cost associated with any substring (partial tour) is independent of the rest of the tour, but this is certainly not true for query optimization. Thus it is questionable whether edge recombination crossover is the most effective mutation procedure.

60.4. Further Reading

The following resources contain additional information about genetic algorithms:

- *The Hitch-Hiker's Guide to Evolutionary Computation*, (FAQ for *news://comp.ai.genetic*)
- *Evolutionary Computation and its application to art and design*, by Craig Reynolds
- elma04
- fong

Chapter 61. Table Access Method Interface Definition

This chapter explains the interface between the core PostgreSQL system and *table access methods*, which manage the storage for tables. The core system knows little about these access methods beyond what is specified here, so it is possible to develop entirely new access method types by writing add-on code.

Each table access method is described by a row in the `pg_am` system catalog. The `pg_am` entry specifies a name and a *handler function* for the table access method. These entries can be created and deleted using the CREATE ACCESS METHOD and DROP ACCESS METHOD SQL commands.

A table access method handler function must be declared to accept a single argument of type `internal` and to return the pseudo-type `table_am_handler`. The argument is a dummy value that simply serves to prevent handler functions from being called directly from SQL commands. The result of the function must be a pointer to a struct of type `TableAmRoutine`, which contains everything that the core code needs to know to make use of the table access method. The return value needs to be of server lifetime, which is typically achieved by defining it as a `static const` variable in global scope. The `TableAmRoutine` struct, also called the access method's *API struct*, defines the behavior of the access method using callbacks. These callbacks are pointers to plain C functions and are not visible or callable at the SQL level. All the callbacks and their behavior is defined in the `TableAmRoutine` structure (with comments inside the struct defining the requirements for callbacks). Most callbacks have wrapper functions, which are documented from the point of view of a user (rather than an implementor) of the table access method. For details, please refer to the *`src/include/access/tableam.h`* file.

To implement an access method, an implementor will typically need to implement an AM-specific type of tuple table slot (see *`src/include/executor/tuptable.h`*), which allows code outside the access method to hold references to tuples of the AM, and to access the columns of the tuple.

Currently, the way an AM actually stores data is fairly unconstrained. For example, it's possible, but not required, to use postgres' shared buffer cache. In case it is used, it likely makes sense to use PostgreSQL's standard page layout as described in Section 70.6.

One fairly large constraint of the table access method API is that, currently, if the AM wants to support modifications and/or indexes, it is necessary for each tuple to have a tuple identifier (TID) consisting of a block number and an item number (see also Section 70.6). It is not strictly necessary that the sub-parts of TIDs have the same meaning they e.g., have for `heap`, but if bitmap scan support is desired (it is optional), the block number needs to provide locality.

For crash safety, an AM can use postgres' WAL, or a custom implementation. If WAL is chosen, either Generic WAL Records can be used, or a new type of WAL records can be implemented. Generic WAL Records are easy, but imply higher WAL volume. Implementation of a new type of WAL record currently requires modifications to core code (specifically, `src/include/access/rmgrlist.h`).

To implement transactional support in a manner that allows different table access methods be accessed within a single transaction, it likely is necessary to closely integrate with the machinery in *`src/backend/access/transam/xlog.c`*.

Chapter 62. Index Access Method Interface Definition

This chapter defines the interface between the core Postgres Pro system and *index access methods*, which manage individual index types. The core system knows nothing about indexes beyond what is specified here, so it is possible to develop entirely new index types by writing add-on code.

All indexes in Postgres Pro are what are known technically as *secondary indexes*; that is, the index is physically separate from the table file that it describes. Each index is stored as its own physical *relation* and so is described by an entry in the `pg_class` catalog. The contents of an index are entirely under the control of its index access method. In practice, all index access methods divide indexes into standard-size pages so that they can use the regular storage manager and buffer manager to access the index contents. (All the existing index access methods furthermore use the standard page layout described in Section 70.6, and most use the same format for index tuple headers; but these decisions are not forced on an access method.)

An index is effectively a mapping from some data key values to *tuple identifiers*, or TIDs, of row versions (tuples) in the index's parent table. A TID consists of a block number and an item number within that block (see Section 70.6). This is sufficient information to fetch a particular row version from the table. Indexes are not directly aware that under MVCC, there might be multiple extant versions of the same logical row; to an index, each tuple is an independent object that needs its own index entry. Thus, an update of a row always creates all-new index entries for the row, even if the key values did not change. (HOT tuples are an exception to this statement; but indexes do not deal with those, either.) Index entries for dead tuples are reclaimed (by vacuuming) when the dead tuples themselves are reclaimed.

62.1. Basic API Structure for Indexes

Each index access method is described by a row in the `pg_am` system catalog. The `pg_am` entry specifies a name and a *handler function* for the index access method. These entries can be created and deleted using the CREATE ACCESS METHOD and DROP ACCESS METHOD SQL commands.

An index access method handler function must be declared to accept a single argument of type `internal` and to return the pseudo-type `index_am_handler`. The argument is a dummy value that simply serves to prevent handler functions from being called directly from SQL commands. The result of the function must be a palloc'd struct of type `IndexAmRoutine`, which contains everything that the core code needs to know to make use of the index access method. The `IndexAmRoutine` struct, also called the access method's *API struct*, includes fields specifying assorted fixed properties of the access method, such as whether it can support multicolumn indexes. More importantly, it contains pointers to support functions for the access method, which do all of the real work to access indexes. These support functions are plain C functions and are not visible or callable at the SQL level. The support functions are described in Section 62.2.

The structure `IndexAmRoutine` is defined thus:

```
typedef struct IndexAmRoutine
{
    NodeTag     type;

    /*
     * Total number of strategies (operators) by which we can traverse/search
     * this AM.  Zero if AM does not have a fixed set of strategy assignments.
     */
    uint16      amstrategies;
    /* total number of support functions that this AM uses */
    uint16      amsupport;
    /* opclass options support function number or 0 */
    uint16      amoptsprocnum;
    /* does AM support ORDER BY indexed column's value? */
```

```
bool        amcanorder;
/* does AM support ORDER BY result of an operator on indexed column? */
bool        amcanorderbyop;
/*
 * Does AM support only one ORDER BY operator on first indexed column?
 * amcanorderbyop is implied.
 */
bool        amorderbyopfirstcol;
/* does AM support backward scanning? */
bool        amcanbackward;
/* does AM support UNIQUE indexes? */
bool        amcanunique;
/* does AM support multi-column indexes? */
bool        amcanmulticol;
/* does AM require scans to have a constraint on the first index column? */
bool        amoptionalkey;
/* does AM handle ScalarArrayOpExpr quals? */
bool        amsearcharray;
/* does AM handle IS NULL/IS NOT NULL quals? */
bool        amsearchnulls;
/* can index storage data type differ from column data type? */
bool        amstorage;
/* can an index of this type be clustered on? */
bool        amclusterable;
/* does AM handle predicate locks? */
bool        ampredlocks;
/* does AM support parallel scan? */
bool        amcanparallel;
/* does AM support columns included with clause INCLUDE? */
bool        amcaninclude;
/* does AM use maintenance_work_mem? */
bool        amusemaintenanceworkmem;
/* OR of parallel vacuum flags */
uint8       amparallelvacuumoptions;
/* type of data stored in index, or InvalidOid if variable */
Oid         amkeytype;

/* interface functions */
ambuild_function ambuild;
ambuildempty_function ambuildempty;
aminsert_function aminsert;
ambulkdelete_function ambulkdelete;
amvacuumcleanup_function amvacuumcleanup;
amcanreturn_function amcanreturn;   /* can be NULL */
amcostestimate_function amcostestimate;
amoptions_function amoptions;
amproperty_function amproperty;     /* can be NULL */
ambuildphasename_function ambuildphasename;   /* can be NULL */
amvalidate_function amvalidate;
amadjustmembers_function amadjustmembers; /* can be NULL */
ambeginscan_function ambeginscan;
amrescan_function amrescan;
amgettuple_function amgettuple;     /* can be NULL */
amgetbitmap_function amgetbitmap;   /* can be NULL */
amendscan_function amendscan;
ammarkpos_function ammarkpos;       /* can be NULL */
amrestrpos_function amrestrpos;     /* can be NULL */
```

```
    /* interface functions to support parallel index scans */
    amestimateparallelscan_function amestimateparallelscan;    /* can be NULL */
    aminitparallelscan_function aminitparallelscan;    /* can be NULL */
    amparallelrescan_function amparallelrescan;    /* can be NULL */
} IndexAmRoutine;
```

To be useful, an index access method must also have one or more *operator families* and *operator classes* defined in pg_opfamily, pg_opclass, pg_amop, and pg_amproc. These entries allow the planner to determine what kinds of query qualifications can be used with indexes of this access method. Operator families and classes are described in Section 40.16, which is prerequisite material for reading this chapter.

An individual index is defined by a pg_class entry that describes it as a physical relation, plus a pg_index entry that shows the logical content of the index — that is, the set of index columns it has and the semantics of those columns, as captured by the associated operator classes. The index columns (key values) can be either simple columns of the underlying table or expressions over the table rows. The index access method normally has no interest in where the index key values come from (it is always handed precomputed key values) but it will be very interested in the operator class information in pg_index. Both of these catalog entries can be accessed as part of the Relation data structure that is passed to all operations on the index.

Some of the flag fields of IndexAmRoutine have nonobvious implications. The requirements of amcanunique are discussed in Section 62.5. The amcanmulticol flag asserts that the access method supports multi-key-column indexes, while amoptionalkey asserts that it allows scans where no indexable restriction clause is given for the first index column. When amcanmulticol is false, amoptionalkey essentially says whether the access method supports full-index scans without any restriction clause. Access methods that support multiple index columns *must* support scans that omit restrictions on any or all of the columns after the first; however they are permitted to require some restriction to appear for the first index column, and this is signaled by setting amoptionalkey false. One reason that an index AM might set amoptionalkey false is if it doesn't index null values. Since most indexable operators are strict and hence cannot return true for null inputs, it is at first sight attractive to not store index entries for null values: they could never be returned by an index scan anyway. However, this argument fails when an index scan has no restriction clause for a given index column. In practice this means that indexes that have amoptionalkey true must index nulls, since the planner might decide to use such an index with no scan keys at all. A related restriction is that an index access method that supports multiple index columns *must* support indexing null values in columns after the first, because the planner will assume the index can be used for queries that do not restrict these columns. For example, consider an index on (a,b) and a query with WHERE a = 4. The system will assume the index can be used to scan for rows with a = 4, which is wrong if the index omits rows where b is null. It is, however, OK to omit rows where the first indexed column is null. An index access method that does index nulls may also set amsearchnulls, indicating that it supports IS NULL and IS NOT NULL clauses as search conditions.

The amcaninclude flag indicates whether the access method supports “included” columns, that is it can store (without processing) additional columns beyond the key column(s). The requirements of the preceding paragraph apply only to the key columns. In particular, the combination of amcanmulticol=false and amcaninclude=true is sensible: it means that there can only be one key column, but there can also be included column(s). Also, included columns must be allowed to be null, independently of amoptionalkey.

62.2. Index Access Method Functions

The index construction and maintenance functions that an index access method must provide in IndexAmRoutine are:

```
IndexBuildResult *
ambuild (Relation heapRelation,
         Relation indexRelation,
         IndexInfo *indexInfo);
```

Build a new index. The index relation has been physically created, but is empty. It must be filled in with whatever fixed data the access method requires, plus entries for all tuples already existing in the table.

Ordinarily the `ambuild` function will call `table_index_build_scan()` to scan the table for existing tuples and compute the keys that need to be inserted into the index. The function must return a palloc'd struct containing statistics about the new index.

```
void
ambuildempty (Relation indexRelation);
```

Build an empty index, and write it to the initialization fork (`INIT_FORKNUM`) of the given relation. This method is called only for unlogged indexes; the empty index written to the initialization fork will be copied over the main relation fork on each server restart.

```
bool
aminsert (Relation indexRelation,
          Datum *values,
          bool *isnull,
          ItemPointer heap_tid,
          Relation heapRelation,
          IndexUniqueCheck checkUnique,
          bool indexUnchanged,
          IndexInfo *indexInfo);
```

Insert a new tuple into an existing index. The `values` and `isnull` arrays give the key values to be indexed, and `heap_tid` is the TID to be indexed. If the access method supports unique indexes (its `amcanunique` flag is true) then `checkUnique` indicates the type of uniqueness check to perform. This varies depending on whether the unique constraint is deferrable; see Section 62.5 for details. Normally the access method only needs the `heapRelation` parameter when performing uniqueness checking (since then it will have to look into the heap to verify tuple liveness).

The `indexUnchanged` Boolean value gives a hint about the nature of the tuple to be indexed. When it is true, the tuple is a duplicate of some existing tuple in the index. The new tuple is a logically unchanged successor MVCC tuple version. This happens when an `UPDATE` takes place that does not modify any columns covered by the index, but nevertheless requires a new version in the index. The index AM may use this hint to decide to apply bottom-up index deletion in parts of the index where many versions of the same logical row accumulate. Note that updating a non-key column or a column that only appears in a partial index predicate does not affect the value of `indexUnchanged`. The core code determines each tuple's `indexUnchanged` value using a low overhead approach that allows both false positives and false negatives. Index AMs must not treat `indexUnchanged` as an authoritative source of information about tuple visibility or versioning.

The function's Boolean result value is significant only when `checkUnique` is `UNIQUE_CHECK_PARTIAL`. In this case a true result means the new entry is known unique, whereas false means it might be non-unique (and a deferred uniqueness check must be scheduled). For other cases a constant false result is recommended.

Some indexes might not index all tuples. If the tuple is not to be indexed, `aminsert` should just return without doing anything.

If the index AM wishes to cache data across successive index insertions within an SQL statement, it can allocate space in `indexInfo->ii_Context` and store a pointer to the data in `indexInfo->ii_AmCache` (which will be NULL initially).

```
IndexBulkDeleteResult *
ambulkdelete (IndexVacuumInfo *info,
              IndexBulkDeleteResult *stats,
              IndexBulkDeleteCallback callback,
              void *callback_state);
```

Delete tuple(s) from the index. This is a “bulk delete” operation that is intended to be implemented by scanning the whole index and checking each entry to see if it should be deleted. The passed-in `callback` function must be called, in the style `callback(`*`TID`*`, callback_state) returns bool`, to determine whether any particular index entry, as identified by its referenced TID, is to be deleted. Must return

either NULL or a palloc'd struct containing statistics about the effects of the deletion operation. It is OK to return NULL if no information needs to be passed on to amvacuumcleanup.

Because of limited maintenance_work_mem, ambulkdelete might need to be called more than once when many tuples are to be deleted. The stats argument is the result of the previous call for this index (it is NULL for the first call within a VACUUM operation). This allows the AM to accumulate statistics across the whole operation. Typically, ambulkdelete will modify and return the same struct if the passed stats is not null.

```
IndexBulkDeleteResult *
amvacuumcleanup (IndexVacuumInfo *info,
                 IndexBulkDeleteResult *stats);
```

Clean up after a VACUUM operation (zero or more ambulkdelete calls). This does not have to do anything beyond returning index statistics, but it might perform bulk cleanup such as reclaiming empty index pages. stats is whatever the last ambulkdelete call returned, or NULL if ambulkdelete was not called because no tuples needed to be deleted. If the result is not NULL it must be a palloc'd struct. The statistics it contains will be used to update pg_class, and will be reported by VACUUM if VERBOSE is given. It is OK to return NULL if the index was not changed at all during the VACUUM operation, but otherwise correct stats should be returned.

amvacuumcleanup will also be called at completion of an ANALYZE operation. In this case stats is always NULL and any return value will be ignored. This case can be distinguished by checking info->analyze_only. It is recommended that the access method do nothing except post-insert cleanup in such a call, and that only in an autovacuum worker process.

```
bool
amcanreturn (Relation indexRelation, int attno);
```

Check whether the index can support *index-only scans* on the given column, by returning the column's original indexed value. The attribute number is 1-based, i.e., the first column's attno is 1. Returns true if supported, else false. This function should always return true for included columns (if those are supported), since there's little point in an included column that can't be retrieved. If the access method does not support index-only scans at all, the amcanreturn field in its IndexAmRoutine struct can be set to NULL.

```
void
amcostestimate (PlannerInfo *root,
                IndexPath *path,
                double loop_count,
                Cost *indexStartupCost,
                Cost *indexTotalCost,
                Selectivity *indexSelectivity,
                double *indexCorrelation,
                double *indexPages);
```

Estimate the costs of an index scan. This function is described fully in Section 62.6, below.

```
bytea *
amoptions (ArrayType *reloptions,
           bool validate);
```

Parse and validate the reloptions array for an index. This is called only when a non-null reloptions array exists for the index. *reloptions* is a text array containing entries of the form *name=value*. The function should construct a bytea value, which will be copied into the rd_options field of the index's relcache entry. The data contents of the bytea value are open for the access method to define; most of the standard access methods use struct StdRdOptions. When *validate* is true, the function should report a suitable error message if any of the options are unrecognized or have invalid values; when *validate* is false, invalid entries should be silently ignored. (*validate* is false when loading options already stored in pg_catalog; an invalid entry could only be found if the access method has changed its rules for options, and in that case ignoring obsolete entries is appropriate.) It is OK to return NULL if default behavior is wanted.

```
bool
amproperty (Oid index_oid, int attno,
            IndexAMProperty prop, const char *propname,
            bool *res, bool *isnull);
```

The `amproperty` method allows index access methods to override the default behavior of `pg_index_column_has_property` and related functions. If the access method does not have any special behavior for index property inquiries, the `amproperty` field in its `IndexAmRoutine` struct can be set to NULL. Otherwise, the `amproperty` method will be called with *`index_oid`* and *`attno`* both zero for `pg_indexam_has_property` calls, or with *`index_oid`* valid and *`attno`* zero for `pg_index_has_property` calls, or with *`index_oid`* valid and *`attno`* greater than zero for `pg_index_column_has_property` calls. *`prop`* is an enum value identifying the property being tested, while *`propname`* is the original property name string. If the core code does not recognize the property name then *`prop`* is `AMPROP_UNKNOWN`. Access methods can define custom property names by checking *`propname`* for a match (use `pg_strcasecmp` to match, for consistency with the core code); for names known to the core code, it's better to inspect *`prop`*. If the `amproperty` method returns `true` then it has determined the property test result: it must set `*res` to the Boolean value to return, or set `*isnull` to `true` to return a NULL. (Both of the referenced variables are initialized to `false` before the call.) If the `amproperty` method returns `false` then the core code will proceed with its normal logic for determining the property test result.

Access methods that support ordering operators should implement `AMPROP_DISTANCE_ORDERABLE` property testing, as the core code does not know how to do that and will return NULL. It may also be advantageous to implement `AMPROP_RETURNABLE` testing, if that can be done more cheaply than by opening the index and calling `amcanreturn`, which is the core code's default behavior. The default behavior should be satisfactory for all other standard properties.

```
char *
ambuildphasename (int64 phasenum);
```

Return the textual name of the given build phase number. The phase numbers are those reported during an index build via the `pgstat_progress_update_param` interface. The phase names are then exposed in the `pg_stat_progress_create_index` view.

```
bool
amvalidate (Oid opclassoid);
```

Validate the catalog entries for the specified operator class, so far as the access method can reasonably do that. For example, this might include testing that all required support functions are provided. The `amvalidate` function must return false if the opclass is invalid. Problems should be reported with `ereport` messages, typically at `INFO` level.

```
void
amadjustmembers (Oid opfamilyoid,
                 Oid opclassoid,
                 List *operators,
                 List *functions);
```

Validate proposed new operator and function members of an operator family, so far as the access method can reasonably do that, and set their dependency types if the default is not satisfactory. This is called during `CREATE OPERATOR CLASS` and during `ALTER OPERATOR FAMILY ADD`; in the latter case *`opclassoid`* is `InvalidOid`. The `List` arguments are lists of `OpFamilyMember` structs. Tests done by this function will typically be a subset of those performed by `amvalidate`, since `amadjustmembers` cannot assume that it is seeing a complete set of members. For example, it would be reasonable to check the signature of a support function, but not to check whether all required support functions are provided. Any problems can be reported by throwing an error. The dependency-related fields of the `OpFamilyMember` structs are initialized by the core code to create hard dependencies on the opclass if this is `CREATE OPERATOR CLASS`, or soft dependencies on the opfamily if this is `ALTER OPERATOR FAMILY ADD`. `amadjustmembers` can adjust these fields if some other behavior is more appropriate. For example, GIN, GiST, and SP-GiST always set operator members to have soft dependencies on the opfamily, since the connection between an operator and an opclass is relatively weak in these index types; so it is reasonable to allow operator members to

be added and removed freely. Optional support functions are typically also given soft dependencies, so that they can be removed if necessary.

The purpose of an index, of course, is to support scans for tuples matching an indexable `WHERE` condition, often called a *qualifier* or *scan key*. The semantics of index scanning are described more fully in Section 62.3, below. An index access method can support "plain" index scans, "bitmap" index scans, or both. The scan-related functions that an index access method must or may provide are:

```
IndexScanDesc
ambeginscan (Relation indexRelation,
             int nkeys,
             int norderbys);
```

Prepare for an index scan. The `nkeys` and `norderbys` parameters indicate the number of quals and ordering operators that will be used in the scan; these may be useful for space allocation purposes. Note that the actual values of the scan keys aren't provided yet. The result must be a palloc'd struct. For implementation reasons the index access method *must* create this struct by calling `RelationGetIndexScan()`. In most cases `ambeginscan` does little beyond making that call and perhaps acquiring locks; the interesting parts of index-scan startup are in `amrescan`.

```
void
amrescan (IndexScanDesc scan,
          ScanKey keys,
          int nkeys,
          ScanKey orderbys,
          int norderbys);
```

Start or restart an index scan, possibly with new scan keys. (To restart using previously-passed keys, NULL is passed for `keys` and/or `orderbys`.) Note that it is not allowed for the number of keys or order-by operators to be larger than what was passed to `ambeginscan`. In practice the restart feature is used when a new outer tuple is selected by a nested-loop join and so a new key comparison value is needed, but the scan key structure remains the same.

```
bool
amgettuple (IndexScanDesc scan,
            ScanDirection direction);
```

Fetch the next tuple in the given scan, moving in the given direction (forward or backward in the index). Returns true if a tuple was obtained, false if no matching tuples remain. In the true case the tuple TID is stored into the `scan` structure. Note that "success" means only that the index contains an entry that matches the scan keys, not that the tuple necessarily still exists in the heap or will pass the caller's snapshot test. On success, `amgettuple` must also set `scan->xs_recheck` to true or false. False means it is certain that the index entry matches the scan keys. True means this is not certain, and the conditions represented by the scan keys must be rechecked against the heap tuple after fetching it. This provision supports "lossy" index operators. Note that rechecking will extend only to the scan conditions; a partial index predicate (if any) is never rechecked by `amgettuple` callers.

If the index supports index-only scans (i.e., `amcanreturn` returns true for any of its columns), then on success the AM must also check `scan->xs_want_itup`, and if that is true it must return the originally indexed data for the index entry. Columns for which `amcanreturn` returns false can be returned as nulls. The data can be returned in the form of an `IndexTuple` pointer stored at `scan->xs_itup`, with tuple descriptor `scan->xs_itupdesc`; or in the form of a `HeapTuple` pointer stored at `scan->xs_hitup`, with tuple descriptor `scan->xs_hitupdesc`. (The latter format should be used when reconstructing data that might possibly not fit into an `IndexTuple`.) In either case, management of the data referenced by the pointer is the access method's responsibility. The data must remain good at least until the next `amgettuple`, `amrescan`, or `amendscan` call for the scan.

The `amgettuple` function need only be provided if the access method supports "plain" index scans. If it doesn't, the `amgettuple` field in its `IndexAmRoutine` struct must be set to NULL.

```
int64
```

```
amgetbitmap (IndexScanDesc scan,
             TIDBitmap *tbm);
```

Fetch all tuples in the given scan and add them to the caller-supplied `TIDBitmap` (that is, OR the set of tuple IDs into whatever set is already in the bitmap). The number of tuples fetched is returned (this might be just an approximate count, for instance some AMs do not detect duplicates). While inserting tuple IDs into the bitmap, `amgetbitmap` can indicate that rechecking of the scan conditions is required for specific tuple IDs. This is analogous to the `xs_recheck` output parameter of `amgettuple`. Note: in the current implementation, support for this feature is conflated with support for lossy storage of the bitmap itself, and therefore callers recheck both the scan conditions and the partial index predicate (if any) for recheckable tuples. That might not always be true, however. `amgetbitmap` and `amgettuple` cannot be used in the same index scan; there are other restrictions too when using `amgetbitmap`, as explained in Section 62.3.

The `amgetbitmap` function need only be provided if the access method supports “bitmap” index scans. If it doesn't, the `amgetbitmap` field in its `IndexAmRoutine` struct must be set to NULL.

```
void
amendscan (IndexScanDesc scan);
```

End a scan and release resources. The `scan` struct itself should not be freed, but any locks or pins taken internally by the access method must be released, as well as any other memory allocated by `ambeginscan` and other scan-related functions.

```
void
ammarkpos (IndexScanDesc scan);
```

Mark current scan position. The access method need only support one remembered scan position per scan.

The `ammarkpos` function need only be provided if the access method supports ordered scans. If it doesn't, the `ammarkpos` field in its `IndexAmRoutine` struct may be set to NULL.

```
void
amrestrpos (IndexScanDesc scan);
```

Restore the scan to the most recently marked position.

The `amrestrpos` function need only be provided if the access method supports ordered scans. If it doesn't, the `amrestrpos` field in its `IndexAmRoutine` struct may be set to NULL.

In addition to supporting ordinary index scans, some types of index may wish to support *parallel index scans*, which allow multiple backends to cooperate in performing an index scan. The index access method should arrange things so that each cooperating process returns a subset of the tuples that would be performed by an ordinary, non-parallel index scan, but in such a way that the union of those subsets is equal to the set of tuples that would be returned by an ordinary, non-parallel index scan. Furthermore, while there need not be any global ordering of tuples returned by a parallel scan, the ordering of that subset of tuples returned within each cooperating backend must match the requested ordering. The following functions may be implemented to support parallel index scans:

```
Size
amestimateparallelscan (void);
```

Estimate and return the number of bytes of dynamic shared memory which the access method will be needed to perform a parallel scan. (This number is in addition to, not in lieu of, the amount of space needed for AM-independent data in `ParallelIndexScanDescData`.)

It is not necessary to implement this function for access methods which do not support parallel scans or for which the number of additional bytes of storage required is zero.

```
void
aminitparallelscan (void *target);
```

This function will be called to initialize dynamic shared memory at the beginning of a parallel scan. *target* will point to at least the number of bytes previously returned by amestimateparallelscan, and this function may use that amount of space to store whatever data it wishes.

It is not necessary to implement this function for access methods which do not support parallel scans or in cases where the shared memory space required needs no initialization.

```
void
amparallelrescan (IndexScanDesc scan);
```

This function, if implemented, will be called when a parallel index scan must be restarted. It should reset any shared state set up by aminitparallelscan such that the scan will be restarted from the beginning.

62.3. Index Scanning

In an index scan, the index access method is responsible for regurgitating the TIDs of all the tuples it has been told about that match the *scan keys*. The access method is *not* involved in actually fetching those tuples from the index's parent table, nor in determining whether they pass the scan's visibility test or other conditions.

A scan key is the internal representation of a WHERE clause of the form *index_key operator constant*, where the index key is one of the columns of the index and the operator is one of the members of the operator family associated with that index column. An index scan has zero or more scan keys, which are implicitly ANDed — the returned tuples are expected to satisfy all the indicated conditions.

The access method can report that the index is *lossy*, or requires rechecks, for a particular query. This implies that the index scan will return all the entries that pass the scan key, plus possibly additional entries that do not. The core system's index-scan machinery will then apply the index conditions again to the heap tuple to verify whether or not it really should be selected. If the recheck option is not specified, the index scan must return exactly the set of matching entries.

Note that it is entirely up to the access method to ensure that it correctly finds all and only the entries passing all the given scan keys. Also, the core system will simply hand off all the WHERE clauses that match the index keys and operator families, without any semantic analysis to determine whether they are redundant or contradictory. As an example, given WHERE x > 4 AND x > 14 where x is a b-tree indexed column, it is left to the b-tree amrescan function to realize that the first scan key is redundant and can be discarded. The extent of preprocessing needed during amrescan will depend on the extent to which the index access method needs to reduce the scan keys to a “normalized” form.

Some access methods return index entries in a well-defined order, others do not. There are actually two different ways that an access method can support sorted output:

- Access methods that always return entries in the natural ordering of their data (such as btree) should set amcanorder to true. Currently, such access methods must use btree-compatible strategy numbers for their equality and ordering operators.
- Access methods that support ordering operators should set amcanorderbyop to true. This indicates that the index is capable of returning entries in an order satisfying ORDER BY *index_key operator constant*. Scan modifiers of that form can be passed to amrescan as described previously. If the access method supports only one ORDER BY operator on the first indexed column, then it should set amorderbyopfirstcol to true.

The amgettuple function has a direction argument, which can be either ForwardScanDirection (the normal case) or BackwardScanDirection. If the first call after amrescan specifies BackwardScanDirection, then the set of matching index entries is to be scanned back-to-front rather than in the normal front-to-back direction, so amgettuple must return the last matching tuple in the index, rather than the first one as it normally would. (This will only occur for access methods that set amcanorder to true.) After the first call, amgettuple must be prepared to advance the scan in either direction from the most recently returned entry. (But if amcanbackward is false, all subsequent calls will have the same direction as the first one.)

Access methods that support ordered scans must support “marking” a position in a scan and later returning to the marked position. The same position might be restored multiple times. However, only one position need be remembered per scan; a new `ammarkpos` call overrides the previously marked position. An access method that does not support ordered scans need not provide `ammarkpos` and `amrestrpos` functions in `IndexAmRoutine`; set those pointers to NULL instead.

Both the scan position and the mark position (if any) must be maintained consistently in the face of concurrent insertions or deletions in the index. It is OK if a freshly-inserted entry is not returned by a scan that would have found the entry if it had existed when the scan started, or for the scan to return such an entry upon rescanning or backing up even though it had not been returned the first time through. Similarly, a concurrent delete might or might not be reflected in the results of a scan. What is important is that insertions or deletions not cause the scan to miss or multiply return entries that were not themselves being inserted or deleted.

If the index stores the original indexed data values (and not some lossy representation of them), it is useful to support index-only scans, in which the index returns the actual data not just the TID of the heap tuple. This will only avoid I/O if the visibility map shows that the TID is on an all-visible page; else the heap tuple must be visited anyway to check MVCC visibility. But that is no concern of the access method's.

Instead of using `amgettuple`, an index scan can be done with `amgetbitmap` to fetch all tuples in one call. This can be noticeably more efficient than `amgettuple` because it allows avoiding lock/unlock cycles within the access method. In principle `amgetbitmap` should have the same effects as repeated `amgettuple` calls, but we impose several restrictions to simplify matters. First of all, `amgetbitmap` returns all tuples at once and marking or restoring scan positions isn't supported. Secondly, the tuples are returned in a bitmap which doesn't have any specific ordering, which is why `amgetbitmap` doesn't take a `direction` argument. (Ordering operators will never be supplied for such a scan, either.) Also, there is no provision for index-only scans with `amgetbitmap`, since there is no way to return the contents of index tuples. Finally, `amgetbitmap` does not guarantee any locking of the returned tuples, with implications spelled out in Section 62.4.

Note that it is permitted for an access method to implement only `amgetbitmap` and not `amgettuple`, or vice versa, if its internal implementation is unsuited to one API or the other.

62.4. Index Locking Considerations

Index access methods must handle concurrent updates of the index by multiple processes. The core Postgres Pro system obtains `AccessShareLock` on the index during an index scan, and `RowExclusiveLock` when updating the index (including plain `VACUUM`). Since these lock types do not conflict, the access method is responsible for handling any fine-grained locking it might need. An `ACCESS EXCLUSIVE` lock on the index as a whole will be taken only during index creation, destruction, or `REINDEX` (`SHARE UPDATE EXCLUSIVE` is taken instead with `CONCURRENTLY`).

Building an index type that supports concurrent updates usually requires extensive and subtle analysis of the required behavior.

Aside from the index's own internal consistency requirements, concurrent updates create issues about consistency between the parent table (the *heap*) and the index. Because Postgres Pro separates accesses and updates of the heap from those of the index, there are windows in which the index might be inconsistent with the heap. We handle this problem with the following rules:

- A new heap entry is made before making its index entries. (Therefore a concurrent index scan is likely to fail to see the heap entry. This is okay because the index reader would be uninterested in an uncommitted row anyway. But see Section 62.5.)
- When a heap entry is to be deleted (by `VACUUM`), all its index entries must be removed first.
- An index scan must maintain a pin on the index page holding the item last returned by `amgettuple`, and `ambulkdelete` cannot delete entries from pages that are pinned by other backends. The need for this rule is explained below.

Without the third rule, it is possible for an index reader to see an index entry just before it is removed by VACUUM, and then to arrive at the corresponding heap entry after that was removed by VACUUM. This creates no serious problems if that item number is still unused when the reader reaches it, since an empty item slot will be ignored by heap_fetch(). But what if a third backend has already re-used the item slot for something else? When using an MVCC-compliant snapshot, there is no problem because the new occupant of the slot is certain to be too new to pass the snapshot test. However, with a non-MVCC-compliant snapshot (such as SnapshotAny), it would be possible to accept and return a row that does not in fact match the scan keys. We could defend against this scenario by requiring the scan keys to be rechecked against the heap row in all cases, but that is too expensive. Instead, we use a pin on an index page as a proxy to indicate that the reader might still be “in flight” from the index entry to the matching heap entry. Making ambulkdelete block on such a pin ensures that VACUUM cannot delete the heap entry before the reader is done with it. This solution costs little in run time, and adds blocking overhead only in the rare cases where there actually is a conflict.

This solution requires that index scans be “synchronous”: we have to fetch each heap tuple immediately after scanning the corresponding index entry. This is expensive for a number of reasons. An “asynchronous” scan in which we collect many TIDs from the index, and only visit the heap tuples sometime later, requires much less index locking overhead and can allow a more efficient heap access pattern. Per the above analysis, we must use the synchronous approach for non-MVCC-compliant snapshots, but an asynchronous scan is workable for a query using an MVCC snapshot.

In an amgetbitmap index scan, the access method does not keep an index pin on any of the returned tuples. Therefore it is only safe to use such scans with MVCC-compliant snapshots.

When the ampredlocks flag is not set, any scan using that index access method within a serializable transaction will acquire a nonblocking predicate lock on the full index. This will generate a read-write conflict with the insert of any tuple into that index by a concurrent serializable transaction. If certain patterns of read-write conflicts are detected among a set of concurrent serializable transactions, one of those transactions may be canceled to protect data integrity. When the flag is set, it indicates that the index access method implements finer-grained predicate locking, which will tend to reduce the frequency of such transaction cancellations.

62.5. Index Uniqueness Checks

Postgres Pro enforces SQL uniqueness constraints using *unique indexes*, which are indexes that disallow multiple entries with identical keys. An access method that supports this feature sets amcanunique true. (At present, only b-tree supports it.) Columns listed in the INCLUDE clause are not considered when enforcing uniqueness.

Because of MVCC, it is always necessary to allow duplicate entries to exist physically in an index: the entries might refer to successive versions of a single logical row. The behavior we actually want to enforce is that no MVCC snapshot could include two rows with equal index keys. This breaks down into the following cases that must be checked when inserting a new row into a unique index:

- If a conflicting valid row has been deleted by the current transaction, it's okay. (In particular, since an UPDATE always deletes the old row version before inserting the new version, this will allow an UPDATE on a row without changing the key.)
- If a conflicting row has been inserted by an as-yet-uncommitted transaction, the would-be inserter must wait to see if that transaction commits. If it rolls back then there is no conflict. If it commits without deleting the conflicting row again, there is a uniqueness violation. (In practice we just wait for the other transaction to end and then redo the visibility check in toto.)
- Similarly, if a conflicting valid row has been deleted by an as-yet-uncommitted transaction, the would-be inserter must wait for that transaction to commit or abort, and then repeat the test.

Furthermore, immediately before reporting a uniqueness violation according to the above rules, the access method must recheck the liveness of the row being inserted. If it is committed dead then no violation should be reported. (This case cannot occur during the ordinary scenario of inserting a row that's just been created by the current transaction. It can happen during CREATE UNIQUE INDEX CONCURRENTLY, however.)

We require the index access method to apply these tests itself, which means that it must reach into the heap to check the commit status of any row that is shown to have a duplicate key according to the index contents. This is without a doubt ugly and non-modular, but it saves redundant work: if we did a separate probe then the index lookup for a conflicting row would be essentially repeated while finding the place to insert the new row's index entry. What's more, there is no obvious way to avoid race conditions unless the conflict check is an integral part of insertion of the new index entry.

If the unique constraint is deferrable, there is additional complexity: we need to be able to insert an index entry for a new row, but defer any uniqueness-violation error until end of statement or even later. To avoid unnecessary repeat searches of the index, the index access method should do a preliminary uniqueness check during the initial insertion. If this shows that there is definitely no conflicting live tuple, we are done. Otherwise, we schedule a recheck to occur when it is time to enforce the constraint. If, at the time of the recheck, both the inserted tuple and some other tuple with the same key are live, then the error must be reported. (Note that for this purpose, “live” actually means “any tuple in the index entry's HOT chain is live”.) To implement this, the `aminsert` function is passed a `checkUnique` parameter having one of the following values:

- `UNIQUE_CHECK_NO` indicates that no uniqueness checking should be done (this is not a unique index).
- `UNIQUE_CHECK_YES` indicates that this is a non-deferrable unique index, and the uniqueness check must be done immediately, as described above.
- `UNIQUE_CHECK_PARTIAL` indicates that the unique constraint is deferrable. Postgres Pro will use this mode to insert each row's index entry. The access method must allow duplicate entries into the index, and report any potential duplicates by returning false from `aminsert`. For each row for which false is returned, a deferred recheck will be scheduled.

  The access method must identify any rows which might violate the unique constraint, but it is not an error for it to report false positives. This allows the check to be done without waiting for other transactions to finish; conflicts reported here are not treated as errors and will be rechecked later, by which time they may no longer be conflicts.
- `UNIQUE_CHECK_EXISTING` indicates that this is a deferred recheck of a row that was reported as a potential uniqueness violation. Although this is implemented by calling `aminsert`, the access method must *not* insert a new index entry in this case. The index entry is already present. Rather, the access method must check to see if there is another live index entry. If so, and if the target row is also still live, report error.

  It is recommended that in a `UNIQUE_CHECK_EXISTING` call, the access method further verify that the target row actually does have an existing entry in the index, and report error if not. This is a good idea because the index tuple values passed to `aminsert` will have been recomputed. If the index definition involves functions that are not really immutable, we might be checking the wrong area of the index. Checking that the target row is found in the recheck verifies that we are scanning for the same tuple values as were used in the original insertion.

62.6. Index Cost Estimation Functions

The `amcostestimate` function is given information describing a possible index scan, including lists of WHERE and ORDER BY clauses that have been determined to be usable with the index. It must return estimates of the cost of accessing the index and the selectivity of the WHERE clauses (that is, the fraction of parent-table rows that will be retrieved during the index scan). For simple cases, nearly all the work of the cost estimator can be done by calling standard routines in the optimizer; the point of having an `amcostestimate` function is to allow index access methods to provide index-type-specific knowledge, in case it is possible to improve on the standard estimates.

Each `amcostestimate` function must have the signature:

```
void
amcostestimate (PlannerInfo *root,
                IndexPath *path,
```

```
                double loop_count,
                Cost *indexStartupCost,
                Cost *indexTotalCost,
                Selectivity *indexSelectivity,
                double *indexCorrelation,
                double *indexPages);
```

The first three parameters are inputs:

root

The planner's information about the query being processed.

path

The index access path being considered. All fields except cost and selectivity values are valid.

loop_count

The number of repetitions of the index scan that should be factored into the cost estimates. This will typically be greater than one when considering a parameterized scan for use in the inside of a nestloop join. Note that the cost estimates should still be for just one scan; a larger *loop_count* means that it may be appropriate to allow for some caching effects across multiple scans.

The last five parameters are pass-by-reference outputs:

**indexStartupCost*

Set to cost of index start-up processing

**indexTotalCost*

Set to total cost of index processing

**indexSelectivity*

Set to index selectivity

**indexCorrelation*

Set to correlation coefficient between index scan order and underlying table's order

**indexPages*

Set to number of index leaf pages

Note that cost estimate functions must be written in C, not in SQL or any available procedural language, because they must access internal data structures of the planner/optimizer.

The index access costs should be computed using the parameters: a sequential disk block fetch has cost `seq_page_cost`, a nonsequential fetch has cost `random_page_cost`, and the cost of processing one index row should usually be taken as `cpu_index_tuple_cost`. In addition, an appropriate multiple of `cpu_operator_cost` should be charged for any comparison operators invoked during index processing (especially evaluation of the indexquals themselves).

The “start-up cost” is the part of the total scan cost that must be expended before we can begin to fetch the first row. For most indexes this can be taken as zero, but an index type with a high start-up cost might want to set it nonzero.

The *indexSelectivity* should be set to the estimated fraction of the parent table rows that will be retrieved during the index scan. In the case of a lossy query, this will typically be higher than the fraction of rows that actually pass the given qual conditions.

The *indexCorrelation* should be set to the correlation (ranging between -1.0 and 1.0) between the index order and the table order. This is used to adjust the estimate for the cost of fetching rows from the parent table.

The *indexPages* should be set to the number of leaf pages. This is used to estimate the number of workers for parallel index scan.

When *loop_count* is greater than one, the returned numbers should be averages expected for any one scan of the index.

Cost Estimation

A typical cost estimator will proceed as follows:

1. Estimate and return the fraction of parent-table rows that will be visited based on the given qual conditions. In the absence of any index-type-specific knowledge, use the standard optimizer function clauselist_selectivity():

   ```
   *indexSelectivity = clauselist_selectivity(root, path->indexquals,
                                              path->indexinfo->rel->relid,
                                              JOIN_INNER, NULL);
   ```

2. Estimate the number of index rows that will be visited during the scan. For many index types this is the same as *indexSelectivity* times the number of rows in the index, but it might be more. (Note that the index's size in pages and rows is available from the path->indexinfo struct.)

3. Estimate the number of index pages that will be retrieved during the scan. This might be just *indexSelectivity* times the index's size in pages.

4. Compute the index access cost. A generic estimator might do this:

   ```
   /*
    * Our generic assumption is that the index pages will be read
    * sequentially, so they cost seq_page_cost each, not random_page_cost.
    * Also, we charge for evaluation of the indexquals at each index row.
    * All the costs are assumed to be paid incrementally during the scan.
    */
   cost_qual_eval(&index_qual_cost, path->indexquals, root);
   *indexStartupCost = index_qual_cost.startup;
   *indexTotalCost = seq_page_cost * numIndexPages +
       (cpu_index_tuple_cost + index_qual_cost.per_tuple) * numIndexTuples;
   ```

   However, the above does not account for amortization of index reads across repeated index scans.

5. Estimate the index correlation. For a simple ordered index on a single field, this can be retrieved from pg_statistic. If the correlation is not known, the conservative estimate is zero (no correlation).

Chapter 63. Generic WAL Records

Although all built-in WAL-logged modules have their own types of WAL records, there is also a generic WAL record type, which describes changes to pages in a generic way. This is useful for extensions that provide custom access methods, because they cannot register their own WAL redo routines.

The API for constructing generic WAL records is defined in `access/generic_xlog.h` and implemented in `access/transam/generic_xlog.c`.

To perform a WAL-logged data update using the generic WAL record facility, follow these steps:

1. `state = GenericXLogStart(relation)` — start construction of a generic WAL record for the given relation.
2. `page = GenericXLogRegisterBuffer(state, buffer, flags)` — register a buffer to be modified within the current generic WAL record. This function returns a pointer to a temporary copy of the buffer's page, where modifications should be made. (Do not modify the buffer's contents directly.) The third argument is a bit mask of flags applicable to the operation. Currently the only such flag is `GENERIC_XLOG_FULL_IMAGE`, which indicates that a full-page image rather than a delta update should be included in the WAL record. Typically this flag would be set if the page is new or has been rewritten completely. `GenericXLogRegisterBuffer` can be repeated if the WAL-logged action needs to modify multiple pages.
3. Apply modifications to the page images obtained in the previous step.
4. `GenericXLogFinish(state)` — apply the changes to the buffers and emit the generic WAL record.

WAL record construction can be canceled between any of the above steps by calling `GenericXLogAbort(state)`. This will discard all changes to the page image copies.

Please note the following points when using the generic WAL record facility:

- No direct modifications of buffers are allowed! All modifications must be done in copies acquired from `GenericXLogRegisterBuffer()`. In other words, code that makes generic WAL records should never call `BufferGetPage()` for itself. However, it remains the caller's responsibility to pin/unpin and lock/unlock the buffers at appropriate times. Exclusive lock must be held on each target buffer from before `GenericXLogRegisterBuffer()` until after `GenericXLogFinish()`.
- Registrations of buffers (step 2) and modifications of page images (step 3) can be mixed freely, i.e., both steps may be repeated in any sequence. Keep in mind that buffers should be registered in the same order in which locks are to be obtained on them during replay.
- The maximum number of buffers that can be registered for a generic WAL record is `MAX_GENERIC_XLOG_PAGES`. An error will be thrown if this limit is exceeded.
- Generic WAL assumes that the pages to be modified have standard layout, and in particular that there is no useful data between `pd_lower` and `pd_upper`.
- Since you are modifying copies of buffer pages, `GenericXLogStart()` does not start a critical section. Thus, you can safely do memory allocation, error throwing, etc. between `GenericXLogStart()` and `GenericXLogFinish()`. The only actual critical section is present inside `GenericXLogFinish()`. There is no need to worry about calling `GenericXLogAbort()` during an error exit, either.
- `GenericXLogFinish()` takes care of marking buffers dirty and setting their LSNs. You do not need to do this explicitly.
- For unlogged relations, everything works the same except that no actual WAL record is emitted. Thus, you typically do not need to do any explicit checks for unlogged relations.
- The generic WAL redo function will acquire exclusive locks to buffers in the same order as they were registered. After redoing all changes, the locks will be released in the same order.
- If `GENERIC_XLOG_FULL_IMAGE` is not specified for a registered buffer, the generic WAL record contains a delta between the old and the new page images. This delta is based on byte-by-byte compar-

ison. This is not very compact for the case of moving data within a page, and might be improved in the future.

Chapter 64. B-Tree Indexes

64.1. Introduction

Postgres Pro includes an implementation of the standard btree (multi-way balanced tree) index data structure. Any data type that can be sorted into a well-defined linear order can be indexed by a btree index. The only limitation is that an index entry cannot exceed approximately one-third of a page (after TOAST compression, if applicable).

Because each btree operator class imposes a sort order on its data type, btree operator classes (or, really, operator families) have come to be used as Postgres Pro's general representation and understanding of sorting semantics. Therefore, they've acquired some features that go beyond what would be needed just to support btree indexes, and parts of the system that are quite distant from the btree AM make use of them.

64.2. Behavior of B-Tree Operator Classes

As shown in Table 40.3, a btree operator class must provide five comparison operators, <, <=, =, >= and >. One might expect that <> should also be part of the operator class, but it is not, because it would almost never be useful to use a <> WHERE clause in an index search. (For some purposes, the planner treats <> as associated with a btree operator class; but it finds that operator via the = operator's negator link, rather than from `pg_amop`.)

When several data types share near-identical sorting semantics, their operator classes can be grouped into an operator family. Doing so is advantageous because it allows the planner to make deductions about cross-type comparisons. Each operator class within the family should contain the single-type operators (and associated support functions) for its input data type, while cross-type comparison operators and support functions are “loose” in the family. It is recommendable that a complete set of cross-type operators be included in the family, thus ensuring that the planner can represent any comparison conditions that it deduces from transitivity.

There are some basic assumptions that a btree operator family must satisfy:

- An = operator must be an equivalence relation; that is, for all non-null values *A*, *B*, *C* of the data type:
  - *A* = *A* is true (*reflexive law*)
  - if *A* = *B*, then *B* = *A* (*symmetric law*)
  - if *A* = *B* and *B* = *C*, then *A* = *C* (*transitive law*)
- A < operator must be a strong ordering relation; that is, for all non-null values *A*, *B*, *C*:
  - *A* < *A* is false (*irreflexive law*)
  - if *A* < *B* and *B* < *C*, then *A* < *C* (*transitive law*)
- Furthermore, the ordering is total; that is, for all non-null values *A*, *B*:
  - exactly one of *A* < *B*, *A* = *B*, and *B* < *A* is true (*trichotomy law*)

  (The trichotomy law justifies the definition of the comparison support function, of course.)

The other three operators are defined in terms of = and < in the obvious way, and must act consistently with them.

For an operator family supporting multiple data types, the above laws must hold when *A*, *B*, *C* are taken from any data types in the family. The transitive laws are the trickiest to ensure, as in cross-type situations they represent statements that the behaviors of two or three different operators are consistent. As an example, it would not work to put `float8` and `numeric` into the same operator family, at least not with the current semantics that `numeric` values are converted to `float8` for comparison to a `float8`. Because

of the limited accuracy of `float8`, this means there are distinct `numeric` values that will compare equal to the same `float8` value, and thus the transitive law would fail.

Another requirement for a multiple-data-type family is that any implicit or binary-coercion casts that are defined between data types included in the operator family must not change the associated sort ordering.

It should be fairly clear why a btree index requires these laws to hold within a single data type: without them there is no ordering to arrange the keys with. Also, index searches using a comparison key of a different data type require comparisons to behave sanely across two data types. The extensions to three or more data types within a family are not strictly required by the btree index mechanism itself, but the planner relies on them for optimization purposes.

To implement the distance ordered (nearest-neighbor) search, we only need to define a distance operator (usually called `<->`) with the corresponding operator family for distance comparison in the index's operator class. These operators must satisfy the following assumptions for all non-null values *A*, *B*, *C* of the datatype:

- *A* `<->` *B* = *B* `<->` *A* (*symmetric law*)
- if *A* = *B*, then *A* `<->` *C* = *B* `<->` *C* (*distance equivalence*)
- if (*A* `<=` *B* and *B* `<=` *C*) or (*A* `>=` *B* and *B* `>=` *C*), then *A* `<->` *B* `<=` *A* `<->` *C* (*monotonicity*)

64.3. B-Tree Support Functions

As shown in Table 40.9, btree defines one required and four optional support functions. The five user-defined methods are:

`order`

For each combination of data types that a btree operator family provides comparison operators for, it must provide a comparison support function, registered in `pg_amproc` with support function number 1 and `amproclefttype`/`amprocrighttype` equal to the left and right data types for the comparison (i.e., the same data types that the matching operators are registered with in `pg_amop`). The comparison function must take two non-null values *A* and *B* and return an `int32` value that is `< 0`, `0`, or `> 0` when *A* < *B*, *A* = *B*, or *A* > *B*, respectively. A null result is disallowed: all values of the data type must be comparable.

If the compared values are of a collatable data type, the appropriate collation OID will be passed to the comparison support function, using the standard `PG_GET_COLLATION()` mechanism.

`sortsupport`

Optionally, a btree operator family may provide *sort support* function(s), registered under support function number 2. These functions allow implementing comparisons for sorting purposes in a more efficient way than naively calling the comparison support function. The APIs involved in this are defined in *src/include/utils/sortsupport.h*.

`in_range`

Optionally, a btree operator family may provide *in_range* support function(s), registered under support function number 3. These are not used during btree index operations; rather, they extend the semantics of the operator family so that it can support window clauses containing the `RANGE` *offset* `PRECEDING` and `RANGE` *offset* `FOLLOWING` frame bound types (see Section 4.2.8). Fundamentally, the extra information provided is how to add or subtract an *offset* value in a way that is compatible with the family's data ordering.

An `in_range` function must have the signature

```
in_range(val type1, base type1, offset type2, sub bool, less bool)
returns bool
```

val and *base* must be of the same type, which is one of the types supported by the operator family (i.e., a type for which it provides an ordering). However, *offset* could be of a different type, which might be one otherwise unsupported by the family. An example is that the built-in time_ops family provides an in_range function that has *offset* of type interval. A family can provide in_range functions for any of its supported types and one or more *offset* types. Each in_range function should be entered in pg_amproc with amproclefttype equal to type1 and amprocrighttype equal to type2.

The essential semantics of an in_range function depend on the two Boolean flag parameters. It should add or subtract *base* and *offset*, then compare *val* to the result, as follows:

- if !*sub* and !*less*, return *val* >= (*base* + *offset*)
- if !*sub* and *less*, return *val* <= (*base* + *offset*)
- if *sub* and !*less*, return *val* >= (*base* - *offset*)
- if *sub* and *less*, return *val* <= (*base* - *offset*)

Before doing so, the function should check the sign of *offset*: if it is less than zero, raise error ERRCODE_INVALID_PRECEDING_OR_FOLLOWING_SIZE (22013) with error text like "invalid preceding or following size in window function". (This is required by the SQL standard, although nonstandard operator families might perhaps choose to ignore this restriction, since there seems to be little semantic necessity for it.) This requirement is delegated to the in_range function so that the core code needn't understand what "less than zero" means for a particular data type.

An additional expectation is that in_range functions should, if practical, avoid throwing an error if *base* + *offset* or *base* - *offset* would overflow. The correct comparison result can be determined even if that value would be out of the data type's range. Note that if the data type includes concepts such as "infinity" or "NaN", extra care may be needed to ensure that in_range's results agree with the normal sort order of the operator family.

The results of the in_range function must be consistent with the sort ordering imposed by the operator family. To be precise, given any fixed values of *offset* and *sub*, then:

- If in_range with *less* = true is true for some *val1* and *base*, it must be true for every *val2* <= *val1* with the same *base*.
- If in_range with *less* = true is false for some *val1* and *base*, it must be false for every *val2* >= *val1* with the same *base*.
- If in_range with *less* = true is true for some *val* and *base1*, it must be true for every *base2* >= *base1* with the same *val*.
- If in_range with *less* = true is false for some *val* and *base1*, it must be false for every *base2* <= *base1* with the same *val*.

Analogous statements with inverted conditions hold when *less* = false.

If the type being ordered (type1) is collatable, the appropriate collation OID will be passed to the in_range function, using the standard PG_GET_COLLATION() mechanism.

in_range functions need not handle NULL inputs, and typically will be marked strict.

equalimage

Optionally, a btree operator family may provide equalimage ("equality implies image equality") support functions, registered under support function number 4. These functions allow the core code to determine when it is safe to apply the btree deduplication optimization. Currently, equalimage functions are only called when building or rebuilding an index.

An equalimage function must have the signature

```
equalimage(opcintype oid) returns bool
```

The return value is static information about an operator class and collation. Returning `true` indicates that the `order` function for the operator class is guaranteed to only return `0` (“arguments are equal”) when its *`A`* and *`B`* arguments are also interchangeable without any loss of semantic information. Not registering an `equalimage` function or returning `false` indicates that this condition cannot be assumed to hold.

The *`opcintype`* argument is the `pg_type.oid` of the data type that the operator class indexes. This is a convenience that allows reuse of the same underlying `equalimage` function across operator classes. If *`opcintype`* is a collatable data type, the appropriate collation OID will be passed to the `equalimage` function, using the standard `PG_GET_COLLATION()` mechanism.

As far as the operator class is concerned, returning `true` indicates that deduplication is safe (or safe for the collation whose OID was passed to its `equalimage` function). However, the core code will only deem deduplication safe for an index when *every* indexed column uses an operator class that registers an `equalimage` function, and each function actually returns `true` when called.

Image equality is *almost* the same condition as simple bitwise equality. There is one subtle difference: When indexing a varlena data type, the on-disk representation of two image equal datums may not be bitwise equal due to inconsistent application of TOAST compression on input. Formally, when an operator class's `equalimage` function returns `true`, it is safe to assume that the `datum_image_eq()` C function will always agree with the operator class's `order` function (provided that the same collation OID is passed to both the `equalimage` and `order` functions).

The core code is fundamentally unable to deduce anything about the “equality implies image equality” status of an operator class within a multiple-data-type family based on details from other operator classes in the same family. Also, it is not sensible for an operator family to register a cross-type `equalimage` function, and attempting to do so will result in an error. This is because “equality implies image equality” status does not just depend on sorting/equality semantics, which are more or less defined at the operator family level. In general, the semantics that one particular data type implements must be considered separately.

The convention followed by the operator classes included with the core Postgres Pro distribution is to register a stock, generic `equalimage` function. Most operator classes register `btequalimage()`, which indicates that deduplication is safe unconditionally. Operator classes for collatable data types such as `text` register `btvarstrequalimage()`, which indicates that deduplication is safe with deterministic collations. Best practice for third-party extensions is to register their own custom function to retain control.

`options`

Optionally, a B-tree operator family may provide `options` (“operator class specific options”) support functions, registered under support function number 5. These functions define a set of user-visible parameters that control operator class behavior.

An `options` support function must have the signature

```
options(relopts local_relopts *) returns void
```

The function is passed a pointer to a `local_relopts` struct, which needs to be filled with a set of operator class specific options. The options can be accessed from other support functions using the `PG_HAS_OPCLASS_OPTIONS()` and `PG_GET_OPCLASS_OPTIONS()` macros.

Currently, no B-Tree operator class has an `options` support function. B-tree doesn't allow flexible representation of keys like GiST, SP-GiST, GIN and BRIN do. So, `options` probably doesn't have much application in the current B-tree index access method. Nevertheless, this support function was added to B-tree for uniformity, and will probably find uses during further evolution of B-tree in Postgres Pro.

64.4. Implementation

This section covers B-Tree index implementation details that may be of use to advanced users.

64.4.1. B-Tree Structure

Postgres Pro Enterprise B-Tree indexes are multi-level tree structures, where each level of the tree can be used as a doubly-linked list of pages. A single metapage is stored in a fixed position at the start of the first segment file of the index. All other pages are either leaf pages or internal pages. Leaf pages are the pages on the lowest level of the tree. All other levels consist of internal pages. Each leaf page contains tuples that point to table rows. Each internal page contains tuples that point to the next level down in the tree. Typically, over 99% of all pages are leaf pages. Both internal pages and leaf pages use the standard page format described in Section 70.6.

New leaf pages are added to a B-Tree index when an existing leaf page cannot fit an incoming tuple. A *page split* operation makes room for items that originally belonged on the overflowing page by moving a portion of the items to a new page. Page splits must also insert a new *downlink* to the new page in the parent page, which may cause the parent to split in turn. Page splits "cascade upwards" in a recursive fashion. When the root page finally cannot fit a new downlink, a *root page split* operation takes place. This adds a new level to the tree structure by creating a new root page that is one level above the original root page.

64.4.2. Bottom-up Index Deletion

B-Tree indexes are not directly aware that under MVCC, there might be multiple extant versions of the same logical table row; to an index, each tuple is an independent object that needs its own index entry. "Version churn" tuples may sometimes accumulate and adversely affect query latency and throughput. This typically occurs with `UPDATE`-heavy workloads where most individual updates cannot apply the HOT optimization. Changing the value of only one column covered by one index during an `UPDATE` *always* necessitates a new set of index tuples — one for *each and every* index on the table. Note in particular that this includes indexes that were not "logically modified" by the `UPDATE`. All indexes will need a successor physical index tuple that points to the latest version in the table. Each new tuple within each index will generally need to coexist with the original "updated" tuple for a short period of time (typically until shortly after the `UPDATE` transaction commits).

B-Tree indexes incrementally delete version churn index tuples by performing *bottom-up index deletion* passes. Each deletion pass is triggered in reaction to an anticipated "version churn page split". This only happens with indexes that are not logically modified by `UPDATE` statements, where concentrated build up of obsolete versions in particular pages would occur otherwise. A page split will usually be avoided, though it's possible that certain implementation-level heuristics will fail to identify and delete even one garbage index tuple (in which case a page split or deduplication pass resolves the issue of an incoming new tuple not fitting on a leaf page). The worst-case number of versions that any index scan must traverse (for any single logical row) is an important contributor to overall system responsiveness and throughput. A bottom-up index deletion pass targets suspected garbage tuples in a single leaf page based on *qualitative* distinctions involving logical rows and versions. This contrasts with the "top-down" index cleanup performed by autovacuum workers, which is triggered when certain *quantitative* table-level thresholds are exceeded (see Section 24.1.6).

> **Note**
>
> Not all deletion operations that are performed within B-Tree indexes are bottom-up deletion operations. There is a distinct category of index tuple deletion: *simple index tuple deletion*. This is a deferred maintenance operation that deletes index tuples that are known to be safe to delete (those whose item identifier's `LP_DEAD` bit is already set). Like bottom-up index deletion, simple index deletion takes place at the point that a page split is anticipated as a way of avoiding the split.
>
> Simple deletion is opportunistic in the sense that it can only take place when recent index scans set the `LP_DEAD` bits of affected items in passing. Prior to PostgreSQL 14, the only category of B-Tree deletion was simple deletion. The main differences between it and bottom-up deletion are that only the former is opportunistically driven by the activity of passing index scans, while only the latter specifically targets version churn from `UPDATE`s that do not logically modify indexed columns.

Bottom-up index deletion performs the vast majority of all garbage index tuple cleanup for particular indexes with certain workloads. This is expected with any B-Tree index that is subject to significant version churn from UPDATEs that rarely or never logically modify the columns that the index covers. The average and worst-case number of versions per logical row can be kept low purely through targeted incremental deletion passes. It's quite possible that the on-disk size of certain indexes will never increase by even one single page/block despite *constant* version churn from UPDATEs. Even then, an exhaustive "clean sweep" by a VACUUM operation (typically run in an autovacuum worker process) will eventually be required as a part of *collective* cleanup of the table and each of its indexes.

Unlike VACUUM, bottom-up index deletion does not provide any strong guarantees about how old the oldest garbage index tuple may be. No index can be permitted to retain "floating garbage" index tuples that became dead prior to a conservative cutoff point shared by the table and all of its indexes collectively. This fundamental table-level invariant makes it safe to recycle table TIDs. This is how it is possible for distinct logical rows to reuse the same table TID over time (though this can never happen with two logical rows whose lifetimes span the same VACUUM cycle).

64.4.3. Deduplication

A duplicate is a leaf page tuple (a tuple that points to a table row) where *all* indexed key columns have values that match corresponding column values from at least one other leaf page tuple in the same index. Duplicate tuples are quite common in practice. B-Tree indexes can use a special, space-efficient representation for duplicates when an optional technique is enabled: *deduplication*.

Deduplication works by periodically merging groups of duplicate tuples together, forming a single *posting list* tuple for each group. The column key value(s) only appear once in this representation. This is followed by a sorted array of TIDs that point to rows in the table. This significantly reduces the storage size of indexes where each value (or each distinct combination of column values) appears several times on average. The latency of queries can be reduced significantly. Overall query throughput may increase significantly. The overhead of routine index vacuuming may also be reduced significantly.

> **Note**
>
> B-Tree deduplication is just as effective with "duplicates" that contain a NULL value, even though NULL values are never equal to each other according to the = member of any B-Tree operator class. As far as any part of the implementation that understands the on-disk B-Tree structure is concerned, NULL is just another value from the domain of indexed values.

The deduplication process occurs lazily, when a new item is inserted that cannot fit on an existing leaf page, though only when index tuple deletion could not free sufficient space for the new item (typically deletion is briefly considered and then skipped over). Unlike GIN posting list tuples, B-Tree posting list tuples do not need to expand every time a new duplicate is inserted; they are merely an alternative physical representation of the original logical contents of the leaf page. This design prioritizes consistent performance with mixed read-write workloads. Most client applications will at least see a moderate performance benefit from using deduplication. Deduplication is enabled by default.

CREATE INDEX and REINDEX apply deduplication to create posting list tuples, though the strategy they use is slightly different. Each group of duplicate ordinary tuples encountered in the sorted input taken from the table is merged into a posting list tuple *before* being added to the current pending leaf page. Individual posting list tuples are packed with as many TIDs as possible. Leaf pages are written out in the usual way, without any separate deduplication pass. This strategy is well-suited to CREATE INDEX and REINDEX because they are once-off batch operations.

Write-heavy workloads that don't benefit from deduplication due to having few or no duplicate values in indexes will incur a small, fixed performance penalty (unless deduplication is explicitly disabled). The deduplicate_items storage parameter can be used to disable deduplication within individual indexes. There is never any performance penalty with read-only workloads, since reading posting list tuples is at least as efficient as reading the standard tuple representation. Disabling deduplication isn't usually helpful.

It is sometimes possible for unique indexes (as well as unique constraints) to use deduplication. This allows leaf pages to temporarily “absorb” extra version churn duplicates. Deduplication in unique indexes augments bottom-up index deletion, especially in cases where a long-running transaction holds a snapshot that blocks garbage collection. The goal is to buy time for the bottom-up index deletion strategy to become effective again. Delaying page splits until a single long-running transaction naturally goes away can allow a bottom-up deletion pass to succeed where an earlier deletion pass failed.

> **Tip**
>
> A special heuristic is applied to determine whether a deduplication pass in a unique index should take place. It can often skip straight to splitting a leaf page, avoiding a performance penalty from wasting cycles on unhelpful deduplication passes. If you're concerned about the overhead of deduplication, consider setting `deduplicate_items = off` selectively. Leaving deduplication enabled in unique indexes has little downside.

Deduplication cannot be used in all cases due to implementation-level restrictions. Deduplication safety is determined when `CREATE INDEX` or `REINDEX` is run.

Note that deduplication is deemed unsafe and cannot be used in the following cases involving semantically significant differences among equal datums:

- `text`, `varchar`, and `char` cannot use deduplication when a *nondeterministic* collation is used. Case and accent differences must be preserved among equal datums.
- `numeric` cannot use deduplication. Numeric display scale must be preserved among equal datums.
- `jsonb` cannot use deduplication, since the `jsonb` B-Tree operator class uses `numeric` internally.
- `float4` and `float8` cannot use deduplication. These types have distinct representations for `-0` and `0`, which are nevertheless considered equal. This difference must be preserved.

There is one further implementation-level restriction that may be lifted in a future version of Postgres Pro Enterprise:

- Container types (such as composite types, arrays, or range types) cannot use deduplication.

There is one further implementation-level restriction that applies regardless of the operator class or collation used:

- `INCLUDE` indexes can never use deduplication.

Chapter 65. GiST Indexes

65.1. Introduction

GiST stands for Generalized Search Tree. It is a balanced, tree-structured access method, that acts as a base template in which to implement arbitrary indexing schemes. B-trees, R-trees and many other indexing schemes can be implemented in GiST.

One advantage of GiST is that it allows the development of custom data types with the appropriate access methods, by an expert in the domain of the data type, rather than a database expert.

Some of the information here is derived from the University of California at Berkeley's GiST Indexing Project *web site* and Marcel Kornacker's thesis, *Access Methods for Next-Generation Database Systems*. The GiST implementation in Postgres Pro is primarily maintained by Teodor Sigaev and Oleg Bartunov, and there is more information on their *web site*.

65.2. Built-in Operator Classes

The core Postgres Pro distribution includes the GiST operator classes shown in Table 65.1. (Some of the optional modules described in Appendix F provide additional GiST operator classes.)

Table 65.1. Built-in GiST Operator Classes

Name	Indexable Operators	Ordering Operators
box_ops	<< (box, box)	<-> (box, point)
	&< (box, box)	
	&& (box, box)	
	&> (box, box)	
	>> (box, box)	
	~= (box, box)	
	@> (box, box)	
	<@ (box, box)	
	&<| (box, box)	
	<<| (box, box)	
	|>> (box, box)	
	|&> (box, box)	
circle_ops	<< (circle, circle)	<-> (circle, point)
	&< (circle, circle)	
	&> (circle, circle)	
	>> (circle, circle)	
	<@ (circle, circle)	
	@> (circle, circle)	
	~= (circle, circle)	
	&& (circle, circle)	
	|>> (circle, circle)	
	<<| (circle, circle)	
	&<| (circle, circle)	
	|&> (circle, circle)	

Name	Indexable Operators	Ordering Operators
inet_ops	<< (inet, inet)	
	<<= (inet, inet)	
	>> (inet, inet)	
	>>= (inet, inet)	
	= (inet, inet)	
	<> (inet, inet)	
	< (inet, inet)	
	<= (inet, inet)	
	> (inet, inet)	
	>= (inet, inet)	
	&& (inet, inet)	
multirange_ops	= (anymultirange, anymultirange)	
	&& (anymultirange, anymultirange)	
	&& (anymultirange, anyrange)	
	@> (anymultirange, anyelement)	
	@> (anymultirange, anymultirange)	
	@> (anymultirange, anyrange)	
	<@ (anymultirange, anymultirange)	
	<@ (anymultirange, anyrange)	
	<< (anymultirange, anymultirange)	
	<< (anymultirange, anyrange)	
	>> (anymultirange, anymultirange)	
	>> (anymultirange, anyrange)	
	&< (anymultirange, anymultirange)	
	&< (anymultirange, anyrange)	
	&> (anymultirange, anymultirange)	
	&> (anymultirange, anyrange)	
	-|- (anymultirange, anymultirange)	
	-|- (anymultirange, anyrange)	
point_ops	|>> (point, point)	<-> (point, point)
	<< (point, point)	
	>> (point, point)	
	<<| (point, point)	
	~= (point, point)	
	<@ (point, box)	
	<@ (point, polygon)	
	<@ (point, circle)	
poly_ops	<< (polygon, polygon)	<-> (polygon, point)
	&< (polygon, polygon)	
	&> (polygon, polygon)	

Name	Indexable Operators	Ordering Operators
	>> (polygon, polygon)	
	<@ (polygon, polygon)	
	@> (polygon, polygon)	
	~= (polygon, polygon)	
	&& (polygon, polygon)	
	<<| (polygon, polygon)	
	&<| (polygon, polygon)	
	|&> (polygon, polygon)	
	|>> (polygon, polygon)	
range_ops	= (anyrange, anyrange)	
	&& (anyrange, anyrange)	
	&& (anyrange, anymultirange)	
	@> (anyrange, anyelement)	
	@> (anyrange, anyrange)	
	@> (anyrange, anymultirange)	
	<@ (anyrange, anyrange)	
	<@ (anyrange, anymultirange)	
	<< (anyrange, anyrange)	
	<< (anyrange, anymultirange)	
	>> (anyrange, anyrange)	
	>> (anyrange, anymultirange)	
	&< (anyrange, anyrange)	
	&< (anyrange, anymultirange)	
	&> (anyrange, anyrange)	
	&> (anyrange, anymultirange)	
	-|- (anyrange, anyrange)	
	-|- (anyrange, anymultirange)	
tsquery_ops	<@ (tsquery, tsquery)	
	@> (tsquery, tsquery)	
tsvector_ops	@@ (tsvector, tsquery)	

For historical reasons, the `inet_ops` operator class is not the default class for types `inet` and `cidr`. To use it, mention the class name in `CREATE INDEX`, for example

```
CREATE INDEX ON my_table USING GIST (my_inet_column inet_ops);
```

65.3. Extensibility

Traditionally, implementing a new index access method meant a lot of difficult work. It was necessary to understand the inner workings of the database, such as the lock manager and Write-Ahead Log. The GiST interface has a high level of abstraction, requiring the access method implementer only to implement the semantics of the data type being accessed. The GiST layer itself takes care of concurrency, logging and searching the tree structure.

This extensibility should not be confused with the extensibility of the other standard search trees in terms of the data they can handle. For example, Postgres Pro supports extensible B-trees and hash indexes.

That means that you can use Postgres Pro to build a B-tree or hash over any data type you want. But B-trees only support range predicates (<, =, >), and hash indexes only support equality queries.

So if you index, say, an image collection with a Postgres Pro B-tree, you can only issue queries such as “is imagex equal to imagey”, “is imagex less than imagey” and “is imagex greater than imagey”. Depending on how you define “equals”, “less than” and “greater than” in this context, this could be useful. However, by using a GiST based index, you could create ways to ask domain-specific questions, perhaps “find all images of horses” or “find all over-exposed images”.

All it takes to get a GiST access method up and running is to implement several user-defined methods, which define the behavior of keys in the tree. Of course these methods have to be pretty fancy to support fancy queries, but for all the standard queries (B-trees, R-trees, etc.) they're relatively straightforward. In short, GiST combines extensibility along with generality, code reuse, and a clean interface.

There are five methods that an index operator class for GiST must provide, and six that are optional. Correctness of the index is ensured by proper implementation of the `same`, `consistent` and `union` methods, while efficiency (size and speed) of the index will depend on the `penalty` and `picksplit` methods. Two optional methods are `compress` and `decompress`, which allow an index to have internal tree data of a different type than the data it indexes. The leaves are to be of the indexed data type, while the other tree nodes can be of any C struct (but you still have to follow Postgres Pro data type rules here, see about `varlena` for variable sized data). If the tree's internal data type exists at the SQL level, the `STORAGE` option of the `CREATE OPERATOR CLASS` command can be used. The optional eighth method is `distance`, which is needed if the operator class wishes to support ordered scans (nearest-neighbor searches). The optional ninth method `fetch` is needed if the operator class wishes to support index-only scans, except when the `compress` method is omitted. The optional tenth method `options` is needed if the operator class has user-specified parameters. The optional eleventh method `sortsupport` is used to speed up building a GiST index.

`consistent`

Given an index entry `p` and a query value `q`, this function determines whether the index entry is “consistent” with the query; that is, could the predicate “*indexed_column indexable_operator* `q`” be true for any row represented by the index entry? For a leaf index entry this is equivalent to testing the indexable condition, while for an internal tree node this determines whether it is necessary to scan the subtree of the index represented by the tree node. When the result is `true`, a `recheck` flag must also be returned. This indicates whether the predicate is certainly true or only possibly true. If `recheck` = `false` then the index has tested the predicate condition exactly, whereas if `recheck` = `true` the row is only a candidate match. In that case the system will automatically evaluate the *`indexable_operator`* against the actual row value to see if it is really a match. This convention allows GiST to support both lossless and lossy index structures.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_consistent(internal, data_type, smallint, oid,
 internal)
RETURNS bool
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_consistent);

Datum
my_consistent(PG_FUNCTION_ARGS)
{
    GISTENTRY  *entry = (GISTENTRY *) PG_GETARG_POINTER(0);
    data_type  *query = PG_GETARG_DATA_TYPE_P(1);
    StrategyNumber strategy = (StrategyNumber) PG_GETARG_UINT16(2);
    /* Oid subtype = PG_GETARG_OID(3); */
    bool       *recheck = (bool *) PG_GETARG_POINTER(4);
```

```
    data_type  *key = DatumGetDataType(entry->key);
    bool        retval;

    /*
     * determine return value as a function of strategy, key and query.
     *
     * Use GIST_LEAF(entry) to know where you're called in the index tree,
     * which comes handy when supporting the = operator for example (you could
     * check for non empty union() in non-leaf nodes and equality in leaf
     * nodes).
     */

    *recheck = true;        /* or false if check is exact */

    PG_RETURN_BOOL(retval);
}
```

Here, `key` is an element in the index and `query` the value being looked up in the index. The `StrategyNumber` parameter indicates which operator of your operator class is being applied — it matches one of the operator numbers in the `CREATE OPERATOR CLASS` command.

Depending on which operators you have included in the class, the data type of `query` could vary with the operator, since it will be whatever type is on the right-hand side of the operator, which might be different from the indexed data type appearing on the left-hand side. (The above code skeleton assumes that only one type is possible; if not, fetching the `query` argument value would have to depend on the operator.) It is recommended that the SQL declaration of the `consistent` function use the opclass's indexed data type for the `query` argument, even though the actual type might be something else depending on the operator.

`union`

This method consolidates information in the tree. Given a set of entries, this function generates a new index entry that represents all the given entries.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_union(internal, internal)
RETURNS storage_type
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_union);

Datum
my_union(PG_FUNCTION_ARGS)
{
    GistEntryVector *entryvec = (GistEntryVector *) PG_GETARG_POINTER(0);
    GISTENTRY  *ent = entryvec->vector;
    data_type  *out,
               *tmp,
               *old;
    int         numranges,
                i = 0;

    numranges = entryvec->n;
    tmp = DatumGetDataType(ent[0].key);
    out = tmp;

    if (numranges == 1)
    {
```

```
            out = data_type_deep_copy(tmp);

            PG_RETURN_DATA_TYPE_P(out);
        }

        for (i = 1; i < numranges; i++)
        {
            old = out;
            tmp = DatumGetDataType(ent[i].key);
            out = my_union_implementation(out, tmp);
        }

        PG_RETURN_DATA_TYPE_P(out);
    }
```

As you can see, in this skeleton we're dealing with a data type where `union(X, Y, Z) = union(union(X, Y), Z)`. It's easy enough to support data types where this is not the case, by implementing the proper union algorithm in this GiST support method.

The result of the `union` function must be a value of the index's storage type, whatever that is (it might or might not be different from the indexed column's type). The `union` function should return a pointer to newly `palloc()`ed memory. You can't just return the input value as-is, even if there is no type change.

As shown above, the `union` function's first `internal` argument is actually a `GistEntryVector` pointer. The second argument is a pointer to an integer variable, which can be ignored. (It used to be required that the `union` function store the size of its result value into that variable, but this is no longer necessary.)

`compress`

Converts a data item into a format suitable for physical storage in an index page. If the `compress` method is omitted, data items are stored in the index without modification.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_compress(internal)
RETURNS internal
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_compress);

Datum
my_compress(PG_FUNCTION_ARGS)
{
    GISTENTRY  *entry = (GISTENTRY *) PG_GETARG_POINTER(0);
    GISTENTRY  *retval;

    if (entry->leafkey)
    {
        /* replace entry->key with a compressed version */
        compressed_data_type *compressed_data =
 palloc(sizeof(compressed_data_type));

        /* fill *compressed_data from entry->key ... */

        retval = palloc(sizeof(GISTENTRY));
        gistentryinit(*retval, PointerGetDatum(compressed_data),
                      entry->rel, entry->page, entry->offset, FALSE);
```

```
        }
        else
        {
            /* typically we needn't do anything with non-leaf entries */
            retval = entry;
        }

        PG_RETURN_POINTER(retval);
    }
```

You have to adapt *compressed_data_type* to the specific type you're converting to in order to compress your leaf nodes, of course.

`decompress`

Converts the stored representation of a data item into a format that can be manipulated by the other GiST methods in the operator class. If the `decompress` method is omitted, it is assumed that the other GiST methods can work directly on the stored data format. (`decompress` is not necessarily the reverse of the `compress` method; in particular, if `compress` is lossy then it's impossible for `decompress` to exactly reconstruct the original data. `decompress` is not necessarily equivalent to `fetch`, either, since the other GiST methods might not require full reconstruction of the data.)

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_decompress(internal)
RETURNS internal
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_decompress);

Datum
my_decompress(PG_FUNCTION_ARGS)
{
    PG_RETURN_POINTER(PG_GETARG_POINTER(0));
}
```

The above skeleton is suitable for the case where no decompression is needed. (But, of course, omitting the method altogether is even easier, and is recommended in such cases.)

`penalty`

Returns a value indicating the “cost” of inserting the new entry into a particular branch of the tree. Items will be inserted down the path of least `penalty` in the tree. Values returned by `penalty` should be non-negative. If a negative value is returned, it will be treated as zero.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_penalty(internal, internal, internal)
RETURNS internal
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;  -- in some cases penalty functions need not be strict
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_penalty);

Datum
my_penalty(PG_FUNCTION_ARGS)
{
    GISTENTRY  *origentry = (GISTENTRY *) PG_GETARG_POINTER(0);
    GISTENTRY  *newentry = (GISTENTRY *) PG_GETARG_POINTER(1);
    float      *penalty = (float *) PG_GETARG_POINTER(2);
```

```
    data_type  *orig = DatumGetDataType(origentry->key);
    data_type  *new = DatumGetDataType(newentry->key);

    *penalty = my_penalty_implementation(orig, new);
    PG_RETURN_POINTER(penalty);
}
```

For historical reasons, the `penalty` function doesn't just return a `float` result; instead it has to store the value at the location indicated by the third argument. The return value per se is ignored, though it's conventional to pass back the address of that argument.

The `penalty` function is crucial to good performance of the index. It'll get used at insertion time to determine which branch to follow when choosing where to add the new entry in the tree. At query time, the more balanced the index, the quicker the lookup.

`picksplit`

When an index page split is necessary, this function decides which entries on the page are to stay on the old page, and which are to move to the new page.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_picksplit(internal, internal)
RETURNS internal
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_picksplit);

Datum
my_picksplit(PG_FUNCTION_ARGS)
{
    GistEntryVector *entryvec = (GistEntryVector *) PG_GETARG_POINTER(0);
    GIST_SPLITVEC *v = (GIST_SPLITVEC *) PG_GETARG_POINTER(1);
    OffsetNumber maxoff = entryvec->n - 1;
    GISTENTRY  *ent = entryvec->vector;
    int         i,
                nbytes;
    OffsetNumber *left,
               *right;
    data_type  *tmp_union;
    data_type  *unionL;
    data_type  *unionR;
    GISTENTRY **raw_entryvec;

    maxoff = entryvec->n - 1;
    nbytes = (maxoff + 1) * sizeof(OffsetNumber);

    v->spl_left = (OffsetNumber *) palloc(nbytes);
    left = v->spl_left;
    v->spl_nleft = 0;

    v->spl_right = (OffsetNumber *) palloc(nbytes);
    right = v->spl_right;
    v->spl_nright = 0;

    unionL = NULL;
    unionR = NULL;

    /* Initialize the raw entry vector. */
```

```
    raw_entryvec = (GISTENTRY **) malloc(entryvec->n * sizeof(void *));
    for (i = FirstOffsetNumber; i <= maxoff; i = OffsetNumberNext(i))
        raw_entryvec[i] = &(entryvec->vector[i]);

    for (i = FirstOffsetNumber; i <= maxoff; i = OffsetNumberNext(i))
    {
        int         real_index = raw_entryvec[i] - entryvec->vector;

        tmp_union = DatumGetDataType(entryvec->vector[real_index].key);
        Assert(tmp_union != NULL);

        /*
         * Choose where to put the index entries and update unionL and unionR
         * accordingly. Append the entries to either v->spl_left or
         * v->spl_right, and care about the counters.
         */

        if (my_choice_is_left(unionL, curl, unionR, curr))
        {
            if (unionL == NULL)
                unionL = tmp_union;
            else
                unionL = my_union_implementation(unionL, tmp_union);

            *left = real_index;
            ++left;
            ++(v->spl_nleft);
        }
        else
        {
            /*
             * Same on the right
             */
        }
    }

    v->spl_ldatum = DataTypeGetDatum(unionL);
    v->spl_rdatum = DataTypeGetDatum(unionR);
    PG_RETURN_POINTER(v);
}
```

Notice that the `picksplit` function's result is delivered by modifying the passed-in `v` structure. The return value per se is ignored, though it's conventional to pass back the address of `v`.

Like `penalty`, the `picksplit` function is crucial to good performance of the index. Designing suitable `penalty` and `picksplit` implementations is where the challenge of implementing well-performing GiST indexes lies.

`same`

Returns true if two index entries are identical, false otherwise. (An “index entry” is a value of the index's storage type, not necessarily the original indexed column's type.)

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_same(storage_type, storage_type, internal)
RETURNS internal
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_same);

Datum
my_same(PG_FUNCTION_ARGS)
{
    prefix_range *v1 = PG_GETARG_PREFIX_RANGE_P(0);
    prefix_range *v2 = PG_GETARG_PREFIX_RANGE_P(1);
    bool       *result = (bool *) PG_GETARG_POINTER(2);

    *result = my_eq(v1, v2);
    PG_RETURN_POINTER(result);
}
```

For historical reasons, the `same` function doesn't just return a Boolean result; instead it has to store the flag at the location indicated by the third argument. The return value per se is ignored, though it's conventional to pass back the address of that argument.

`distance`

Given an index entry `p` and a query value `q`, this function determines the index entry's “distance” from the query value. This function must be supplied if the operator class contains any ordering operators. A query using the ordering operator will be implemented by returning index entries with the smallest “distance” values first, so the results must be consistent with the operator's semantics. For a leaf index entry the result just represents the distance to the index entry; for an internal tree node, the result must be the smallest distance that any child entry could have.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_distance(internal, data_type, smallint, oid, internal)
RETURNS float8
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

And the matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_distance);

Datum
my_distance(PG_FUNCTION_ARGS)
{
    GISTENTRY  *entry = (GISTENTRY *) PG_GETARG_POINTER(0);
    data_type  *query = PG_GETARG_DATA_TYPE_P(1);
    StrategyNumber strategy = (StrategyNumber) PG_GETARG_UINT16(2);
    /* Oid subtype = PG_GETARG_OID(3); */
    /* bool *recheck = (bool *) PG_GETARG_POINTER(4); */
    data_type  *key = DatumGetDataType(entry->key);
    double      retval;

    /*
     * determine return value as a function of strategy, key and query.
     */

    PG_RETURN_FLOAT8(retval);
}
```

The arguments to the `distance` function are identical to the arguments of the `consistent` function.

Some approximation is allowed when determining the distance, so long as the result is never greater than the entry's actual distance. Thus, for example, distance to a bounding box is usually sufficient in geometric applications. For an internal tree node, the distance returned must not be greater than the distance to any of the child nodes. If the returned distance is not exact, the function must set `*recheck` to true. (This is not necessary for internal tree nodes; for them, the calculation is always

assumed to be inexact.) In this case the executor will calculate the accurate distance after fetching the tuple from the heap, and reorder the tuples if necessary.

If the distance function returns `*recheck = true` for any leaf node, the original ordering operator's return type must be `float8` or `float4`, and the distance function's result values must be comparable to those of the original ordering operator, since the executor will sort using both distance function results and recalculated ordering-operator results. Otherwise, the distance function's result values can be any finite `float8` values, so long as the relative order of the result values matches the order returned by the ordering operator. (Infinity and minus infinity are used internally to handle cases such as nulls, so it is not recommended that `distance` functions return these values.)

`fetch`

Converts the compressed index representation of a data item into the original data type, for index-only scans. The returned data must be an exact, non-lossy copy of the originally indexed value.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_fetch(internal)
RETURNS internal
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

The argument is a pointer to a `GISTENTRY` struct. On entry, its `key` field contains a non-NULL leaf datum in compressed form. The return value is another `GISTENTRY` struct, whose `key` field contains the same datum in its original, uncompressed form. If the opclass's compress function does nothing for leaf entries, the `fetch` method can return the argument as-is. Or, if the opclass does not have a compress function, the `fetch` method can be omitted as well, since it would necessarily be a no-op.

The matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_fetch);

Datum
my_fetch(PG_FUNCTION_ARGS)
{
    GISTENTRY  *entry = (GISTENTRY *) PG_GETARG_POINTER(0);
    input_data_type *in = DatumGetPointer(entry->key);
    fetched_data_type *fetched_data;
    GISTENTRY  *retval;

    retval = palloc(sizeof(GISTENTRY));
    fetched_data = palloc(sizeof(fetched_data_type));

    /*
     * Convert 'fetched_data' into the a Datum of the original datatype.
     */

    /* fill *retval from fetched_data. */
    gistentryinit(*retval, PointerGetDatum(converted_datum),
                  entry->rel, entry->page, entry->offset, FALSE);

    PG_RETURN_POINTER(retval);
}
```

If the compress method is lossy for leaf entries, the operator class cannot support index-only scans, and must not define a `fetch` function.

`options`

Allows definition of user-visible parameters that control operator class behavior.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_options(internal)
RETURNS void
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

The function is passed a pointer to a `local_relopts` struct, which needs to be filled with a set of operator class specific options. The options can be accessed from other support functions using the `PG_HAS_OPCLASS_OPTIONS()` and `PG_GET_OPCLASS_OPTIONS()` macros.

An example implementation of my_options() and parameters use from other support functions are given below:

```
typedef enum MyEnumType
{
    MY_ENUM_ON,
    MY_ENUM_OFF,
    MY_ENUM_AUTO
} MyEnumType;

typedef struct
{
    int32   vl_len_;    /* varlena header (do not touch directly!) */
    int     int_param;  /* integer parameter */
    double  real_param; /* real parameter */
    MyEnumType enum_param; /* enum parameter */
    int     str_param;  /* string parameter */
} MyOptionsStruct;

/* String representation of enum values */
static relopt_enum_elt_def myEnumValues[] =
{
    {"on", MY_ENUM_ON},
    {"off", MY_ENUM_OFF},
    {"auto", MY_ENUM_AUTO},
    {(const char *) NULL}   /* list terminator */
};

static char *str_param_default = "default";

/*
 * Sample validator: checks that string is not longer than 8 bytes.
 */
static void
validate_my_string_relopt(const char *value)
{
    if (strlen(value) > 8)
        ereport(ERROR,
                (errcode(ERRCODE_INVALID_PARAMETER_VALUE),
                 errmsg("str_param must be at most 8 bytes")));
}

/*
 * Sample filler: switches characters to lower case.
 */
static Size
fill_my_string_relopt(const char *value, void *ptr)
{
    char   *tmp = str_tolower(value, strlen(value), DEFAULT_COLLATION_OID);
    int     len = strlen(tmp);
```

```
    if (ptr)
        strcpy((char *) ptr, tmp);

    pfree(tmp);
    return len + 1;
}

PG_FUNCTION_INFO_V1(my_options);

Datum
my_options(PG_FUNCTION_ARGS)
{
    local_relopts *relopts = (local_relopts *) PG_GETARG_POINTER(0);

    init_local_reloptions(relopts, sizeof(MyOptionsStruct));
    add_local_int_reloption(relopts, "int_param", "integer parameter",
                            100, 0, 1000000,
                            offsetof(MyOptionsStruct, int_param));
    add_local_real_reloption(relopts, "real_param", "real parameter",
                             1.0, 0.0, 1000000.0,
                             offsetof(MyOptionsStruct, real_param));
    add_local_enum_reloption(relopts, "enum_param", "enum parameter",
                             myEnumValues, MY_ENUM_ON,
                             "Valid values are: \"on\", \"off\" and \"auto\".",
                             offsetof(MyOptionsStruct, enum_param));
    add_local_string_reloption(relopts, "str_param", "string parameter",
                               str_param_default,
                               &validate_my_string_relopt,
                               &fill_my_string_relopt,
                               offsetof(MyOptionsStruct, str_param));

    PG_RETURN_VOID();
}

PG_FUNCTION_INFO_V1(my_compress);

Datum
my_compress(PG_FUNCTION_ARGS)
{
    int     int_param = 100;
    double  real_param = 1.0;
    MyEnumType enum_param = MY_ENUM_ON;
    char   *str_param = str_param_default;

    /*
     * Normally, when opclass contains 'options' method, then options are always
     * passed to support functions.  However, if you add 'options' method to
     * existing opclass, previously defined indexes have no options, so the
     * check is required.
     */
    if (PG_HAS_OPCLASS_OPTIONS())
    {
        MyOptionsStruct *options = (MyOptionsStruct *) PG_GET_OPCLASS_OPTIONS();

        int_param = options->int_param;
        real_param = options->real_param;
        enum_param = options->enum_param;
```

```
            str_param = GET_STRING_RELOPTION(options, str_param);
        }

        /* the rest implementation of support function */
    }
```

Since the representation of the key in GiST is flexible, it may depend on user-specified parameters. For instance, the length of key signature may be specified. See `gtsvector_options()` for example.

`sortsupport`

Returns a comparator function to sort data in a way that preserves locality. It is used by `CREATE INDEX` and `REINDEX` commands. The quality of the created index depends on how well the sort order determined by the comparator function preserves locality of the inputs.

The `sortsupport` method is optional. If it is not provided, `CREATE INDEX` builds the index by inserting each tuple to the tree using the `penalty` and `picksplit` functions, which is much slower.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_sortsupport(internal)
RETURNS void
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

The argument is a pointer to a `SortSupport` struct. At a minimum, the function must fill in its comparator field. The comparator takes three arguments: two Datums to compare, and a pointer to the `SortSupport` struct. The Datums are the two indexed values in the format that they are stored in the index; that is, in the format returned by the `compress` method. The full API is defined in *src/include/utils/sortsupport.h*.

The matching code in the C module could then follow this skeleton:

```
PG_FUNCTION_INFO_V1(my_sortsupport);

static int
my_fastcmp(Datum x, Datum y, SortSupport ssup)
{
  /* establish order between x and y by computing some sorting value z */

  int z1 = ComputeSpatialCode(x);
  int z2 = ComputeSpatialCode(y);

  return z1 == z2 ? 0 : z1 > z2 ? 1 : -1;
}

Datum
my_sortsupport(PG_FUNCTION_ARGS)
{
  SortSupport ssup = (SortSupport) PG_GETARG_POINTER(0);

  ssup->comparator = my_fastcmp;
  PG_RETURN_VOID();
}
```

All the GiST support methods are normally called in short-lived memory contexts; that is, `CurrentMemoryContext` will get reset after each tuple is processed. It is therefore not very important to worry about pfree'ing everything you palloc. However, in some cases it's useful for a support method to cache data across repeated calls. To do that, allocate the longer-lived data in `fcinfo->flinfo->fn_mcxt`, and keep a pointer to it in `fcinfo->flinfo->fn_extra`. Such data will survive for the life of the index operation

(e.g., a single GiST index scan, index build, or index tuple insertion). Be careful to pfree the previous value when replacing a `fn_extra` value, or the leak will accumulate for the duration of the operation.

65.4. Implementation

65.4.1. GiST Index Build Methods

The simplest way to build a GiST index is just to insert all the entries, one by one. This tends to be slow for large indexes, because if the index tuples are scattered across the index and the index is large enough to not fit in cache, a lot of random I/O will be needed. PostgreSQL supports two alternative methods for initial build of a GiST index: *sorted* and *buffered* modes.

The sorted method is only available if each of the opclasses used by the index provides a `sortsupport` function, as described in Section 65.3. If they do, this method is usually the best, so it is used by default.

The buffered method works by not inserting tuples directly into the index right away. It can dramatically reduce the amount of random I/O needed for non-ordered data sets. For well-ordered data sets the benefit is smaller or non-existent, because only a small number of pages receive new tuples at a time, and those pages fit in cache even if the index as a whole does not.

The buffered method needs to call the `penalty` function more often than the simple method does, which consumes some extra CPU resources. Also, the buffers need temporary disk space, up to the size of the resulting index. Buffering can also influence the quality of the resulting index, in both positive and negative directions. That influence depends on various factors, like the distribution of the input data and the operator class implementation.

If sorting is not possible, then by default a GiST index build switches to the buffering method when the index size reaches effective_cache_size. Buffering can be manually forced or prevented by the `buffering` parameter to the CREATE INDEX command. The default behavior is good for most cases, but turning buffering off might speed up the build somewhat if the input data is ordered.

65.5. Examples

The Postgres Pro core system currently provides text search support (indexing for `tsvector` and `tsquery`) as well as R-Tree equivalent functionality for some of the built-in geometric data types. The following `contrib` modules also contain GiST operator classes:

`btree_gist`

B-tree equivalent functionality for several data types

`cube`

Indexing for multidimensional cubes

`hstore`

Module for storing (key, value) pairs

`intarray`

RD-Tree for one-dimensional array of int4 values

`ltree`

Indexing for tree-like structures

`pg_trgm`

Text similarity using trigram matching

`seg`

Indexing for “float ranges”

Chapter 66. SP-GiST Indexes

66.1. Introduction

SP-GiST is an abbreviation for space-partitioned GiST. SP-GiST supports partitioned search trees, which facilitate development of a wide range of different non-balanced data structures, such as quad-trees, k-d trees, and radix trees (tries). The common feature of these structures is that they repeatedly divide the search space into partitions that need not be of equal size. Searches that are well matched to the partitioning rule can be very fast.

These popular data structures were originally developed for in-memory usage. In main memory, they are usually designed as a set of dynamically allocated nodes linked by pointers. This is not suitable for direct storing on disk, since these chains of pointers can be rather long which would require too many disk accesses. In contrast, disk-based data structures should have a high fanout to minimize I/O. The challenge addressed by SP-GiST is to map search tree nodes to disk pages in such a way that a search need access only a few disk pages, even if it traverses many nodes.

Like GiST, SP-GiST is meant to allow the development of custom data types with the appropriate access methods, by an expert in the domain of the data type, rather than a database expert.

Some of the information here is derived from Purdue University's SP-GiST Indexing Project *web site*. The SP-GiST implementation in Postgres Pro is primarily maintained by Teodor Sigaev and Oleg Bartunov, and there is more information on their *web site*.

66.2. Built-in Operator Classes

The core Postgres Pro distribution includes the SP-GiST operator classes shown in Table 66.1.

Table 66.1. Built-in SP-GiST Operator Classes

Name	Indexable Operators	Ordering Operators
box_ops	<< (box,box)	<-> (box,point)
	&< (box,box)	
	&> (box,box)	
	>> (box,box)	
	<@ (box,box)	
	@> (box,box)	
	~= (box,box)	
	&& (box,box)	
	<<| (box,box)	
	&<| (box,box)	
	|&> (box,box)	
	|>> (box,box)	
inet_ops	<< (inet,inet)	
	<<= (inet,inet)	
	>> (inet,inet)	
	>>= (inet,inet)	
	= (inet,inet)	
	<> (inet,inet)	
	< (inet,inet)	
	<= (inet,inet)	

Name	Indexable Operators	Ordering Operators
	> (inet,inet)	
	>= (inet,inet)	
	&& (inet,inet)	
kd_point_ops	|>> (point,point)	<-> (point,point)
	<< (point,point)	
	>> (point,point)	
	<<| (point,point)	
	~= (point,point)	
	<@ (point,box)	
poly_ops	<< (polygon,polygon)	<-> (polygon,point)
	&< (polygon,polygon)	
	&> (polygon,polygon)	
	>> (polygon,polygon)	
	<@ (polygon,polygon)	
	@> (polygon,polygon)	
	~= (polygon,polygon)	
	&& (polygon,polygon)	
	<<| (polygon,polygon)	
	&<| (polygon,polygon)	
	|>> (polygon,polygon)	
	|&> (polygon,polygon)	
quad_point_ops	|>> (point,point)	<-> (point,point)
	<< (point,point)	
	>> (point,point)	
	<<| (point,point)	
	~= (point,point)	
	<@ (point,box)	
range_ops	= (anyrange,anyrange)	
	&& (anyrange,anyrange)	
	@> (anyrange,anyelement)	
	@> (anyrange,anyrange)	
	<@ (anyrange,anyrange)	
	<< (anyrange,anyrange)	
	>> (anyrange,anyrange)	
	&< (anyrange,anyrange)	
	&> (anyrange,anyrange)	
	-|- (anyrange,anyrange)	
text_ops	= (text,text)	
	< (text,text)	
	<= (text,text)	

Name	Indexable Operators	Ordering Operators
	> (text,text)	
	>= (text,text)	
	~<~ (text,text)	
	~<=~ (text,text)	
	~>=~ (text,text)	
	~>~ (text,text)	
	^@ (text,text)	

Of the two operator classes for type `point`, `quad_point_ops` is the default. `kd_point_ops` supports the same operators but uses a different index data structure that may offer better performance in some applications.

The `quad_point_ops`, `kd_point_ops` and `poly_ops` operator classes support the `<->` ordering operator, which enables the k-nearest neighbor (`k-NN`) search over indexed point or polygon data sets.

66.3. Extensibility

SP-GiST offers an interface with a high level of abstraction, requiring the access method developer to implement only methods specific to a given data type. The SP-GiST core is responsible for efficient disk mapping and searching the tree structure. It also takes care of concurrency and logging considerations.

Leaf tuples of an SP-GiST tree usually contain values of the same data type as the indexed column, although it is also possible for them to contain lossy representations of the indexed column. Leaf tuples stored at the root level will directly represent the original indexed data value, but leaf tuples at lower levels might contain only a partial value, such as a suffix. In that case the operator class support functions must be able to reconstruct the original value using information accumulated from the inner tuples that are passed through to reach the leaf level.

When an SP-GiST index is created with `INCLUDE` columns, the values of those columns are also stored in leaf tuples. The `INCLUDE` columns are of no concern to the SP-GiST operator class, so they are not discussed further here.

Inner tuples are more complex, since they are branching points in the search tree. Each inner tuple contains a set of one or more *nodes*, which represent groups of similar leaf values. A node contains a downlink that leads either to another, lower-level inner tuple, or to a short list of leaf tuples that all lie on the same index page. Each node normally has a *label* that describes it; for example, in a radix tree the node label could be the next character of the string value. (Alternatively, an operator class can omit the node labels, if it works with a fixed set of nodes for all inner tuples; see Section 66.4.2.) Optionally, an inner tuple can have a *prefix* value that describes all its members. In a radix tree this could be the common prefix of the represented strings. The prefix value is not necessarily really a prefix, but can be any data needed by the operator class; for example, in a quad-tree it can store the central point that the four quadrants are measured with respect to. A quad-tree inner tuple would then also contain four nodes corresponding to the quadrants around this central point.

Some tree algorithms require knowledge of level (or depth) of the current tuple, so the SP-GiST core provides the possibility for operator classes to manage level counting while descending the tree. There is also support for incrementally reconstructing the represented value when that is needed, and for passing down additional data (called *traverse values*) during a tree descent.

> **Note**
>
> The SP-GiST core code takes care of null entries. Although SP-GiST indexes do store entries for nulls in indexed columns, this is hidden from the index operator class code: no null index entries or search conditions will ever be passed to the operator class methods. (It is assumed that SP-

GiST operators are strict and so cannot succeed for null values.) Null values are therefore not discussed further here.

There are five user-defined methods that an index operator class for SP-GiST must provide, and two are optional. All five mandatory methods follow the convention of accepting two `internal` arguments, the first of which is a pointer to a C struct containing input values for the support method, while the second argument is a pointer to a C struct where output values must be placed. Four of the mandatory methods just return `void`, since all their results appear in the output struct; but `leaf_consistent` returns a `boolean` result. The methods must not modify any fields of their input structs. In all cases, the output struct is initialized to zeroes before calling the user-defined method. The optional sixth method `compress` accepts a `datum` to be indexed as the only argument and returns a value suitable for physical storage in a leaf tuple. The optional seventh method `options` accepts an `internal` pointer to a C struct, where opclass-specific parameters should be placed, and returns `void`.

The five mandatory user-defined methods are:

`config`

Returns static information about the index implementation, including the data type OIDs of the prefix and node label data types.

The SQL declaration of the function must look like this:

```
CREATE FUNCTION my_config(internal, internal) RETURNS void ...
```

The first argument is a pointer to a `spgConfigIn` C struct, containing input data for the function. The second argument is a pointer to a `spgConfigOut` C struct, which the function must fill with result data.

```
typedef struct spgConfigIn
{
    Oid         attType;        /* Data type to be indexed */
} spgConfigIn;

typedef struct spgConfigOut
{
    Oid         prefixType;     /* Data type of inner-tuple prefixes */
    Oid         labelType;      /* Data type of inner-tuple node labels */
    Oid         leafType;       /* Data type of leaf-tuple values */
    bool        canReturnData;  /* Opclass can reconstruct original data */
    bool        longValuesOK;   /* Opclass can cope with values > 1 page */
} spgConfigOut;
```

`attType` is passed in order to support polymorphic index operator classes; for ordinary fixed-data-type operator classes, it will always have the same value and so can be ignored.

For operator classes that do not use prefixes, `prefixType` can be set to `VOIDOID`. Likewise, for operator classes that do not use node labels, `labelType` can be set to `VOIDOID`. `canReturnData` should be set true if the operator class is capable of reconstructing the originally-supplied index value. `longValuesOK` should be set true only when the `attType` is of variable length and the operator class is capable of segmenting long values by repeated suffixing (see Section 66.4.1).

`leafType` should match the index storage type defined by the operator class's `opckeytype` catalog entry. (Note that `opckeytype` can be zero, implying the storage type is the same as the operator class's input type, which is the most common situation.) For reasons of backward compatibility, the `config` method can set `leafType` to some other value, and that value will be used; but this is deprecated since the index contents are then incorrectly identified in the catalogs. Also, it's permissible to leave `leafType` uninitialized (zero); that is interpreted as meaning the index storage type derived from `opckeytype`.

When `attType` and `leafType` are different, the optional method `compress` must be provided. Method `compress` is responsible for transformation of datums to be indexed from `attType` to `leafType`.

`choose`

Chooses a method for inserting a new value into an inner tuple.

The SQL declaration of the function must look like this:

```
CREATE FUNCTION my_choose(internal, internal) RETURNS void ...
```

The first argument is a pointer to a `spgChooseIn` C struct, containing input data for the function. The second argument is a pointer to a `spgChooseOut` C struct, which the function must fill with result data.

```
typedef struct spgChooseIn
{
    Datum       datum;          /* original datum to be indexed */
    Datum       leafDatum;      /* current datum to be stored at leaf */
    int         level;          /* current level (counting from zero) */

    /* Data from current inner tuple */
    bool        allTheSame;     /* tuple is marked all-the-same? */
    bool        hasPrefix;      /* tuple has a prefix? */
    Datum       prefixDatum;    /* if so, the prefix value */
    int         nNodes;         /* number of nodes in the inner tuple */
    Datum      *nodeLabels;     /* node label values (NULL if none) */
} spgChooseIn;

typedef enum spgChooseResultType
{
    spgMatchNode = 1,           /* descend into existing node */
    spgAddNode,                 /* add a node to the inner tuple */
    spgSplitTuple               /* split inner tuple (change its prefix) */
} spgChooseResultType;

typedef struct spgChooseOut
{
    spgChooseResultType resultType;     /* action code, see above */
    union
    {
        struct                  /* results for spgMatchNode */
        {
            int         nodeN;      /* descend to this node (index from 0) */
            int         levelAdd;   /* increment level by this much */
            Datum       restDatum;  /* new leaf datum */
        }           matchNode;
        struct                  /* results for spgAddNode */
        {
            Datum       nodeLabel;  /* new node's label */
            int         nodeN;      /* where to insert it (index from 0) */
        }           addNode;
        struct                  /* results for spgSplitTuple */
        {
            /* Info to form new upper-level inner tuple with one child tuple */
            bool        prefixHasPrefix;    /* tuple should have a prefix? */
            Datum       prefixPrefixDatum;  /* if so, its value */
            int         prefixNNodes;       /* number of nodes */
            Datum      *prefixNodeLabels;   /* their labels (or NULL for
                                             * no labels) */
            int         childNodeN;         /* which node gets child tuple */

            /* Info to form new lower-level inner tuple with all old nodes */
            bool        postfixHasPrefix;   /* tuple should have a prefix? */
```

```
            Datum       postfixPrefixDatum; /* if so, its value */
        }           splitTuple;
    }           result;
} spgChooseOut;
```

`datum` is the original datum of `spgConfigIn.attType` type that was to be inserted into the index. `leafDatum` is a value of `spgConfigOut.leafType` type, which is initially a result of method `compress` applied to `datum` when method `compress` is provided, or the same value as `datum` otherwise. `leafDatum` can change at lower levels of the tree if the `choose` or `picksplit` methods change it. When the insertion search reaches a leaf page, the current value of `leafDatum` is what will be stored in the newly created leaf tuple. `level` is the current inner tuple's level, starting at zero for the root level. `allTheSame` is true if the current inner tuple is marked as containing multiple equivalent nodes (see Section 66.4.3). `hasPrefix` is true if the current inner tuple contains a prefix; if so, `prefixDatum` is its value. `nNodes` is the number of child nodes contained in the inner tuple, and `nodeLabels` is an array of their label values, or NULL if there are no labels.

The `choose` function can determine either that the new value matches one of the existing child nodes, or that a new child node must be added, or that the new value is inconsistent with the tuple prefix and so the inner tuple must be split to create a less restrictive prefix.

If the new value matches one of the existing child nodes, set `resultType` to `spgMatchNode`. Set `nodeN` to the index (from zero) of that node in the node array. Set `levelAdd` to the increment in `level` caused by descending through that node, or leave it as zero if the operator class does not use levels. Set `restDatum` to equal `leafDatum` if the operator class does not modify datums from one level to the next, or otherwise set it to the modified value to be used as `leafDatum` at the next level.

If a new child node must be added, set `resultType` to `spgAddNode`. Set `nodeLabel` to the label to be used for the new node, and set `nodeN` to the index (from zero) at which to insert the node in the node array. After the node has been added, the `choose` function will be called again with the modified inner tuple; that call should result in an `spgMatchNode` result.

If the new value is inconsistent with the tuple prefix, set `resultType` to `spgSplitTuple`. This action moves all the existing nodes into a new lower-level inner tuple, and replaces the existing inner tuple with a tuple having a single downlink pointing to the new lower-level inner tuple. Set `prefixHasPrefix` to indicate whether the new upper tuple should have a prefix, and if so set `prefixPrefixDatum` to the prefix value. This new prefix value must be sufficiently less restrictive than the original to accept the new value to be indexed. Set `prefixNNodes` to the number of nodes needed in the new tuple, and set `prefixNodeLabels` to a palloc'd array holding their labels, or to NULL if node labels are not required. Note that the total size of the new upper tuple must be no more than the total size of the tuple it is replacing; this constrains the lengths of the new prefix and new labels. Set `childNodeN` to the index (from zero) of the node that will downlink to the new lower-level inner tuple. Set `postfixHasPrefix` to indicate whether the new lower-level inner tuple should have a prefix, and if so set `postfixPrefixDatum` to the prefix value. The combination of these two prefixes and the downlink node's label (if any) must have the same meaning as the original prefix, because there is no opportunity to alter the node labels that are moved to the new lower-level tuple, nor to change any child index entries. After the node has been split, the `choose` function will be called again with the replacement inner tuple. That call may return an `spgAddNode` result, if no suitable node was created by the `spgSplitTuple` action. Eventually `choose` must return `spgMatchNode` to allow the insertion to descend to the next level.

`picksplit`

Decides how to create a new inner tuple over a set of leaf tuples.

The SQL declaration of the function must look like this:

```
CREATE FUNCTION my_picksplit(internal, internal) RETURNS void ...
```

The first argument is a pointer to a `spgPickSplitIn` C struct, containing input data for the function. The second argument is a pointer to a `spgPickSplitOut` C struct, which the function must fill with result data.

```
typedef struct spgPickSplitIn
{
    int          nTuples;        /* number of leaf tuples */
    Datum       *datums;         /* their datums (array of length nTuples) */
    int          level;          /* current level (counting from zero) */
} spgPickSplitIn;

typedef struct spgPickSplitOut
{
    bool         hasPrefix;      /* new inner tuple should have a prefix? */
    Datum        prefixDatum;    /* if so, its value */

    int          nNodes;         /* number of nodes for new inner tuple */
    Datum       *nodeLabels;     /* their labels (or NULL for no labels) */

    int         *mapTuplesToNodes;   /* node index for each leaf tuple */
    Datum       *leafTupleDatums;    /* datum to store in each new leaf tuple */
} spgPickSplitOut;
```

`nTuples` is the number of leaf tuples provided. `datums` is an array of their datum values of `spgConfigOut.leafType` type. `level` is the current level that all the leaf tuples share, which will become the level of the new inner tuple.

Set `hasPrefix` to indicate whether the new inner tuple should have a prefix, and if so set `prefixDatum` to the prefix value. Set `nNodes` to indicate the number of nodes that the new inner tuple will contain, and set `nodeLabels` to an array of their label values, or to NULL if node labels are not required. Set `mapTuplesToNodes` to an array that gives the index (from zero) of the node that each leaf tuple should be assigned to. Set `leafTupleDatums` to an array of the values to be stored in the new leaf tuples (these will be the same as the input `datums` if the operator class does not modify datums from one level to the next). Note that the `picksplit` function is responsible for palloc'ing the `nodeLabels`, `mapTuplesToNodes` and `leafTupleDatums` arrays.

If more than one leaf tuple is supplied, it is expected that the `picksplit` function will classify them into more than one node; otherwise it is not possible to split the leaf tuples across multiple pages, which is the ultimate purpose of this operation. Therefore, if the `picksplit` function ends up placing all the leaf tuples in the same node, the core SP-GiST code will override that decision and generate an inner tuple in which the leaf tuples are assigned at random to several identically-labeled nodes. Such a tuple is marked `allTheSame` to signify that this has happened. The `choose` and `inner_consistent` functions must take suitable care with such inner tuples. See Section 66.4.3 for more information.

`picksplit` can be applied to a single leaf tuple only in the case that the `config` function set `longValuesOK` to true and a larger-than-a-page input value has been supplied. In this case the point of the operation is to strip off a prefix and produce a new, shorter leaf datum value. The call will be repeated until a leaf datum short enough to fit on a page has been produced. See Section 66.4.1 for more information.

`inner_consistent`

Returns set of nodes (branches) to follow during tree search.

The SQL declaration of the function must look like this:

```
CREATE FUNCTION my_inner_consistent(internal, internal) RETURNS void ...
```

The first argument is a pointer to a `spgInnerConsistentIn` C struct, containing input data for the function. The second argument is a pointer to a `spgInnerConsistentOut` C struct, which the function must fill with result data.

```
typedef struct spgInnerConsistentIn
{
    ScanKey     scankeys;       /* array of operators and comparison values */
```

```
    ScanKey     orderbys;       /* array of ordering operators and comparison
                                 * values */
    int         nkeys;          /* length of scankeys array */
    int         norderbys;      /* length of orderbys array */

    Datum       reconstructedValue;     /* value reconstructed at parent */
    void       *traversalValue; /* opclass-specific traverse value */
    MemoryContext traversalMemoryContext;   /* put new traverse values here */
    int         level;          /* current level (counting from zero) */
    bool        returnData;     /* original data must be returned? */

    /* Data from current inner tuple */
    bool        allTheSame;     /* tuple is marked all-the-same? */
    bool        hasPrefix;      /* tuple has a prefix? */
    Datum       prefixDatum;    /* if so, the prefix value */
    int         nNodes;         /* number of nodes in the inner tuple */
    Datum      *nodeLabels;     /* node label values (NULL if none) */
} spgInnerConsistentIn;

typedef struct spgInnerConsistentOut
{
    int         nNodes;         /* number of child nodes to be visited */
    int        *nodeNumbers;    /* their indexes in the node array */
    int        *levelAdds;      /* increment level by this much for each */
    Datum      *reconstructedValues;    /* associated reconstructed values */
    void      **traversalValues;        /* opclass-specific traverse values */
    double    **distances;              /* associated distances */
} spgInnerConsistentOut;
```

The array `scankeys`, of length `nkeys`, describes the index search condition(s). These conditions are combined with AND — only index entries that satisfy all of them are interesting. (Note that `nkeys` = 0 implies that all index entries satisfy the query.) Usually the consistent function only cares about the `sk_strategy` and `sk_argument` fields of each array entry, which respectively give the indexable operator and comparison value. In particular it is not necessary to check `sk_flags` to see if the comparison value is NULL, because the SP-GiST core code will filter out such conditions. The array `orderbys`, of length `norderbys`, describes ordering operators (if any) in the same manner. `reconstructedValue` is the value reconstructed for the parent tuple; it is `(Datum) 0` at the root level or if the `inner_consistent` function did not provide a value at the parent level. `traversalValue` is a pointer to any traverse data passed down from the previous call of `inner_consistent` on the parent index tuple, or NULL at the root level. `traversalMemoryContext` is the memory context in which to store output traverse values (see below). `level` is the current inner tuple's level, starting at zero for the root level. `returnData` is `true` if reconstructed data is required for this query; this will only be so if the `config` function asserted `canReturnData`. `allTheSame` is true if the current inner tuple is marked “all-the-same”; in this case all the nodes have the same label (if any) and so either all or none of them match the query (see Section 66.4.3). `hasPrefix` is true if the current inner tuple contains a prefix; if so, `prefixDatum` is its value. `nNodes` is the number of child nodes contained in the inner tuple, and `nodeLabels` is an array of their label values, or NULL if the nodes do not have labels.

`nNodes` must be set to the number of child nodes that need to be visited by the search, and `nodeNumbers` must be set to an array of their indexes. If the operator class keeps track of levels, set `levelAdds` to an array of the level increments required when descending to each node to be visited. (Often these increments will be the same for all the nodes, but that's not necessarily so, so an array is used.) If value reconstruction is needed, set `reconstructedValues` to an array of the values reconstructed for each child node to be visited; otherwise, leave `reconstructedValues` as NULL. The reconstructed values are assumed to be of type `spgConfigOut.leafType`. (However, since the core system will do nothing with them except possibly copy them, it is sufficient for them to have the same `typlen` and `typbyval` properties as `leafType`.) If ordered search is performed, set `distances` to an array of distance values according to `orderbys` array (nodes with lowest distances will be processed first).

Leave it NULL otherwise. If it is desired to pass down additional out-of-band information ("traverse values") to lower levels of the tree search, set `traversalValues` to an array of the appropriate traverse values, one for each child node to be visited; otherwise, leave `traversalValues` as NULL. Note that the `inner_consistent` function is responsible for palloc'ing the `nodeNumbers`, `levelAdds`, `distances`, `reconstructedValues`, and `traversalValues` arrays in the current memory context. However, any output traverse values pointed to by the `traversalValues` array should be allocated in `traversalMemoryContext`. Each traverse value must be a single palloc'd chunk.

`leaf_consistent`

Returns true if a leaf tuple satisfies a query.

The SQL declaration of the function must look like this:

```
CREATE FUNCTION my_leaf_consistent(internal, internal) RETURNS bool ...
```

The first argument is a pointer to a `spgLeafConsistentIn` C struct, containing input data for the function. The second argument is a pointer to a `spgLeafConsistentOut` C struct, which the function must fill with result data.

```
typedef struct spgLeafConsistentIn
{
    ScanKey     scankeys;       /* array of operators and comparison values */
    ScanKey     orderbys;       /* array of ordering operators and comparison
                                 * values */
    int         nkeys;          /* length of scankeys array */
    int         norderbys;      /* length of orderbys array */

    Datum       reconstructedValue;     /* value reconstructed at parent */
    void       *traversalValue; /* opclass-specific traverse value */
    int         level;          /* current level (counting from zero) */
    bool        returnData;     /* original data must be returned? */

    Datum       leafDatum;      /* datum in leaf tuple */
} spgLeafConsistentIn;

typedef struct spgLeafConsistentOut
{
    Datum       leafValue;        /* reconstructed original data, if any */
    bool        recheck;          /* set true if operator must be rechecked */
    bool        recheckDistances; /* set true if distances must be rechecked */
    double     *distances;        /* associated distances */
} spgLeafConsistentOut;
```

The array `scankeys`, of length `nkeys`, describes the index search condition(s). These conditions are combined with AND — only index entries that satisfy all of them satisfy the query. (Note that `nkeys` = 0 implies that all index entries satisfy the query.) Usually the consistent function only cares about the `sk_strategy` and `sk_argument` fields of each array entry, which respectively give the indexable operator and comparison value. In particular it is not necessary to check `sk_flags` to see if the comparison value is NULL, because the SP-GiST core code will filter out such conditions. The array `orderbys`, of length `norderbys`, describes the ordering operators in the same manner. `reconstructedValue` is the value reconstructed for the parent tuple; it is `(Datum) 0` at the root level or if the `inner_consistent` function did not provide a value at the parent level. `traversalValue` is a pointer to any traverse data passed down from the previous call of `inner_consistent` on the parent index tuple, or NULL at the root level. `level` is the current leaf tuple's level, starting at zero for the root level. `returnData` is `true` if reconstructed data is required for this query; this will only be so if the `config` function asserted `canReturnData`. `leafDatum` is the key value of `spgConfigOut.leafType` stored in the current leaf tuple.

The function must return `true` if the leaf tuple matches the query, or `false` if not. In the `true` case, if `returnData` is `true` then `leafValue` must be set to the value (of type `spgConfigIn.attType`) originally

supplied to be indexed for this leaf tuple. Also, `recheck` may be set to `true` if the match is uncertain and so the operator(s) must be re-applied to the actual heap tuple to verify the match. If ordered search is performed, set `distances` to an array of distance values according to `orderbys` array. Leave it NULL otherwise. If at least one of returned distances is not exact, set `recheckDistances` to true. In this case, the executor will calculate the exact distances after fetching the tuple from the heap, and will reorder the tuples if needed.

The optional user-defined methods are:

`Datum compress(Datum in)`

Converts a data item into a format suitable for physical storage in a leaf tuple of the index. It accepts a value of type `spgConfigIn.attType` and returns a value of type `spgConfigOut.leafType`. The output value must not contain an out-of-line TOAST pointer.

Note: the `compress` method is only applied to values to be stored. The consistent methods receive query `scankeys` unchanged, without transformation using `compress`.

`options`

Defines a set of user-visible parameters that control operator class behavior.

The SQL declaration of the function must look like this:

```
CREATE OR REPLACE FUNCTION my_options(internal)
RETURNS void
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;
```

The function is passed a pointer to a `local_relopts` struct, which needs to be filled with a set of operator class specific options. The options can be accessed from other support functions using the `PG_HAS_OPCLASS_OPTIONS()` and `PG_GET_OPCLASS_OPTIONS()` macros.

Since the representation of the key in SP-GiST is flexible, it may depend on user-specified parameters.

All the SP-GiST support methods are normally called in a short-lived memory context; that is, `CurrentMemoryContext` will be reset after processing of each tuple. It is therefore not very important to worry about pfree'ing everything you palloc. (The `config` method is an exception: it should try to avoid leaking memory. But usually the `config` method need do nothing but assign constants into the passed parameter struct.)

If the indexed column is of a collatable data type, the index collation will be passed to all the support methods, using the standard `PG_GET_COLLATION()` mechanism.

66.4. Implementation

This section covers implementation details and other tricks that are useful for implementers of SP-GiST operator classes to know.

66.4.1. SP-GiST Limits

Individual leaf tuples and inner tuples must fit on a single index page (8kB by default). Therefore, when indexing values of variable-length data types, long values can only be supported by methods such as radix trees, in which each level of the tree includes a prefix that is short enough to fit on a page, and the final leaf level includes a suffix also short enough to fit on a page. The operator class should set `longValuesOK` to true only if it is prepared to arrange for this to happen. Otherwise, the SP-GiST core will reject any request to index a value that is too large to fit on an index page.

Likewise, it is the operator class's responsibility that inner tuples do not grow too large to fit on an index page; this limits the number of child nodes that can be used in one inner tuple, as well as the maximum size of a prefix value.

Another limitation is that when an inner tuple's node points to a set of leaf tuples, those tuples must all be in the same index page. (This is a design decision to reduce seeking and save space in the links that chain such tuples together.) If the set of leaf tuples grows too large for a page, a split is performed and an intermediate inner tuple is inserted. For this to fix the problem, the new inner tuple *must* divide the set of leaf values into more than one node group. If the operator class's `picksplit` function fails to do that, the SP-GiST core resorts to extraordinary measures described in Section 66.4.3.

When `longValuesOK` is true, it is expected that successive levels of the SP-GiST tree will absorb more and more information into the prefixes and node labels of the inner tuples, making the required leaf datum smaller and smaller, so that eventually it will fit on a page. To prevent bugs in operator classes from causing infinite insertion loops, the SP-GiST core will raise an error if the leaf datum does not become any smaller within ten cycles of `choose` method calls.

66.4.2. SP-GiST Without Node Labels

Some tree algorithms use a fixed set of nodes for each inner tuple; for example, in a quad-tree there are always exactly four nodes corresponding to the four quadrants around the inner tuple's centroid point. In such a case the code typically works with the nodes by number, and there is no need for explicit node labels. To suppress node labels (and thereby save some space), the `picksplit` function can return NULL for the `nodeLabels` array, and likewise the `choose` function can return NULL for the `prefixNodeLabels` array during a `spgSplitTuple` action. This will in turn result in `nodeLabels` being NULL during subsequent calls to `choose` and `inner_consistent`. In principle, node labels could be used for some inner tuples and omitted for others in the same index.

When working with an inner tuple having unlabeled nodes, it is an error for `choose` to return `spgAddNode`, since the set of nodes is supposed to be fixed in such cases.

66.4.3. “All-the-Same” Inner Tuples

The SP-GiST core can override the results of the operator class's `picksplit` function when `picksplit` fails to divide the supplied leaf values into at least two node categories. When this happens, the new inner tuple is created with multiple nodes that each have the same label (if any) that `picksplit` gave to the one node it did use, and the leaf values are divided at random among these equivalent nodes. The `allTheSame` flag is set on the inner tuple to warn the `choose` and `inner_consistent` functions that the tuple does not have the node set that they might otherwise expect.

When dealing with an `allTheSame` tuple, a `choose` result of `spgMatchNode` is interpreted to mean that the new value can be assigned to any of the equivalent nodes; the core code will ignore the supplied `nodeN` value and descend into one of the nodes at random (so as to keep the tree balanced). It is an error for `choose` to return `spgAddNode`, since that would make the nodes not all equivalent; the `spgSplitTuple` action must be used if the value to be inserted doesn't match the existing nodes.

When dealing with an `allTheSame` tuple, the `inner_consistent` function should return either all or none of the nodes as targets for continuing the index search, since they are all equivalent. This may or may not require any special-case code, depending on how much the `inner_consistent` function normally assumes about the meaning of the nodes.

Chapter 67. GIN Indexes

67.1. Introduction

GIN stands for Generalized Inverted Index. GIN is designed for handling cases where the items to be indexed are composite values, and the queries to be handled by the index need to search for element values that appear within the composite items. For example, the items could be documents, and the queries could be searches for documents containing specific words.

We use the word *item* to refer to a composite value that is to be indexed, and the word *key* to refer to an element value. GIN always stores and searches for keys, not item values per se.

A GIN index stores a set of (key, posting list) pairs, where a *posting list* is a set of row IDs in which the key occurs. The same row ID can appear in multiple posting lists, since an item can contain more than one key. Each key value is stored only once, so a GIN index is very compact for cases where the same key appears many times.

GIN is generalized in the sense that the GIN access method code does not need to know the specific operations that it accelerates. Instead, it uses custom strategies defined for particular data types. The strategy defines how keys are extracted from indexed items and query conditions, and how to determine whether a row that contains some of the key values in a query actually satisfies the query.

One advantage of GIN is that it allows the development of custom data types with the appropriate access methods, by an expert in the domain of the data type, rather than a database expert. This is much the same advantage as using GiST.

The GIN implementation in Postgres Pro is primarily maintained by Teodor Sigaev and Oleg Bartunov. There is more information about GIN on their *website*.

67.2. Built-in Operator Classes

The core Postgres Pro distribution includes the GIN operator classes shown in Table 67.1. (Some of the optional modules described in Appendix F provide additional GIN operator classes.)

Table 67.1. Built-in GIN Operator Classes

Name	Indexable Operators
array_ops	&& (anyarray,anyarray)
	@> (anyarray,anyarray)
	<@ (anyarray,anyarray)
	= (anyarray,anyarray)
jsonb_ops	@> (jsonb,jsonb)
	@? (jsonb,jsonpath)
	@@ (jsonb,jsonpath)
	? (jsonb,text)
	?| (jsonb,text[])
	?& (jsonb,text[])
jsonb_path_ops	@> (jsonb,jsonb)
	@? (jsonb,jsonpath)
	@@ (jsonb,jsonpath)
tsvector_ops	@@ (tsvector,tsquery)

Name	Indexable Operators
	`@@@ (tsvector,tsquery)`

Of the two operator classes for type `jsonb`, `jsonb_ops` is the default. `jsonb_path_ops` supports fewer operators but offers better performance for those operators. See Section 8.14.4 for details.

67.3. Extensibility

The GIN interface has a high level of abstraction, requiring the access method implementer only to implement the semantics of the data type being accessed. The GIN layer itself takes care of concurrency, logging and searching the tree structure.

All it takes to get a GIN access method working is to implement a few user-defined methods, which define the behavior of keys in the tree and the relationships between keys, indexed items, and indexable queries. In short, GIN combines extensibility with generality, code reuse, and a clean interface.

There are two methods that an operator class for GIN must provide:

```
Datum *extractValue(Datum itemValue, int32 *nkeys, bool **nullFlags)
```

Returns a palloc'd array of keys given an item to be indexed. The number of returned keys must be stored into `*nkeys`. If any of the keys can be null, also palloc an array of `*nkeys` `bool` fields, store its address at `*nullFlags`, and set these null flags as needed. `*nullFlags` can be left `NULL` (its initial value) if all keys are non-null. The return value can be `NULL` if the item contains no keys.

```
Datum *extractQuery(Datum query, int32 *nkeys, StrategyNumber n, bool **pmatch, Pointer
**extra_data, bool **nullFlags, int32 *searchMode)
```

Returns a palloc'd array of keys given a value to be queried; that is, `query` is the value on the right-hand side of an indexable operator whose left-hand side is the indexed column. `n` is the strategy number of the operator within the operator class (see Section 40.16.2). Often, `extractQuery` will need to consult `n` to determine the data type of `query` and the method it should use to extract key values. The number of returned keys must be stored into `*nkeys`. If any of the keys can be null, also palloc an array of `*nkeys` `bool` fields, store its address at `*nullFlags`, and set these null flags as needed. `*nullFlags` can be left `NULL` (its initial value) if all keys are non-null. The return value can be `NULL` if the `query` contains no keys.

`searchMode` is an output argument that allows `extractQuery` to specify details about how the search will be done. If `*searchMode` is set to `GIN_SEARCH_MODE_DEFAULT` (which is the value it is initialized to before call), only items that match at least one of the returned keys are considered candidate matches. If `*searchMode` is set to `GIN_SEARCH_MODE_INCLUDE_EMPTY`, then in addition to items containing at least one matching key, items that contain no keys at all are considered candidate matches. (This mode is useful for implementing is-subset-of operators, for example.) If `*searchMode` is set to `GIN_SEARCH_MODE_ALL`, then all non-null items in the index are considered candidate matches, whether they match any of the returned keys or not. (This mode is much slower than the other two choices, since it requires scanning essentially the entire index, but it may be necessary to implement corner cases correctly. An operator that needs this mode in most cases is probably not a good candidate for a GIN operator class.) The symbols to use for setting this mode are defined in `access/gin.h`.

`pmatch` is an output argument for use when partial match is supported. To use it, `extractQuery` must allocate an array of `*nkeys` `bool`s and store its address at `*pmatch`. Each element of the array should be set to true if the corresponding key requires partial match, false if not. If `*pmatch` is set to `NULL` then GIN assumes partial match is not required. The variable is initialized to `NULL` before call, so this argument can simply be ignored by operator classes that do not support partial match.

`extra_data` is an output argument that allows `extractQuery` to pass additional data to the `consistent` and `comparePartial` methods. To use it, `extractQuery` must allocate an array of `*nkeys` pointers and store its address at `*extra_data`, then store whatever it wants to into the individual pointers.

The variable is initialized to NULL before call, so this argument can simply be ignored by operator classes that do not require extra data. If *extra_data is set, the whole array is passed to the consistent method, and the appropriate element to the comparePartial method.

An operator class must also provide a function to check if an indexed item matches the query. It comes in two flavors, a Boolean consistent function, and a ternary triConsistent function. triConsistent covers the functionality of both, so providing triConsistent alone is sufficient. However, if the Boolean variant is significantly cheaper to calculate, it can be advantageous to provide both. If only the Boolean variant is provided, some optimizations that depend on refuting index items before fetching all the keys are disabled.

```
bool consistent(bool check[], StrategyNumber n, Datum query, int32 nkeys, Pointer extra_data[], bool *recheck, Datum queryKeys[], bool nullFlags[])
```

Returns true if an indexed item satisfies the query operator with strategy number n (or might satisfy it, if the recheck indication is returned). This function does not have direct access to the indexed item's value, since GIN does not store items explicitly. Rather, what is available is knowledge about which key values extracted from the query appear in a given indexed item. The check array has length nkeys, which is the same as the number of keys previously returned by extractQuery for this query datum. Each element of the check array is true if the indexed item contains the corresponding query key, i.e., if (check[i] == true) the i-th key of the extractQuery result array is present in the indexed item. The original query datum is passed in case the consistent method needs to consult it, and so are the queryKeys[] and nullFlags[] arrays previously returned by extractQuery. extra_data is the extra-data array returned by extractQuery, or NULL if none.

When extractQuery returns a null key in queryKeys[], the corresponding check[] element is true if the indexed item contains a null key; that is, the semantics of check[] are like IS NOT DISTINCT FROM. The consistent function can examine the corresponding nullFlags[] element if it needs to tell the difference between a regular value match and a null match.

On success, *recheck should be set to true if the heap tuple needs to be rechecked against the query operator, or false if the index test is exact. That is, a false return value guarantees that the heap tuple does not match the query; a true return value with *recheck set to false guarantees that the heap tuple does match the query; and a true return value with *recheck set to true means that the heap tuple might match the query, so it needs to be fetched and rechecked by evaluating the query operator directly against the originally indexed item.

```
GinTernaryValue triConsistent(GinTernaryValue check[], StrategyNumber n, Datum query, int32 nkeys, Pointer extra_data[], Datum queryKeys[], bool nullFlags[])
```

triConsistent is similar to consistent, but instead of Booleans in the check vector, there are three possible values for each key: GIN_TRUE, GIN_FALSE and GIN_MAYBE. GIN_FALSE and GIN_TRUE have the same meaning as regular Boolean values, while GIN_MAYBE means that the presence of that key is not known. When GIN_MAYBE values are present, the function should only return GIN_TRUE if the item certainly matches whether or not the index item contains the corresponding query keys. Likewise, the function must return GIN_FALSE only if the item certainly does not match, whether or not it contains the GIN_MAYBE keys. If the result depends on the GIN_MAYBE entries, i.e., the match cannot be confirmed or refuted based on the known query keys, the function must return GIN_MAYBE.

When there are no GIN_MAYBE values in the check vector, a GIN_MAYBE return value is the equivalent of setting the recheck flag in the Boolean consistent function.

In addition, GIN must have a way to sort the key values stored in the index. The operator class can define the sort ordering by specifying a comparison method:

```
int compare(Datum a, Datum b)
```

Compares two keys (not indexed items!) and returns an integer less than zero, zero, or greater than zero, indicating whether the first key is less than, equal to, or greater than the second. Null keys are never passed to this function.

Alternatively, if the operator class does not provide a `compare` method, GIN will look up the default btree operator class for the index key data type, and use its comparison function. It is recommended to specify the comparison function in a GIN operator class that is meant for just one data type, as looking up the btree operator class costs a few cycles. However, polymorphic GIN operator classes (such as `array_ops`) typically cannot specify a single comparison function.

An operator class for GIN can optionally supply the following methods:

`int comparePartial(Datum partial_key, Datum key, StrategyNumber n, Pointer extra_data)`

Compare a partial-match query key to an index key. Returns an integer whose sign indicates the result: less than zero means the index key does not match the query, but the index scan should continue; zero means that the index key does match the query; greater than zero indicates that the index scan should stop because no more matches are possible. The strategy number `n` of the operator that generated the partial match query is provided, in case its semantics are needed to determine when to end the scan. Also, `extra_data` is the corresponding element of the extra-data array made by `extractQuery`, or `NULL` if none. Null keys are never passed to this function.

`void options(local_relopts *relopts)`

Defines a set of user-visible parameters that control operator class behavior.

The `options` function is passed a pointer to a `local_relopts` struct, which needs to be filled with a set of operator class specific options. The options can be accessed from other support functions using the `PG_HAS_OPCLASS_OPTIONS()` and `PG_GET_OPCLASS_OPTIONS()` macros.

Since both key extraction of indexed values and representation of the key in GIN are flexible, they may depend on user-specified parameters.

To support “partial match” queries, an operator class must provide the `comparePartial` method, and its `extractQuery` method must set the `pmatch` parameter when a partial-match query is encountered. See Section 67.4.2 for details.

The actual data types of the various `Datum` values mentioned above vary depending on the operator class. The item values passed to `extractValue` are always of the operator class's input type, and all key values must be of the class's `STORAGE` type. The type of the `query` argument passed to `extractQuery`, `consistent` and `triConsistent` is whatever is the right-hand input type of the class member operator identified by the strategy number. This need not be the same as the indexed type, so long as key values of the correct type can be extracted from it. However, it is recommended that the SQL declarations of these three support functions use the opclass's indexed data type for the `query` argument, even though the actual type might be something else depending on the operator.

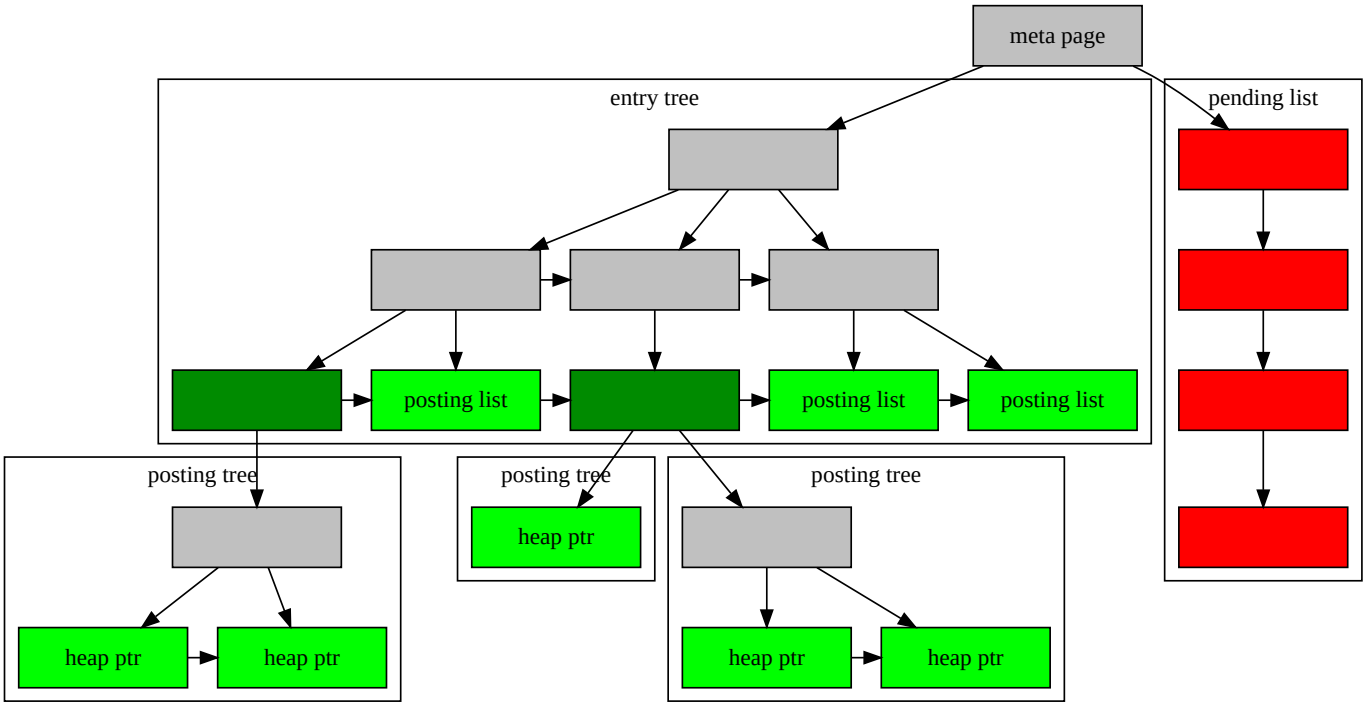
67.4. Implementation

Internally, a GIN index contains a B-tree index constructed over keys, where each key is an element of one or more indexed items (a member of an array, for example) and where each tuple in a leaf page contains either a pointer to a B-tree of heap pointers (a “posting tree”), or a simple list of heap pointers (a “posting list”) when the list is small enough to fit into a single index tuple along with the key value. Figure 67.1 illustrates these components of a GIN index.

As of PostgreSQL 9.1, null key values can be included in the index. Also, placeholder nulls are included in the index for indexed items that are null or contain no keys according to `extractValue`. This allows searches that should find empty items to do so.

Multicolumn GIN indexes are implemented by building a single B-tree over composite values (column number, key value). The key values for different columns can be of different types.

Figure 67.1. GIN Internals



67.4.1. GIN Fast Update Technique

Updating a GIN index tends to be slow because of the intrinsic nature of inverted indexes: inserting or updating one heap row can cause many inserts into the index (one for each key extracted from the indexed item). GIN is capable of postponing much of this work by inserting new tuples into a temporary, unsorted list of pending entries. When the table is vacuumed or autoanalyzed, or when `gin_clean_pending_list` function is called, or if the pending list becomes larger than gin_pending_list_limit, the entries are moved to the main GIN data structure using the same bulk insert techniques used during initial index creation. This greatly improves GIN index update speed, even counting the additional vacuum overhead. Moreover the overhead work can be done by a background process instead of in foreground query processing.

The main disadvantage of this approach is that searches must scan the list of pending entries in addition to searching the regular index, and so a large list of pending entries will slow searches significantly. Another disadvantage is that, while most updates are fast, an update that causes the pending list to become “too large” will incur an immediate cleanup cycle and thus be much slower than other updates. Proper use of autovacuum can minimize both of these problems.

If consistent response time is more important than update speed, use of pending entries can be disabled by turning off the `fastupdate` storage parameter for a GIN index. See CREATE INDEX for details.

67.4.2. Partial Match Algorithm

GIN can support “partial match” queries, in which the query does not determine an exact match for one or more keys, but the possible matches fall within a reasonably narrow range of key values (within the key sorting order determined by the `compare` support method). The `extractQuery` method, instead of returning a key value to be matched exactly, returns a key value that is the lower bound of the range to be searched, and sets the `pmatch` flag true. The key range is then scanned using the `comparePartial` method. `comparePartial` must return zero for a matching index key, less than zero for a non-match that is still within the range to be searched, or greater than zero if the index key is past the range that could match.

67.5. GIN Tips and Tricks

Create vs. insert

Insertion into a GIN index can be slow due to the likelihood of many keys being inserted for each item. So, for bulk insertions into a table it is advisable to drop the GIN index and recreate it after finishing bulk insertion.

When `fastupdate` is enabled for GIN (see Section 67.4.1 for details), the penalty is less than when it is not. But for very large updates it may still be best to drop and recreate the index.

maintenance_work_mem

Build time for a GIN index is very sensitive to the `maintenance_work_mem` setting; it doesn't pay to skimp on work memory during index creation.

gin_pending_list_limit

During a series of insertions into an existing GIN index that has `fastupdate` enabled, the system will clean up the pending-entry list whenever the list grows larger than `gin_pending_list_limit`. To avoid fluctuations in observed response time, it's desirable to have pending-list cleanup occur in the background (i.e., via autovacuum). Foreground cleanup operations can be avoided by increasing `gin_pending_list_limit` or making autovacuum more aggressive. However, enlarging the threshold of the cleanup operation means that if a foreground cleanup does occur, it will take even longer.

`gin_pending_list_limit` can be overridden for individual GIN indexes by changing storage parameters, which allows each GIN index to have its own cleanup threshold. For example, it's possible to increase the threshold only for the GIN index which can be updated heavily, and decrease it otherwise.

gin_fuzzy_search_limit

The primary goal of developing GIN indexes was to create support for highly scalable full-text search in Postgres Pro, and there are often situations when a full-text search returns a very large set of results. Moreover, this often happens when the query contains very frequent words, so that the large result set is not even useful. Since reading many tuples from the disk and sorting them could take a lot of time, this is unacceptable for production. (Note that the index search itself is very fast.)

To facilitate controlled execution of such queries, GIN has a configurable soft upper limit on the number of rows returned: the `gin_fuzzy_search_limit` configuration parameter. It is set to 0 (meaning no limit) by default. If a non-zero limit is set, then the returned set is a subset of the whole result set, chosen at random.

“Soft” means that the actual number of returned results could differ somewhat from the specified limit, depending on the query and the quality of the system's random number generator.

From experience, values in the thousands (e.g., 5000 — 20000) work well.

67.6. Limitations

GIN assumes that indexable operators are strict. This means that `extractValue` will not be called at all on a null item value (instead, a placeholder index entry is created automatically), and `extractQuery` will not be called on a null query value either (instead, the query is presumed to be unsatisfiable). Note however that null key values contained within a non-null composite item or query value are supported.

67.7. Examples

The core Postgres Pro distribution includes the GIN operator classes previously shown in Table 67.1. The following `contrib` modules also contain GIN operator classes:

`btree_gin`

B-tree equivalent functionality for several data types

`hstore`

Module for storing (key, value) pairs

`intarray`

Enhanced support for `int[]`

`pg_trgm`

Text similarity using trigram matching

Chapter 68. BRIN Indexes

68.1. Introduction

BRIN stands for Block Range Index. BRIN is designed for handling very large tables in which certain columns have some natural correlation with their physical location within the table.

BRIN works in terms of *block ranges* (or "page ranges"). A block range is a group of pages that are physically adjacent in the table; for each block range, some summary info is stored by the index. For example, a table storing a store's sale orders might have a date column on which each order was placed, and most of the time the entries for earlier orders will appear earlier in the table as well; a table storing a ZIP code column might have all codes for a city grouped together naturally.

BRIN indexes can satisfy queries via regular bitmap index scans, and will return all tuples in all pages within each range if the summary info stored by the index is *consistent* with the query conditions. The query executor is in charge of rechecking these tuples and discarding those that do not match the query conditions — in other words, these indexes are lossy. Because a BRIN index is very small, scanning the index adds little overhead compared to a sequential scan, but may avoid scanning large parts of the table that are known not to contain matching tuples.

The specific data that a BRIN index will store, as well as the specific queries that the index will be able to satisfy, depend on the operator class selected for each column of the index. Data types having a linear sort order can have operator classes that store the minimum and maximum value within each block range, for instance; geometrical types might store the bounding box for all the objects in the block range.

The size of the block range is determined at index creation time by the `pages_per_range` storage parameter. The number of index entries will be equal to the size of the relation in pages divided by the selected value for `pages_per_range`. Therefore, the smaller the number, the larger the index becomes (because of the need to store more index entries), but at the same time the summary data stored can be more precise and more data blocks can be skipped during an index scan.

68.1.1. Index Maintenance

At the time of creation, all existing heap pages are scanned and a summary index tuple is created for each range, including the possibly-incomplete range at the end. As new pages are filled with data, page ranges that are already summarized will cause the summary information to be updated with data from the new tuples. When a new page is created that does not fall within the last summarized range, the range that the new page belongs to does not automatically acquire a summary tuple; those tuples remain unsummarized until a summarization run is invoked later, creating the initial summary for that range.

There are several ways to trigger the initial summarization of a page range. If the table is vacuumed, either manually or by autovacuum, all existing unsummarized page ranges are summarized. Also, if the index's autosummarize parameter is enabled, which it isn't by default, whenever autovacuum runs in that database, summarization will occur for all unsummarized page ranges that have been filled, regardless of whether the table itself is processed by autovacuum; see below.

Lastly, the following functions can be used:

`brin_summarize_new_values(regclass)` which summarizes all unsummarized ranges;
`brin_summarize_range(regclass, bigint)` which summarizes only the range containing the given page, if it is unsummarized.

When autosummarization is enabled, a request is sent to `autovacuum` to execute a targeted summarization for a block range when an insertion is detected for the first item of the first page of the next block range, to be fulfilled the next time an autovacuum worker finishes running in the same database. If the request queue is full, the request is not recorded and a message is sent to the server log:

```
LOG:  request for BRIN range summarization for index "brin_wi_idx" page 128 was not
 recorded
```

When this happens, the range will remain unsummarized until the next regular vacuum run on the table, or one of the functions mentioned above are invoked.

Conversely, a range can be de-summarized using the `brin_desummarize_range(regclass, bigint)` function, which is useful when the index tuple is no longer a very good representation because the existing values have changed. See Section 9.27.8 for details.

68.2. Built-in Operator Classes

The core Postgres Pro distribution includes the BRIN operator classes shown in Table 68.1.

The *minmax* operator classes store the minimum and the maximum values appearing in the indexed column within the range. The *inclusion* operator classes store a value which includes the values in the indexed column within the range. The *bloom* operator classes build a Bloom filter for all values in the range. The *minmax-multi* operator classes store multiple minimum and maximum values, representing values appearing in the indexed column within the range.

Table 68.1. Built-in BRIN Operator Classes

Name	Indexable Operators
bit_minmax_ops	= (bit,bit)
	< (bit,bit)
	> (bit,bit)
	<= (bit,bit)
	>= (bit,bit)
box_inclusion_ops	@> (box,point)
	<< (box,box)
	&< (box,box)
	&> (box,box)
	>> (box,box)
	<@ (box,box)
	@> (box,box)
	~= (box,box)
	&& (box,box)
	<<| (box,box)
	&<| (box,box)
	|&> (box,box)
	|>> (box,box)
bpchar_bloom_ops	= (character,character)
bpchar_minmax_ops	= (character,character)
	< (character,character)
	<= (character,character)
	> (character,character)
	>= (character,character)
bytea_bloom_ops	= (bytea,bytea)
bytea_minmax_ops	= (bytea,bytea)
	< (bytea,bytea)
	<= (bytea,bytea)
	> (bytea,bytea)
	>= (bytea,bytea)

Name	Indexable Operators
char_bloom_ops	= ("char","char")
char_minmax_ops	= ("char","char")
	< ("char","char")
	<= ("char","char")
	> ("char","char")
	>= ("char","char")
date_bloom_ops	= (date,date)
date_minmax_ops	= (date,date)
	< (date,date)
	<= (date,date)
	> (date,date)
	>= (date,date)
date_minmax_multi_ops	= (date,date)
	< (date,date)
	<= (date,date)
	> (date,date)
	>= (date,date)
float4_bloom_ops	= (float4,float4)
float4_minmax_ops	= (float4,float4)
	< (float4,float4)
	> (float4,float4)
	<= (float4,float4)
	>= (float4,float4)
float4_minmax_multi_ops	= (float4,float4)
	< (float4,float4)
	> (float4,float4)
	<= (float4,float4)
	>= (float4,float4)
float8_bloom_ops	= (float8,float8)
float8_minmax_ops	= (float8,float8)
	< (float8,float8)
	<= (float8,float8)
	> (float8,float8)
	>= (float8,float8)
float8_minmax_multi_ops	= (float8,float8)
	< (float8,float8)
	<= (float8,float8)
	> (float8,float8)
	>= (float8,float8)
inet_inclusion_ops	<< (inet,inet)

Name	Indexable Operators
	<<= (inet,inet)
	>> (inet,inet)
	>>= (inet,inet)
	= (inet,inet)
	&& (inet,inet)
inet_bloom_ops	= (inet,inet)
inet_minmax_ops	= (inet,inet)
	< (inet,inet)
	<= (inet,inet)
	> (inet,inet)
	>= (inet,inet)
inet_minmax_multi_ops	= (inet,inet)
	< (inet,inet)
	<= (inet,inet)
	> (inet,inet)
	>= (inet,inet)
int2_bloom_ops	= (int2,int2)
int2_minmax_ops	= (int2,int2)
	< (int2,int2)
	> (int2,int2)
	<= (int2,int2)
	>= (int2,int2)
int2_minmax_multi_ops	= (int2,int2)
	< (int2,int2)
	> (int2,int2)
	<= (int2,int2)
	>= (int2,int2)
int4_bloom_ops	= (int4,int4)
int4_minmax_ops	= (int4,int4)
	< (int4,int4)
	> (int4,int4)
	<= (int4,int4)
	>= (int4,int4)
int4_minmax_multi_ops	= (int4,int4)
	< (int4,int4)
	> (int4,int4)
	<= (int4,int4)
	>= (int4,int4)
int8_bloom_ops	= (bigint,bigint)
int8_minmax_ops	= (bigint,bigint)

Name	Indexable Operators
	< (bigint,bigint)
	> (bigint,bigint)
	<= (bigint,bigint)
	>= (bigint,bigint)
int8_minmax_multi_ops	= (bigint,bigint)
	< (bigint,bigint)
	> (bigint,bigint)
	<= (bigint,bigint)
	>= (bigint,bigint)
interval_bloom_ops	= (interval,interval)
interval_minmax_ops	= (interval,interval)
	< (interval,interval)
	<= (interval,interval)
	> (interval,interval)
	>= (interval,interval)
interval_minmax_multi_ops	= (interval,interval)
	< (interval,interval)
	<= (interval,interval)
	> (interval,interval)
	>= (interval,interval)
macaddr_bloom_ops	= (macaddr,macaddr)
macaddr_minmax_ops	= (macaddr,macaddr)
	< (macaddr,macaddr)
	<= (macaddr,macaddr)
	> (macaddr,macaddr)
	>= (macaddr,macaddr)
macaddr_minmax_multi_ops	= (macaddr,macaddr)
	< (macaddr,macaddr)
	<= (macaddr,macaddr)
	> (macaddr,macaddr)
	>= (macaddr,macaddr)
macaddr8_bloom_ops	= (macaddr8,macaddr8)
macaddr8_minmax_ops	= (macaddr8,macaddr8)
	< (macaddr8,macaddr8)
	<= (macaddr8,macaddr8)
	> (macaddr8,macaddr8)
	>= (macaddr8,macaddr8)
macaddr8_minmax_multi_ops	= (macaddr8,macaddr8)
	< (macaddr8,macaddr8)
	<= (macaddr8,macaddr8)

Name	Indexable Operators
	> (macaddr8,macaddr8)
	>= (macaddr8,macaddr8)
name_bloom_ops	= (name,name)
name_minmax_ops	= (name,name)
	< (name,name)
	<= (name,name)
	> (name,name)
	>= (name,name)
numeric_bloom_ops	= (numeric,numeric)
numeric_minmax_ops	= (numeric,numeric)
	< (numeric,numeric)
	<= (numeric,numeric)
	> (numeric,numeric)
	>= (numeric,numeric)
numeric_minmax_multi_ops	= (numeric,numeric)
	< (numeric,numeric)
	<= (numeric,numeric)
	> (numeric,numeric)
	>= (numeric,numeric)
oid_bloom_ops	= (oid,oid)
oid_minmax_ops	= (oid,oid)
	< (oid,oid)
	> (oid,oid)
	<= (oid,oid)
	>= (oid,oid)
oid_minmax_multi_ops	= (oid,oid)
	< (oid,oid)
	> (oid,oid)
	<= (oid,oid)
	>= (oid,oid)
pg_lsn_bloom_ops	= (pg_lsn,pg_lsn)
pg_lsn_minmax_ops	= (pg_lsn,pg_lsn)
	< (pg_lsn,pg_lsn)
	> (pg_lsn,pg_lsn)
	<= (pg_lsn,pg_lsn)
	>= (pg_lsn,pg_lsn)
pg_lsn_minmax_multi_ops	= (pg_lsn,pg_lsn)
	< (pg_lsn,pg_lsn)
	> (pg_lsn,pg_lsn)
	<= (pg_lsn,pg_lsn)

Name	Indexable Operators
	>= (pg_lsn,pg_lsn)
range_inclusion_ops	= (anyrange,anyrange)
	< (anyrange,anyrange)
	<= (anyrange,anyrange)
	>= (anyrange,anyrange)
	> (anyrange,anyrange)
	&& (anyrange,anyrange)
	@> (anyrange,anyelement)
	@> (anyrange,anyrange)
	<@ (anyrange,anyrange)
	<< (anyrange,anyrange)
	>> (anyrange,anyrange)
	&< (anyrange,anyrange)
	&> (anyrange,anyrange)
	-|- (anyrange,anyrange)
text_bloom_ops	= (text,text)
text_minmax_ops	= (text,text)
	< (text,text)
	<= (text,text)
	> (text,text)
	>= (text,text)
tid_bloom_ops	= (tid,tid)
tid_minmax_ops	= (tid,tid)
	< (tid,tid)
	> (tid,tid)
	<= (tid,tid)
	>= (tid,tid)
tid_minmax_multi_ops	= (tid,tid)
	< (tid,tid)
	> (tid,tid)
	<= (tid,tid)
	>= (tid,tid)
timestamp_bloom_ops	= (timestamp,timestamp)
timestamp_minmax_ops	= (timestamp,timestamp)
	< (timestamp,timestamp)
	<= (timestamp,timestamp)
	> (timestamp,timestamp)
	>= (timestamp,timestamp)
timestamp_minmax_multi_ops	= (timestamp,timestamp)
	< (timestamp,timestamp)

Name	Indexable Operators
	<= (timestamp,timestamp)
	> (timestamp,timestamp)
	>= (timestamp,timestamp)
timestamptz_bloom_ops	= (timestamptz,timestamptz)
timestamptz_minmax_ops	= (timestamptz,timestamptz)
	< (timestamptz,timestamptz)
	<= (timestamptz,timestamptz)
	> (timestamptz,timestamptz)
	>= (timestamptz,timestamptz)
timestamptz_minmax_multi_ops	= (timestamptz,timestamptz)
	< (timestamptz,timestamptz)
	<= (timestamptz,timestamptz)
	> (timestamptz,timestamptz)
	>= (timestamptz,timestamptz)
time_bloom_ops	= (time,time)
time_minmax_ops	= (time,time)
	< (time,time)
	<= (time,time)
	> (time,time)
	>= (time,time)
time_minmax_multi_ops	= (time,time)
	< (time,time)
	<= (time,time)
	> (time,time)
	>= (time,time)
timetz_bloom_ops	= (timetz,timetz)
timetz_minmax_ops	= (timetz,timetz)
	< (timetz,timetz)
	<= (timetz,timetz)
	> (timetz,timetz)
	>= (timetz,timetz)
timetz_minmax_multi_ops	= (timetz,timetz)
	< (timetz,timetz)
	<= (timetz,timetz)
	> (timetz,timetz)
	>= (timetz,timetz)
uuid_bloom_ops	= (uuid,uuid)
uuid_minmax_ops	= (uuid,uuid)
	< (uuid,uuid)
	> (uuid,uuid)

Name	Indexable Operators
	<= (uuid,uuid)
	>= (uuid,uuid)
uuid_minmax_multi_ops	= (uuid,uuid)
	< (uuid,uuid)
	> (uuid,uuid)
	<= (uuid,uuid)
	>= (uuid,uuid)
varbit_minmax_ops	= (varbit,varbit)
	< (varbit,varbit)
	> (varbit,varbit)
	<= (varbit,varbit)
	>= (varbit,varbit)

68.2.1. Operator Class Parameters

Some of the built-in operator classes allow specifying parameters affecting behavior of the operator class. Each operator class has its own set of allowed parameters. Only the `bloom` and `minmax-multi` operator classes allow specifying parameters:

bloom operator classes accept these parameters:

`n_distinct_per_range`

Defines the estimated number of distinct non-null values in the block range, used by BRIN bloom indexes for sizing of the Bloom filter. It behaves similarly to `n_distinct` option for ALTER TABLE. When set to a positive value, each block range is assumed to contain this number of distinct non-null values. When set to a negative value, which must be greater than or equal to -1, the number of distinct non-null values is assumed to grow linearly with the maximum possible number of tuples in the block range (about 290 rows per block). The default value is `-0.1`, and the minimum number of distinct non-null values is `16`.

`false_positive_rate`

Defines the desired false positive rate used by BRIN bloom indexes for sizing of the Bloom filter. The values must be between 0.0001 and 0.25. The default value is 0.01, which is 1% false positive rate.

minmax-multi operator classes accept these parameters:

`values_per_range`

Defines the maximum number of values stored by BRIN minmax indexes to summarize a block range. Each value may represent either a point, or a boundary of an interval. Values must be between 8 and 256, and the default value is 32.

68.3. Extensibility

The BRIN interface has a high level of abstraction, requiring the access method implementer only to implement the semantics of the data type being accessed. The BRIN layer itself takes care of concurrency, logging and searching the index structure.

All it takes to get a BRIN access method working is to implement a few user-defined methods, which define the behavior of summary values stored in the index and the way they interact with scan keys. In short, BRIN combines extensibility with generality, code reuse, and a clean interface.

There are four methods that an operator class for BRIN must provide:

`BrinOpcInfo *opcInfo(Oid type_oid)`

Returns internal information about the indexed columns' summary data. The return value must point to a palloc'd `BrinOpcInfo`, which has this definition:

```
typedef struct BrinOpcInfo
{
    /* Number of columns stored in an index column of this opclass */
    uint16      oi_nstored;

    /* Opaque pointer for the opclass' private use */
    void       *oi_opaque;

    /* Type cache entries of the stored columns */
    TypeCacheEntry *oi_typcache[FLEXIBLE_ARRAY_MEMBER];
} BrinOpcInfo;
```

`BrinOpcInfo.oi_opaque` can be used by the operator class routines to pass information between support functions during an index scan.

`bool consistent(BrinDesc *bdesc, BrinValues *column, ScanKey *keys, int nkeys)`

Returns whether all the ScanKey entries are consistent with the given indexed values for a range. The attribute number to use is passed as part of the scan key. Multiple scan keys for the same attribute may be passed at once; the number of entries is determined by the `nkeys` parameter.

`bool consistent(BrinDesc *bdesc, BrinValues *column, ScanKey key)`

Returns whether the ScanKey is consistent with the given indexed values for a range. The attribute number to use is passed as part of the scan key. This is an older backward-compatible variant of the consistent function.

`bool addValue(BrinDesc *bdesc, BrinValues *column, Datum newval, bool isnull)`

Given an index tuple and an indexed value, modifies the indicated attribute of the tuple so that it additionally represents the new value. If any modification was done to the tuple, `true` is returned.

`bool unionTuples(BrinDesc *bdesc, BrinValues *a, BrinValues *b)`

Consolidates two index tuples. Given two index tuples, modifies the indicated attribute of the first of them so that it represents both tuples. The second tuple is not modified.

An operator class for BRIN can optionally specify the following method:

`void options(local_relopts *relopts)`

Defines a set of user-visible parameters that control operator class behavior.

The `options` function is passed a pointer to a `local_relopts` struct, which needs to be filled with a set of operator class specific options. The options can be accessed from other support functions using the `PG_HAS_OPCLASS_OPTIONS()` and `PG_GET_OPCLASS_OPTIONS()` macros.

Since both key extraction of indexed values and representation of the key in BRIN are flexible, they may depend on user-specified parameters.

The core distribution includes support for four types of operator classes: minmax, minmax-multi, inclusion and bloom. Operator class definitions using them are shipped for in-core data types as appropriate. Additional operator classes can be defined by the user for other data types using equivalent definitions, without having to write any source code; appropriate catalog entries being declared is enough. Note that assumptions about the semantics of operator strategies are embedded in the support functions' source code.

Operator classes that implement completely different semantics are also possible, provided implementations of the four main support functions described above are written. Note that backwards compatibility across major releases is not guaranteed: for example, additional support functions might be required in later releases.

To write an operator class for a data type that implements a totally ordered set, it is possible to use the minmax support functions alongside the corresponding operators, as shown in Table 68.2. All operator class members (functions and operators) are mandatory.

Table 68.2. Function and Support Numbers for Minmax Operator Classes

Operator class member	Object
Support Function 1	internal function `brin_minmax_opcinfo()`
Support Function 2	internal function `brin_minmax_add_value()`
Support Function 3	internal function `brin_minmax_consistent()`
Support Function 4	internal function `brin_minmax_union()`
Operator Strategy 1	operator less-than
Operator Strategy 2	operator less-than-or-equal-to
Operator Strategy 3	operator equal-to
Operator Strategy 4	operator greater-than-or-equal-to
Operator Strategy 5	operator greater-than

To write an operator class for a complex data type which has values included within another type, it's possible to use the inclusion support functions alongside the corresponding operators, as shown in Table 68.3. It requires only a single additional function, which can be written in any language. More functions can be defined for additional functionality. All operators are optional. Some operators require other operators, as shown as dependencies on the table.

Table 68.3. Function and Support Numbers for Inclusion Operator Classes

Operator class member	Object	Dependency
Support Function 1	internal function `brin_inclusion_opcinfo()`	
Support Function 2	internal function `brin_inclusion_add_value()`	
Support Function 3	internal function `brin_inclusion_consistent()`	
Support Function 4	internal function `brin_inclusion_union()`	
Support Function 11	function to merge two elements	
Support Function 12	optional function to check whether two elements are mergeable	
Support Function 13	optional function to check if an element is contained within another	
Support Function 14	optional function to check whether an element is empty	
Operator Strategy 1	operator left-of	Operator Strategy 4
Operator Strategy 2	operator does-not-extend-to-the-right-of	Operator Strategy 5
Operator Strategy 3	operator overlaps	
Operator Strategy 4	operator does-not-extend-to-the-left-of	Operator Strategy 1
Operator Strategy 5	operator right-of	Operator Strategy 2

Operator class member	Object	Dependency
Operator Strategy 6, 18	operator same-as-or-equal-to	Operator Strategy 7
Operator Strategy 7, 16, 24, 25	operator contains-or-equal-to	
Operator Strategy 8, 26, 27	operator is-contained-by-or-equal-to	Operator Strategy 3
Operator Strategy 9	operator does-not-extend-above	Operator Strategy 11
Operator Strategy 10	operator is-below	Operator Strategy 12
Operator Strategy 11	operator is-above	Operator Strategy 9
Operator Strategy 12	operator does-not-extend-below	Operator Strategy 10
Operator Strategy 20	operator less-than	Operator Strategy 5
Operator Strategy 21	operator less-than-or-equal-to	Operator Strategy 5
Operator Strategy 22	operator greater-than	Operator Strategy 1
Operator Strategy 23	operator greater-than-or-equal-to	Operator Strategy 1

Support function numbers 1 through 10 are reserved for the BRIN internal functions, so the SQL level functions start with number 11. Support function number 11 is the main function required to build the index. It should accept two arguments with the same data type as the operator class, and return the union of them. The inclusion operator class can store union values with different data types if it is defined with the `STORAGE` parameter. The return value of the union function should match the `STORAGE` data type.

Support function numbers 12 and 14 are provided to support irregularities of built-in data types. Function number 12 is used to support network addresses from different families which are not mergeable. Function number 14 is used to support empty ranges. Function number 13 is an optional but recommended one, which allows the new value to be checked before it is passed to the union function. As the BRIN framework can shortcut some operations when the union is not changed, using this function can improve index performance.

To write an operator class for a data type that implements only an equality operator and supports hashing, it is possible to use the bloom support procedures alongside the corresponding operators, as shown in Table 68.4. All operator class members (procedures and operators) are mandatory.

Table 68.4. Procedure and Support Numbers for Bloom Operator Classes

Operator class member	Object
Support Procedure 1	internal function `brin_bloom_opcinfo()`
Support Procedure 2	internal function `brin_bloom_add_value()`
Support Procedure 3	internal function `brin_bloom_consistent()`
Support Procedure 4	internal function `brin_bloom_union()`
Support Procedure 5	internal function `brin_bloom_options()`
Support Procedure 11	function to compute hash of an element
Operator Strategy 1	operator equal-to

Support procedure numbers 1-10 are reserved for the BRIN internal functions, so the SQL level functions start with number 11. Support function number 11 is the main function required to build the index. It should accept one argument with the same data type as the operator class, and return a hash of the value.

The minmax-multi operator class is also intended for data types implementing a totally ordered set, and may be seen as a simple extension of the minmax operator class. While minmax operator class summarizes values from each block range into a single contiguous interval, minmax-multi allows summarization into multiple smaller intervals to improve handling of outlier values. It is possible to use the

minmax-multi support procedures alongside the corresponding operators, as shown in Table 68.5. All operator class members (procedures and operators) are mandatory.

Table 68.5. Procedure and Support Numbers for minmax-multi Operator Classes

Operator class member	Object
Support Procedure 1	internal function `brin_minmax_multi_opcinfo()`
Support Procedure 2	internal function `brin_minmax_multi_add_value()`
Support Procedure 3	internal function `brin_minmax_multi_consistent()`
Support Procedure 4	internal function `brin_minmax_multi_union()`
Support Procedure 5	internal function `brin_minmax_multi_options()`
Support Procedure 11	function to compute distance between two values (length of a range)
Operator Strategy 1	operator less-than
Operator Strategy 2	operator less-than-or-equal-to
Operator Strategy 3	operator equal-to
Operator Strategy 4	operator greater-than-or-equal-to
Operator Strategy 5	operator greater-than

Both minmax and inclusion operator classes support cross-data-type operators, though with these the dependencies become more complicated. The minmax operator class requires a full set of operators to be defined with both arguments having the same data type. It allows additional data types to be supported by defining extra sets of operators. Inclusion operator class operator strategies are dependent on another operator strategy as shown in Table 68.3, or the same operator strategy as themselves. They require the dependency operator to be defined with the `STORAGE` data type as the left-hand-side argument and the other supported data type to be the right-hand-side argument of the supported operator. See `float4_minmax_ops` as an example of minmax, and `box_inclusion_ops` as an example of inclusion.

Chapter 69. Hash Indexes

69.1. Overview

Postgres Pro includes an implementation of persistent on-disk hash indexes, which are fully crash recoverable. Any data type can be indexed by a hash index, including data types that do not have a well-defined linear ordering. Hash indexes store only the hash value of the data being indexed, thus there are no restrictions on the size of the data column being indexed.

Hash indexes support only single-column indexes and do not allow uniqueness checking.

Hash indexes support only the = operator, so WHERE clauses that specify range operations will not be able to take advantage of hash indexes.

Each hash index tuple stores just the 4-byte hash value, not the actual column value. As a result, hash indexes may be much smaller than B-trees when indexing longer data items such as UUIDs, URLs, etc. The absence of the column value also makes all hash index scans lossy. Hash indexes may take part in bitmap index scans and backward scans.

Hash indexes are best optimized for SELECT and UPDATE-heavy workloads that use equality scans on larger tables. In a B-tree index, searches must descend through the tree until the leaf page is found. In tables with millions of rows, this descent can increase access time to data. The equivalent of a leaf page in a hash index is referred to as a bucket page. In contrast, a hash index allows accessing the bucket pages directly, thereby potentially reducing index access time in larger tables. This reduction in "logical I/O" becomes even more pronounced on indexes/data larger than shared_buffers/RAM.

Hash indexes have been designed to cope with uneven distributions of hash values. Direct access to the bucket pages works well if the hash values are evenly distributed. When inserts mean that the bucket page becomes full, additional overflow pages are chained to that specific bucket page, locally expanding the storage for index tuples that match that hash value. When scanning a hash bucket during queries, we need to scan through all of the overflow pages. Thus an unbalanced hash index might actually be worse than a B-tree in terms of number of block accesses required, for some data.

As a result of the overflow cases, we can say that hash indexes are most suitable for unique, nearly unique data or data with a low number of rows per hash bucket. One possible way to avoid problems is to exclude highly non-unique values from the index using a partial index condition, but this may not be suitable in many cases.

Like B-Trees, hash indexes perform simple index tuple deletion. This is a deferred maintenance operation that deletes index tuples that are known to be safe to delete (those whose item identifier's LP_DEAD bit is already set). If an insert finds no space is available on a page we try to avoid creating a new overflow page by attempting to remove dead index tuples. Removal cannot occur if the page is pinned at that time. Deletion of dead index pointers also occurs during VACUUM.

If it can, VACUUM will also try to squeeze the index tuples onto as few overflow pages as possible, minimizing the overflow chain. If an overflow page becomes empty, overflow pages can be recycled for reuse in other buckets, though we never return them to the operating system. There is currently no provision to shrink a hash index, other than by rebuilding it with REINDEX. There is no provision for reducing the number of buckets, either.

Hash indexes may expand the number of bucket pages as the number of rows indexed grows. The hash key-to-bucket-number mapping is chosen so that the index can be incrementally expanded. When a new bucket is to be added to the index, exactly one existing bucket will need to be "split", with some of its tuples being transferred to the new bucket according to the updated key-to-bucket-number mapping.

The expansion occurs in the foreground, which could increase execution time for user inserts. Thus, hash indexes may not be suitable for tables with rapidly increasing number of rows.

69.2. Implementation

There are four kinds of pages in a hash index: the meta page (page zero), which contains statically allocated control information; primary bucket pages; overflow pages; and bitmap pages, which keep track of overflow pages that have been freed and are available for re-use. For addressing purposes, bitmap pages are regarded as a subset of the overflow pages.

Both scanning the index and inserting tuples require locating the bucket where a given tuple ought to be located. To do this, we need the bucket count, highmask, and lowmask from the metapage; however, it's undesirable for performance reasons to have to have to lock and pin the metapage for every such operation. Instead, we retain a cached copy of the metapage in each backend's relcache entry. This will produce the correct bucket mapping as long as the target bucket hasn't been split since the last cache refresh.

Primary bucket pages and overflow pages are allocated independently since any given index might need more or fewer overflow pages relative to its number of buckets. The hash code uses an interesting set of addressing rules to support a variable number of overflow pages while not having to move primary bucket pages around after they are created.

Each row in the table indexed is represented by a single index tuple in the hash index. Hash index tuples are stored in bucket pages, and if they exist, overflow pages. We speed up searches by keeping the index entries in any one index page sorted by hash code, thus allowing binary search to be used within an index page. Note however that there is *no* assumption about the relative ordering of hash codes across different index pages of a bucket.

The bucket splitting algorithms to expand the hash index are too complex to be worthy of mention here. The split algorithm is crash safe and can be restarted if not completed successfully.

Chapter 70. Database Physical Storage

This chapter provides an overview of the physical storage format used by Postgres Pro databases.

70.1. Database File Layout

This section describes the storage format at the level of files and directories.

Traditionally, the configuration and data files used by a database cluster are stored together within the cluster's data directory, commonly referred to as `PGDATA` (after the name of the environment variable that can be used to define it). A common location for `PGDATA` is `/var/lib/pgpro/ent-14/data`. Multiple clusters, managed by different server instances, can exist on the same machine.

The `PGDATA` directory contains several subdirectories and control files, as shown in Table 70.1. In addition to these required items, the cluster configuration files `postgresql.conf`, `pg_hba.conf`, and `pg_ident.conf` are traditionally stored in `PGDATA`, although it is possible to place them elsewhere.

Table 70.1. Contents of `PGDATA`

Item	Description
`PG_VERSION`	A file containing the major version number of Postgres Pro
`base`	Subdirectory containing per-database subdirectories
`current_logfiles`	File recording the log file(s) currently written to by the logging collector
`global`	Subdirectory containing cluster-wide tables, such as `pg_database`
`pg_commit_ts`	Subdirectory containing transaction commit timestamp data
`pg_dynshmem`	Subdirectory containing files used by the dynamic shared memory subsystem
`pg_logical`	Subdirectory containing status data for logical decoding
`pg_multixact`	Subdirectory containing multitransaction status data (used for shared row locks)
`pg_notify`	Subdirectory containing LISTEN/NOTIFY status data
`pg_replslot`	Subdirectory containing replication slot data
`pg_serial`	Subdirectory containing information about committed serializable transactions
`pg_snapshots`	Subdirectory containing exported snapshots
`pg_stat`	Subdirectory containing permanent files for the statistics subsystem
`pg_stat_tmp`	Subdirectory containing temporary files for the statistics subsystem
`pg_subtrans`	Subdirectory containing subtransaction status data
`pg_tblspc`	Subdirectory containing symbolic links to tablespaces
`pg_twophase`	Subdirectory containing state files for prepared transactions

Item	Description
pg_wal	Subdirectory containing WAL (Write Ahead Log) files
pg_xact	Subdirectory containing transaction commit status data
postgresql.auto.conf	A file used for storing configuration parameters that are set by ALTER SYSTEM
postmaster.opts	A file recording the command-line options the server was last started with
postmaster.pid	A lock file recording the current postmaster process ID (PID), cluster data directory path, postmaster start timestamp, port number, Unix-domain socket directory path (could be empty), first valid listen_address (IP address or *, or empty if not listening on TCP), and shared memory segment ID (this file is not present after server shutdown)

For each database in the cluster there is a subdirectory within PGDATA/base, named after the database's OID in pg_database. This subdirectory is the default location for the database's files; in particular, its system catalogs are stored there.

Note that the following sections describe the behavior of the builtin heap table access method, and the builtin index access methods. Due to the extensible nature of Postgres Pro, other access methods might work differently.

Each table and index is stored in a separate file. For ordinary relations, these files are named after the table or index's *filenode* number, which can be found in pg_class.relfilenode. But for temporary relations, the file name is of the form t*BBB*_*FFF*, where *BBB* is the backend ID of the backend which created the file, and *FFF* is the filenode number. In either case, in addition to the main file (a/k/a main fork), each table and index has a *free space map* (see Section 70.3), which stores information about free space available in the relation. The free space map is stored in a file named with the filenode number plus the suffix _fsm. Tables also have a *visibility map*, stored in a fork with the suffix _vm, to track which pages are known to have no dead tuples. The visibility map is described further in Section 70.4. Unlogged tables and indexes have a third fork, known as the initialization fork, which is stored in a fork with the suffix _init (see Section 70.5).

> **Caution**
>
> Note that while a table's filenode often matches its OID, this is *not* necessarily the case; some operations, like TRUNCATE, REINDEX, CLUSTER and some forms of ALTER TABLE, can change the filenode while preserving the OID. Avoid assuming that filenode and table OID are the same. Also, for certain system catalogs including pg_class itself, pg_class.relfilenode contains zero. The actual filenode number of these catalogs is stored in a lower-level data structure, and can be obtained using the pg_relation_filenode() function.

When a table or index exceeds 1 GB, it is divided into gigabyte-sized *segments*. The first segment's file name is the same as the filenode; subsequent segments are named filenode.1, filenode.2, etc. This arrangement avoids problems on platforms that have file size limitations. (Actually, 1 GB is just the default segment size. The segment size can be adjusted using the configuration option --with-segsize when building Postgres Pro.) In principle, free space map and visibility map forks could require multiple segments as well, though this is unlikely to happen in practice.

A table that has columns with potentially large entries will have an associated *TOAST* table, which is used for out-of-line storage of field values that are too large to keep in the table rows proper. pg_class.reltoastrelid links from a table to its TOAST table, if any. See Section 70.2 for more information.

The contents of tables and indexes are discussed further in Section 70.6.

Tablespaces make the scenario more complicated. Each user-defined tablespace has a symbolic link inside the PGDATA/pg_tblspc directory, which points to the physical tablespace directory (i.e., the location specified in the tablespace's CREATE TABLESPACE command). This symbolic link is named after the tablespace's OID. Inside the physical tablespace directory there is a subdirectory with a name that depends on the Postgres Pro server version, such as PG_9.0_201008051. (The reason for using this subdirectory is so that successive versions of the database can use the same CREATE TABLESPACE location value without conflicts.) Within the version-specific subdirectory, there is a subdirectory for each database that has elements in the tablespace, named after the database's OID. Tables and indexes are stored within that directory, using the filenode naming scheme. The pg_default tablespace is not accessed through pg_tblspc, but corresponds to PGDATA/base. Similarly, the pg_global tablespace is not accessed through pg_tblspc, but corresponds to PGDATA/global.

The pg_relation_filepath() function shows the entire path (relative to PGDATA) of any relation. It is often useful as a substitute for remembering many of the above rules. But keep in mind that this function just gives the name of the first segment of the main fork of the relation — you may need to append a segment number and/or _fsm, _vm, or _init to find all the files associated with the relation.

Temporary files (for operations such as sorting more data than can fit in memory) are created within PGDATA/base/pgsql_tmp, or within a pgsql_tmp subdirectory of a tablespace directory if a tablespace other than pg_default is specified for them. The name of a temporary file has the form pgsql_tmp*PPP*.*NNN*, where *PPP* is the PID of the owning backend and *NNN* distinguishes different temporary files of that backend.

70.2. TOAST

This section provides an overview of TOAST (The Oversized-Attribute Storage Technique).

Postgres Pro uses a fixed page size (commonly 8 kB), and does not allow tuples to span multiple pages. Therefore, it is not possible to store very large field values directly. To overcome this limitation, large field values are compressed and/or broken up into multiple physical rows. This happens transparently to the user, with only small impact on most of the backend code. The technique is affectionately known as TOAST (or “the best thing since sliced bread”). The TOAST infrastructure is also used to improve handling of large data values in-memory.

Only certain data types support TOAST — there is no need to impose the overhead on data types that cannot produce large field values. To support TOAST, a data type must have a variable-length (*varlena*) representation, in which, ordinarily, the first four-byte word of any stored value contains the total length of the value in bytes (including itself). TOAST does not constrain the rest of the data type's representation. The special representations collectively called *TOASTed values* work by modifying or reinterpreting this initial length word. Therefore, the C-level functions supporting a TOAST-able data type must be careful about how they handle potentially TOASTed input values: an input might not actually consist of a four-byte length word and contents until after it's been *detoasted*. (This is normally done by invoking PG_DETOAST_DATUM before doing anything with an input value, but in some cases more efficient approaches are possible. See Section 40.13.1 for more detail.)

TOAST usurps two bits of the varlena length word (the high-order bits on big-endian machines, the low-order bits on little-endian machines), thereby limiting the logical size of any value of a TOAST-able data type to 1 GB (2^{30} - 1 bytes). When both bits are zero, the value is an ordinary un-TOASTed value of the data type, and the remaining bits of the length word give the total datum size (including length word) in bytes. When the highest-order or lowest-order bit is set, the value has only a single-byte header instead of the normal four-byte header, and the remaining bits of that byte give the total datum size (including length byte) in bytes. This alternative supports space-efficient storage of values shorter than 127 bytes, while still allowing the data type to grow to 1 GB at need. Values with single-byte headers aren't aligned on any particular boundary, whereas values with four-byte headers are aligned on at least a four-byte boundary; this omission of alignment padding provides additional space savings that is significant compared to short values. As a special case, if the remaining bits of a single-byte header are all zero (which would be impossible for a self-inclusive length), the value is a pointer to out-of-line

data, with several possible alternatives as described below. The type and size of such a *TOAST pointer* are determined by a code stored in the second byte of the datum. Lastly, when the highest-order or lowest-order bit is clear but the adjacent bit is set, the content of the datum has been compressed and must be decompressed before use. In this case the remaining bits of the four-byte length word give the total size of the compressed datum, not the original data. Note that compression is also possible for out-of-line data but the varlena header does not tell whether it has occurred — the content of the TOAST pointer tells that, instead.

The compression technique used for either in-line or out-of-line compressed data can be selected for each column by setting the `COMPRESSION` column option in `CREATE TABLE` or `ALTER TABLE`. The default for columns with no explicit setting is to consult the default_toast_compression parameter at the time data is inserted.

As mentioned, there are multiple types of TOAST pointer datums. The oldest and most common type is a pointer to out-of-line data stored in a *TOAST table* that is separate from, but associated with, the table containing the TOAST pointer datum itself. These *on-disk* pointer datums are created by the TOAST management code when a tuple to be stored on disk is too large to be stored as-is. Further details appear in Section 70.2.1. Alternatively, a TOAST pointer datum can contain a pointer to out-of-line data that appears elsewhere in memory. Such datums are necessarily short-lived, and will never appear on-disk, but they are very useful for avoiding copying and redundant processing of large data values. Further details appear in Section 70.2.2.

70.2.1. Out-of-Line, On-Disk TOAST Storage

If any of the columns of a table are TOAST-able, the table will have an associated TOAST table, whose OID is stored in the table's `pg_class.reltoastrelid` entry. On-disk TOASTed values are kept in the TOAST table, as described in more detail below.

Out-of-line values are divided (after compression if used) into chunks of at most `TOAST_MAX_CHUNK_SIZE` bytes (by default this value is chosen so that four chunk rows will fit on a page, making it about 2000 bytes). Each chunk is stored as a separate row in the TOAST table belonging to the owning table. Every TOAST table has the columns `chunk_id` (an OID identifying the particular TOASTed value), `chunk_seq` (a sequence number for the chunk within its value), and `chunk_data` (the actual data of the chunk). A unique index on `chunk_id` and `chunk_seq` provides fast retrieval of the values. A pointer datum representing an out-of-line on-disk TOASTed value therefore needs to store the OID of the TOAST table in which to look and the OID of the specific value (its `chunk_id`). For convenience, pointer datums also store the logical datum size (original uncompressed data length), physical stored size (different if compression was applied), and the compression method used, if any. Allowing for the varlena header bytes, the total size of an on-disk TOAST pointer datum is therefore 18 bytes regardless of the actual size of the represented value.

The TOAST management code is triggered only when a row value to be stored in a table is wider than `TOAST_TUPLE_THRESHOLD` bytes (normally 2 kB). The TOAST code will compress and/or move field values out-of-line until the row value is shorter than `TOAST_TUPLE_TARGET` bytes (also normally 2 kB, adjustable) or no more gains can be had. During an UPDATE operation, values of unchanged fields are normally preserved as-is; so an UPDATE of a row with out-of-line values incurs no TOAST costs if none of the out-of-line values change.

The TOAST management code recognizes four different strategies for storing TOAST-able columns on disk:

- `PLAIN` prevents either compression or out-of-line storage. This is the only possible strategy for columns of non-TOAST-able data types.
- `EXTENDED` allows both compression and out-of-line storage. This is the default for most TOAST-able data types. Compression will be attempted first, then out-of-line storage if the row is still too big.
- `EXTERNAL` allows out-of-line storage but not compression. Use of `EXTERNAL` will make substring operations on wide `text` and `bytea` columns faster (at the penalty of increased storage space) because these operations are optimized to fetch only the required parts of the out-of-line value when it is not compressed.

- `MAIN` allows compression but not out-of-line storage. (Actually, out-of-line storage will still be performed for such columns, but only as a last resort when there is no other way to make the row small enough to fit on a page.)

Each TOAST-able data type specifies a default strategy for columns of that data type, but the strategy for a given table column can be altered with `ALTER TABLE ... SET STORAGE`.

`TOAST_TUPLE_TARGET` can be adjusted for each table using `ALTER TABLE ... SET (toast_tuple_target = N)`

This scheme has a number of advantages compared to a more straightforward approach such as allowing row values to span pages. Assuming that queries are usually qualified by comparisons against relatively small key values, most of the work of the executor will be done using the main row entry. The big values of TOASTed attributes will only be pulled out (if selected at all) at the time the result set is sent to the client. Thus, the main table is much smaller and more of its rows fit in the shared buffer cache than would be the case without any out-of-line storage. Sort sets shrink also, and sorts will more often be done entirely in memory. A little test showed that a table containing typical HTML pages and their URLs was stored in about half of the raw data size including the TOAST table, and that the main table contained only about 10% of the entire data (the URLs and some small HTML pages). There was no run time difference compared to an un-TOASTed comparison table, in which all the HTML pages were cut down to 7 kB to fit.

70.2.2. Out-of-Line, In-Memory TOAST Storage

TOAST pointers can point to data that is not on disk, but is elsewhere in the memory of the current server process. Such pointers obviously cannot be long-lived, but they are nonetheless useful. There are currently two sub-cases: pointers to *indirect* data and pointers to *expanded* data.

Indirect TOAST pointers simply point at a non-indirect varlena value stored somewhere in memory. This case was originally created merely as a proof of concept, but it is currently used during logical decoding to avoid possibly having to create physical tuples exceeding 1 GB (as pulling all out-of-line field values into the tuple might do). The case is of limited use since the creator of the pointer datum is entirely responsible that the referenced data survives for as long as the pointer could exist, and there is no infrastructure to help with this.

Expanded TOAST pointers are useful for complex data types whose on-disk representation is not especially suited for computational purposes. As an example, the standard varlena representation of a Postgres Pro array includes dimensionality information, a nulls bitmap if there are any null elements, then the values of all the elements in order. When the element type itself is variable-length, the only way to find the *N*'th element is to scan through all the preceding elements. This representation is appropriate for on-disk storage because of its compactness, but for computations with the array it's much nicer to have an “expanded” or “deconstructed” representation in which all the element starting locations have been identified. The TOAST pointer mechanism supports this need by allowing a pass-by-reference Datum to point to either a standard varlena value (the on-disk representation) or a TOAST pointer that points to an expanded representation somewhere in memory. The details of this expanded representation are up to the data type, though it must have a standard header and meet the other API requirements given in *src/include/utils/expandeddatum.h*. C-level functions working with the data type can choose to handle either representation. Functions that do not know about the expanded representation, but simply apply `PG_DETOAST_DATUM` to their inputs, will automatically receive the traditional varlena representation; so support for an expanded representation can be introduced incrementally, one function at a time.

TOAST pointers to expanded values are further broken down into *read-write* and *read-only* pointers. The pointed-to representation is the same either way, but a function that receives a read-write pointer is allowed to modify the referenced value in-place, whereas one that receives a read-only pointer must not; it must first create a copy if it wants to make a modified version of the value. This distinction and some associated conventions make it possible to avoid unnecessary copying of expanded values during query execution.

For all types of in-memory TOAST pointer, the TOAST management code ensures that no such pointer datum can accidentally get stored on disk. In-memory TOAST pointers are automatically expanded to

normal in-line varlena values before storage — and then possibly converted to on-disk TOAST pointers, if the containing tuple would otherwise be too big.

70.3. Free Space Map

Each heap and index relation, except for hash indexes, has a Free Space Map (FSM) to keep track of available space in the relation. It's stored alongside the main relation data in a separate relation fork, named after the filenode number of the relation, plus a `_fsm` suffix. For example, if the filenode of a relation is 12345, the FSM is stored in a file called `12345_fsm`, in the same directory as the main relation file.

The Free Space Map is organized as a tree of FSM pages. The bottom level FSM pages store the free space available on each heap (or index) page, using one byte to represent each such page. The upper levels aggregate information from the lower levels.

Within each FSM page is a binary tree, stored in an array with one byte per node. Each leaf node represents a heap page, or a lower level FSM page. In each non-leaf node, the higher of its children's values is stored. The maximum value in the leaf nodes is therefore stored at the root.

The pg_freespacemap module can be used to examine the information stored in free space maps.

70.4. Visibility Map

Each heap relation has a Visibility Map (VM) to keep track of which pages contain only tuples that are known to be visible to all active transactions; it also keeps track of which pages contain only frozen tuples. It's stored alongside the main relation data in a separate relation fork, named after the filenode number of the relation, plus a `_vm` suffix. For example, if the filenode of a relation is 12345, the VM is stored in a file called `12345_vm`, in the same directory as the main relation file. Note that indexes do not have VMs.

The visibility map stores two bits per heap page. The first bit, if set, indicates that the page is all-visible, or in other words that the page does not contain any tuples that need to be vacuumed. This information can also be used by *index-only scans* to answer queries using only the index tuple. The second bit, if set, means that all tuples on the page have been frozen.

The map is conservative in the sense that we make sure that whenever a bit is set, we know the condition is true, but if a bit is not set, it might or might not be true. Visibility map bits are only set by vacuum, but are cleared by any data-modifying operations on a page.

The pg_visibility module can be used to examine the information stored in the visibility map.

70.5. The Initialization Fork

Each unlogged table, and each index on an unlogged table, has an initialization fork. The initialization fork is an empty table or index of the appropriate type. When an unlogged table must be reset to empty due to a crash, the initialization fork is copied over the main fork, and any other forks are erased (they will be recreated automatically as needed).

70.6. Database Page Layout

This section provides an overview of the page format used within Postgres Pro tables and indexes.[1] Sequences and TOAST tables are formatted just like a regular table.

In the following explanation, a *byte* is assumed to contain 8 bits. In addition, the term *item* refers to an individual data value that is stored on a page. In a table, an item is a row; in an index, an item is an index entry.

[1] Actually, use of this page format is not required for either table or index access methods. The `heap` table access method always uses this format. All the existing index methods also use the basic format, but the data kept on index metapages usually doesn't follow the item layout rules.

Every table and index is stored as an array of *pages* of a fixed size (usually 8 kB, although a different page size can be selected when compiling the server). In a table, all the pages are logically equivalent, so a particular item (row) can be stored in any page. In indexes, the first page is generally reserved as a *metapage* holding control information, and there can be different types of pages within the index, depending on the index access method.

Table 70.2 shows the overall layout of a page. There are five parts to each page.

Table 70.2. Overall Page Layout

Item	Description
PageHeaderData	24 bytes long. Contains general information about the page, including free space pointers.
ItemIdData	Array of item identifiers pointing to the actual items. Each entry is an (offset,length) pair. 4 bytes per item.
Free space	The unallocated space. New item identifiers are allocated from the start of this area, new items from the end.
Items	The actual items themselves.
Special space	Index access method specific data. Different methods store different data. Additionally, this space is used to store information about 64-bit transaction IDs.

The first 20 bytes of each page consists of a page header (`PageHeaderData`). Its format is detailed in Table 70.3. The first field tracks the most recent WAL entry related to this page. The second field contains the page checksum if data checksums are enabled. Next is a 2-byte field containing flag bits. This is followed by three 2-byte integer fields (`pd_lower`, `pd_upper`, and `pd_special`). These contain byte offsets from the page start to the start of unallocated space, to the end of unallocated space, and to the start of the special space. The next 2 bytes of the page header, `pd_pagesize_version`, store both the page size and a version indicator. Beginning with PostgreSQL 8.3 the version number is 4; PostgreSQL 8.1 and 8.2 used version number 3; PostgreSQL 8.0 used version number 2; PostgreSQL 7.3 and 7.4 used version number 1; prior releases used version number 0. (The basic page layout and header format has not changed in most of these versions, but the layout of heap row headers has.) The page size is basically only present as a cross-check; there is no support for having more than one page size in an installation.

Table 70.3. PageHeaderData Layout

Field	Type	Length	Description
pd_lsn	PageXLogRecPtr	8 bytes	LSN: next byte after last byte of WAL record for last change to this page
pd_checksum	uint16	2 bytes	Page checksum
pd_flags	uint16	2 bytes	Flag bits
pd_lower	LocationIndex	2 bytes	Offset to start of free space
pd_upper	LocationIndex	2 bytes	Offset to end of free space
pd_special	LocationIndex	2 bytes	Offset to start of special space
pd_pagesize_version	uint16	2 bytes	Page size and layout version number information

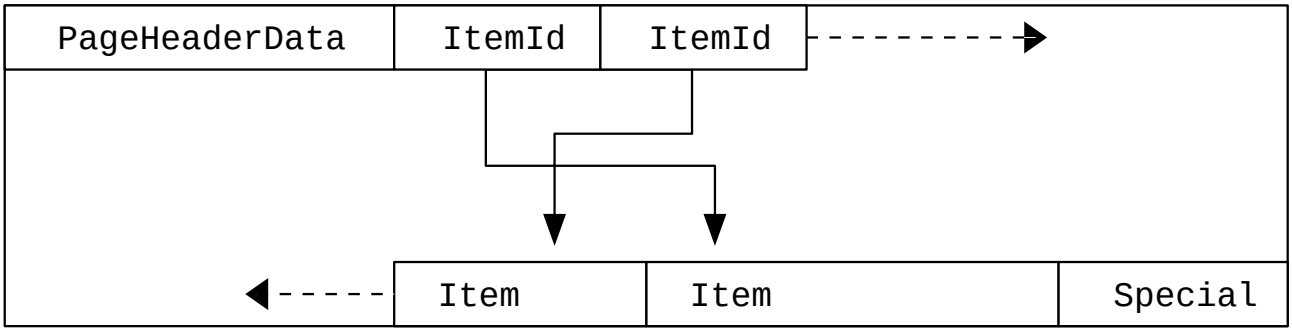
Following the page header are item identifiers (`ItemIdData`), each requiring four bytes. An item identifier contains a byte-offset to the start of an item, its length in bytes, and a few attribute bits which affect its interpretation. New item identifiers are allocated as needed from the beginning of the unallocated space. The number of item identifiers present can be determined by looking at `pd_lower`, which is increased to allocate a new identifier. Because an item identifier is never moved until it is freed, its index can be used on a long-term basis to reference an item, even when the item itself is moved around on the page to compact free space. In fact, every pointer to an item (`ItemPointer`, also known as `CTID`) created by Postgres Pro consists of a page number and the index of an item identifier.

The items themselves are stored in space allocated backwards from the end of unallocated space. The exact structure varies depending on what the table is to contain. Tables and sequences both use a structure named `HeapTupleHeaderData`, described below.

The final section is the “special section” which can contain anything the access method wishes to store. For example, b-tree indexes store links to the page's left and right siblings, as well as some other data relevant to the index structure. Ordinary tables and sequences store the `HeapPageSpecialData` structure in this section. Its format is specified in Table 70.4.

Figure 70.1 illustrates how these parts are laid out in a page.

Figure 70.1. Page Layout



70.6.1. Table Row Layout

`HeapPageSpecialData` is a 24-byte structure. The first two 8-byte fields contain the base (i.e., an offset) for short (4-byte) transaction IDs in this page. The next field is a hint that shows whether pruning the page is likely to be profitable: it tracks the oldest un-pruned XMAX on the page. The last field is a magic number identifying the type of the page (`0x1010` for ordinary tables and `0x1717` for sequences).

Table 70.4. HeapPageSpecialData Layout

Field	Type	Length	Description
pd_xid_base	TransactionId	8 bytes	Base for short 4-byte transaction IDs in this page
pd_multi_base	TransactionId	8 bytes	Base for short 4-byte multixact IDs in this page
pd_prune_xid	ShortTransactionId	4 bytes	Oldest unpruned XMAX on page, or zero if none
pd_magic	uint32	4 bytes	Magic number identifying the type of this page

All table rows are structured in the same way. There is a fixed-size header (occupying 40 bytes on most machines), followed by an optional null bitmap, an optional object ID field, and the user data. The header is detailed in Table 70.5. The actual user data (columns of the row) begins at the offset indicated by `t_hoff`, which must always be a multiple of the MAXALIGN distance for the platform. The null bitmap is only present if the *HEAP_HASNULL* bit is set in `t_infomask`. If it is present it begins just after the fixed header and occupies enough bytes to have one bit per data column (that is, the number of bits that equals the attribute count in `t_infomask2`). In this list of bits, a 1 bit indicates not-null, a 0 bit is a null. When the bitmap is not present, all columns are assumed not-null. The object ID is only present if the *HEAP_HASOID_OLD* bit is set in `t_infomask`. If present, it appears just before the `t_hoff` boundary. Any padding needed to make `t_hoff` a MAXALIGN multiple will appear between the null bitmap and the object ID. (This in turn ensures that the object ID is suitably aligned.)

Table 70.5. HeapTupleHeaderData Layout

Field	Type	Length	Description
t_xmin	ShortTransactionId	4 bytes	insert XID stamp
t_xmax	ShortTransactionId	4 bytes	delete XID stamp
t_cid	CommandId	4 bytes	insert and/or delete CID stamp (overlays with t_xvac)
t_xvac	ShortTransactionId	4 bytes	XID for VACUUM operation moving a row version
t_ctid	ItemPointerData	6 bytes	current TID of this or newer row version
t_infomask2	uint16	2 bytes	number of attributes, plus various flag bits
t_infomask	uint16	2 bytes	various flag bits
t_hoff	uint8	1 byte	offset to user data

Interpreting the actual data can only be done with information obtained from other tables, mostly `pg_attribute`. The key values needed to identify field locations are `attlen` and `attalign`. There is no way to directly get a particular attribute, except when there are only fixed width fields and no null values. All this trickery is wrapped up in the functions *heap_getattr*, *fastgetattr* and *heap_getsysattr*.

To read the data you need to examine each attribute in turn. First check whether the field is NULL according to the null bitmap. If it is, go to the next. Then make sure you have the right alignment. If the field is a fixed width field, then all the bytes are simply placed. If it's a variable length field (attlen = -1) then it's a bit more complicated. All variable-length data types share the common header structure `struct varlena`, which includes the total length of the stored value and some flag bits. Depending on the flags, the data can be either inline or in a TOAST table; it might be compressed, too (see Section 70.2).

70.7. Heap-Only Tuples (HOT)

To allow for high concurrency, PostgreSQL uses multiversion concurrency control (MVCC) to store rows. However, MVCC has some downsides for update queries. Specifically, updates require new versions of rows to be added to tables. This can also require new index entries for each updated row, and removal of old versions of rows and their index entries can be expensive.

To help reduce the overhead of updates, PostgreSQL has an optimization called heap-only tuples (HOT). This optimization is possible when:

- The update does not modify any columns referenced by the table's indexes, including expression and partial indexes.
- There is sufficient free space on the page containing the old row for the updated row.

In such cases, heap-only tuples provide two optimizations:

- New index entries are not needed to represent updated rows.
- Old versions of updated rows can be completely removed during normal operation, including `SELECT`s, instead of requiring periodic vacuum operations. (This is possible because indexes do not reference their page item identifiers.)

In summary, heap-only tuple updates can only be created if columns used by indexes are not updated. You can increase the likelihood of sufficient page space for HOT updates by decreasing a table's `fillfactor`. If you don't, HOT updates will still happen because new rows will naturally migrate to new pages and existing pages with sufficient free space for new row versions. The system view pg_stat_all_tables allows monitoring of the occurrence of HOT and non-HOT updates.

Chapter 71. How the Planner Uses Statistics

This chapter builds on the material covered in Section 14.1 and Section 14.2 to show some additional details about how the planner uses the system statistics to estimate the number of rows each part of a query might return. This is a significant part of the planning process, providing much of the raw material for cost calculation.

The intent of this chapter is not to document the code in detail, but to present an overview of how it works. This will perhaps ease the learning curve for someone who subsequently wishes to read the code.

71.1. Row Estimation Examples

The examples shown below use tables in the Postgres Pro regression test database. The outputs shown are taken from version 8.3. The behavior of earlier (or later) versions might vary. Note also that since `ANALYZE` uses random sampling while producing statistics, the results will change slightly after any new `ANALYZE`.

Let's start with a very simple query:

```
EXPLAIN SELECT * FROM tenk1;

                         QUERY PLAN
-------------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..458.00 rows=10000 width=244)
```

How the planner determines the cardinality of `tenk1` is covered in Section 14.2, but is repeated here for completeness. The number of pages and rows is looked up in `pg_class`:

```
SELECT relpages, reltuples FROM pg_class WHERE relname = 'tenk1';

 relpages | reltuples
----------+-----------
      358 |     10000
```

These numbers are current as of the last `VACUUM` or `ANALYZE` on the table. The planner then fetches the actual current number of pages in the table (this is a cheap operation, not requiring a table scan). If that is different from `relpages` then `reltuples` is scaled accordingly to arrive at a current number-of-rows estimate. In the example above, the value of `relpages` is up-to-date so the rows estimate is the same as `reltuples`.

Let's move on to an example with a range condition in its `WHERE` clause:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 1000;

                                 QUERY PLAN
-----------------------------------------------------------------------------
 Bitmap Heap Scan on tenk1  (cost=24.06..394.64 rows=1007 width=244)
   Recheck Cond: (unique1 < 1000)
   ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..23.80 rows=1007 width=0)
         Index Cond: (unique1 < 1000)
```

The planner examines the `WHERE` clause condition and looks up the selectivity function for the operator `<` in `pg_operator`. This is held in the column `oprrest`, and the entry in this case is `scalarltsel`. The `scalarltsel` function retrieves the histogram for `unique1` from `pg_statistic`. For manual queries it is more convenient to look in the simpler `pg_stats` view:

```
SELECT histogram_bounds FROM pg_stats
WHERE tablename='tenk1' AND attname='unique1';

                    histogram_bounds
------------------------------------------------------
 {0,993,1997,3050,4040,5036,5957,7057,8029,9016,9995}
```

Next the fraction of the histogram occupied by "< 1000" is worked out. This is the selectivity. The histogram divides the range into equal frequency buckets, so all we have to do is locate the bucket that our value is in and count *part* of it and *all* of the ones before. The value 1000 is clearly in the second bucket (993–1997). Assuming a linear distribution of values inside each bucket, we can calculate the selectivity as:

```
selectivity = (1 + (1000 - bucket[2].min)/(bucket[2].max - bucket[2].min))/num_buckets
            = (1 + (1000 - 993)/(1997 - 993))/10
            = 0.100697
```

that is, one whole bucket plus a linear fraction of the second, divided by the number of buckets. The estimated number of rows can now be calculated as the product of the selectivity and the cardinality of `tenk1`:

```
rows = rel_cardinality * selectivity
     = 10000 * 0.100697
     = 1007  (rounding off)
```

Next let's consider an example with an equality condition in its `WHERE` clause:

```
EXPLAIN SELECT * FROM tenk1 WHERE stringu1 = 'CRAAAA';

                        QUERY PLAN
-----------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..483.00 rows=30 width=244)
   Filter: (stringu1 = 'CRAAAA'::name)
```

Again the planner examines the `WHERE` clause condition and looks up the selectivity function for `=`, which is `eqsel`. For equality estimation the histogram is not useful; instead the list of *most common values* (MCVs) is used to determine the selectivity. Let's have a look at the MCVs, with some additional columns that will be useful later:

```
SELECT null_frac, n_distinct, most_common_vals, most_common_freqs FROM pg_stats
WHERE tablename='tenk1' AND attname='stringu1';

null_frac         | 0
n_distinct        | 676
most_common_vals  | {EJAAAA,BBAAAA,CRAAAA,FCAAAA,FEAAAA,GSAAAA,
JOAAAA,MCAAAA,NAAAAA,WGAAAA}
most_common_freqs | {0.00333333,0.003,0.003,0.003,0.003,0.003,0.003,0.003,0.003,0.003}
```

Since `CRAAAA` appears in the list of MCVs, the selectivity is merely the corresponding entry in the list of most common frequencies (MCFs):

```
selectivity = mcf[3]
            = 0.003
```

As before, the estimated number of rows is just the product of this with the cardinality of `tenk1`:

```
rows = 10000 * 0.003
     = 30
```

Now consider the same query, but with a constant that is not in the MCV list:

```
EXPLAIN SELECT * FROM tenk1 WHERE stringu1 = 'xxx';

                        QUERY PLAN
-----------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..483.00 rows=15 width=244)
   Filter: (stringu1 = 'xxx'::name)
```

This is quite a different problem: how to estimate the selectivity when the value is *not* in the MCV list. The approach is to use the fact that the value is not in the list, combined with the knowledge of the frequencies for all of the MCVs:

```
selectivity = (1 - sum(mvf))/(num_distinct - num_mcv)
            = (1 - (0.00333333 + 0.003 + 0.003 + 0.003 + 0.003 + 0.003 +
                    0.003 + 0.003 + 0.003 + 0.003))/(676 - 10)
            = 0.0014559
```

That is, add up all the frequencies for the MCVs and subtract them from one, then divide by the number of *other* distinct values. This amounts to assuming that the fraction of the column that is not any of the MCVs is evenly distributed among all the other distinct values. Notice that there are no null values so we don't have to worry about those (otherwise we'd subtract the null fraction from the numerator as well). The estimated number of rows is then calculated as usual:

```
rows = 10000 * 0.0014559
     = 15  (rounding off)
```

The previous example with `unique1 < 1000` was an oversimplification of what `scalarltsel` really does; now that we have seen an example of the use of MCVs, we can fill in some more detail. The example was correct as far as it went, because since `unique1` is a unique column it has no MCVs (obviously, no value is any more common than any other value). For a non-unique column, there will normally be both a histogram and an MCV list, and *the histogram does not include the portion of the column population represented by the MCVs*. We do things this way because it allows more precise estimation. In this situation `scalarltsel` directly applies the condition (e.g., "< 1000") to each value of the MCV list, and adds up the frequencies of the MCVs for which the condition is true. This gives an exact estimate of the selectivity within the portion of the table that is MCVs. The histogram is then used in the same way as above to estimate the selectivity in the portion of the table that is not MCVs, and then the two numbers are combined to estimate the overall selectivity. For example, consider

```
EXPLAIN SELECT * FROM tenk1 WHERE stringu1 < 'IAAAAA';

                          QUERY PLAN
-------------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..483.00 rows=3077 width=244)
   Filter: (stringu1 < 'IAAAAA'::name)
```

We already saw the MCV information for `stringu1`, and here is its histogram:

```
SELECT histogram_bounds FROM pg_stats
WHERE tablename='tenk1' AND attname='stringu1';

                                histogram_bounds
------------------------------------------------------------------------------
 {AAAAAA,CQAAAA,FRAAAA,IBAAAA,KRAAAA,NFAAAA,PSAAAA,SGAAAA,VAAAAA,XLAAAA,ZZAAAA}
```

Checking the MCV list, we find that the condition `stringu1 < 'IAAAAA'` is satisfied by the first six entries and not the last four, so the selectivity within the MCV part of the population is

```
selectivity = sum(relevant mvfs)
            = 0.00333333 + 0.003 + 0.003 + 0.003 + 0.003 + 0.003
            = 0.01833333
```

Summing all the MCFs also tells us that the total fraction of the population represented by MCVs is 0.03033333, and therefore the fraction represented by the histogram is 0.96966667 (again, there are no nulls, else we'd have to exclude them here). We can see that the value `IAAAAA` falls nearly at the end of the third histogram bucket. Using some rather cheesy assumptions about the frequency of different characters, the planner arrives at the estimate 0.298387 for the portion of the histogram population that is less than `IAAAAA`. We then combine the estimates for the MCV and non-MCV populations:

```
selectivity = mcv_selectivity + histogram_selectivity * histogram_fraction
            = 0.01833333 + 0.298387 * 0.96966667
            = 0.307669

rows        = 10000 * 0.307669
            = 3077  (rounding off)
```

In this particular example, the correction from the MCV list is fairly small, because the column distribution is actually quite flat (the statistics showing these particular values as being more common than others are mostly due to sampling error). In a more typical case where some values are significantly more common than others, this complicated process gives a useful improvement in accuracy because the selectivity for the most common values is found exactly.

Now let's consider a case with more than one condition in the `WHERE` clause:

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 1000 AND stringu1 = 'xxx';

                                     QUERY PLAN
-------------------------------------------------------------------------------
 Bitmap Heap Scan on tenk1  (cost=23.80..396.91 rows=1 width=244)
   Recheck Cond: (unique1 < 1000)
   Filter: (stringu1 = 'xxx'::name)
   ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..23.80 rows=1007 width=0)
         Index Cond: (unique1 < 1000)
```

The planner assumes that the two conditions are independent, so that the individual selectivities of the clauses can be multiplied together:

```
selectivity = selectivity(unique1 < 1000) * selectivity(stringu1 = 'xxx')
            = 0.100697 * 0.0014559
            = 0.0001466

rows        = 10000 * 0.0001466
            = 1  (rounding off)
```

Notice that the number of rows estimated to be returned from the bitmap index scan reflects only the condition used with the index; this is important since it affects the cost estimate for the subsequent heap fetches.

Finally we will examine a query that involves a join:

```
EXPLAIN SELECT * FROM tenk1 t1, tenk2 t2
WHERE t1.unique1 < 50 AND t1.unique2 = t2.unique2;

                                      QUERY PLAN
--------------------------------------------------------------------------------
 Nested Loop  (cost=4.64..456.23 rows=50 width=488)
   ->  Bitmap Heap Scan on tenk1 t1  (cost=4.64..142.17 rows=50 width=244)
         Recheck Cond: (unique1 < 50)
         ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..4.63 rows=50 width=0)
               Index Cond: (unique1 < 50)
   ->  Index Scan using tenk2_unique2 on tenk2 t2  (cost=0.00..6.27 rows=1 width=244)
         Index Cond: (unique2 = t1.unique2)
```

The restriction on `tenk1`, `unique1 < 50`, is evaluated before the nested-loop join. This is handled analogously to the previous range example. This time the value 50 falls into the first bucket of the `unique1` histogram:

```
selectivity = (0 + (50 - bucket[1].min)/(bucket[1].max - bucket[1].min))/num_buckets
            = (0 + (50 - 0)/(993 - 0))/10
            = 0.005035

rows        = 10000 * 0.005035
            = 50  (rounding off)
```

The restriction for the join is `t2.unique2 = t1.unique2`. The operator is just our familiar `=`, however the selectivity function is obtained from the `oprjoin` column of `pg_operator`, and is `eqjoinsel`. `eqjoinsel` looks up the statistical information for both `tenk2` and `tenk1`:

```
SELECT tablename, null_frac,n_distinct, most_common_vals FROM pg_stats
```

```
WHERE tablename IN ('tenk1', 'tenk2') AND attname='unique2';

tablename  | null_frac | n_distinct | most_common_vals
-----------+-----------+------------+------------------
 tenk1     |         0 |         -1 |
 tenk2     |         0 |         -1 |
```

In this case there is no MCV information for `unique2` because all the values appear to be unique, so we use an algorithm that relies only on the number of distinct values for both relations together with their null fractions:

```
selectivity = (1 - null_frac1) * (1 - null_frac2) * min(1/num_distinct1, 1/
num_distinct2)
            = (1 - 0) * (1 - 0) / max(10000, 10000)
            = 0.0001
```

This is, subtract the null fraction from one for each of the relations, and divide by the maximum of the numbers of distinct values. The number of rows that the join is likely to emit is calculated as the cardinality of the Cartesian product of the two inputs, multiplied by the selectivity:

```
rows = (outer_cardinality * inner_cardinality) * selectivity
     = (50 * 10000) * 0.0001
     = 50
```

Had there been MCV lists for the two columns, `eqjoinsel` would have used direct comparison of the MCV lists to determine the join selectivity within the part of the column populations represented by the MCVs. The estimate for the remainder of the populations follows the same approach shown here.

Notice that we showed `inner_cardinality` as 10000, that is, the unmodified size of `tenk2`. It might appear from inspection of the `EXPLAIN` output that the estimate of join rows comes from 50 * 1, that is, the number of outer rows times the estimated number of rows obtained by each inner index scan on `tenk2`. But this is not the case: the join relation size is estimated before any particular join plan has been considered. If everything is working well then the two ways of estimating the join size will produce about the same answer, but due to round-off error and other factors they sometimes diverge significantly.

71.2. Multivariate Statistics Examples

71.2.1. Functional Dependencies

Multivariate correlation can be demonstrated with a very simple data set — a table with two columns, both containing the same values:

```
CREATE TABLE t (a INT, b INT);
INSERT INTO t SELECT i % 100, i % 100 FROM generate_series(1, 10000) s(i);
ANALYZE t;
```

As explained in Section 14.2, the planner can determine cardinality of `t` using the number of pages and rows obtained from `pg_class`:

```
SELECT relpages, reltuples FROM pg_class WHERE relname = 't';

 relpages | reltuples
----------+-----------
       45 |     10000
```

The data distribution is very simple; there are only 100 distinct values in each column, uniformly distributed.

The following example shows the result of estimating a `WHERE` condition on the `a` column:

```
EXPLAIN (ANALYZE, TIMING OFF) SELECT * FROM t WHERE a = 1;
                                  QUERY PLAN
-------------------------------------------------------------------------------
```

```
 Seq Scan on t  (cost=0.00..170.00 rows=100 width=8) (actual rows=100 loops=1)
   Filter: (a = 1)
   Rows Removed by Filter: 9900
```

The planner examines the condition and determines the selectivity of this clause to be 1%. By comparing this estimate and the actual number of rows, we see that the estimate is very accurate (in fact exact, as the table is very small). Changing the `WHERE` condition to use the `b` column, an identical plan is generated. But observe what happens if we apply the same condition on both columns, combining them with `AND`:

```
EXPLAIN (ANALYZE, TIMING OFF) SELECT * FROM t WHERE a = 1 AND b = 1;
                                 QUERY PLAN
-----------------------------------------------------------------------------
 Seq Scan on t  (cost=0.00..195.00 rows=1 width=8) (actual rows=100 loops=1)
   Filter: ((a = 1) AND (b = 1))
   Rows Removed by Filter: 9900
```

The planner estimates the selectivity for each condition individually, arriving at the same 1% estimates as above. Then it assumes that the conditions are independent, and so it multiplies their selectivities, producing a final selectivity estimate of just 0.01%. This is a significant underestimate, as the actual number of rows matching the conditions (100) is two orders of magnitude higher.

This problem can be fixed by creating a statistics object that directs `ANALYZE` to calculate functional-dependency multivariate statistics on the two columns:

```
CREATE STATISTICS stts (dependencies) ON a, b FROM t;
ANALYZE t;
EXPLAIN (ANALYZE, TIMING OFF) SELECT * FROM t WHERE a = 1 AND b = 1;
                                 QUERY PLAN
-----------------------------------------------------------------------------
 Seq Scan on t  (cost=0.00..195.00 rows=100 width=8) (actual rows=100 loops=1)
   Filter: ((a = 1) AND (b = 1))
   Rows Removed by Filter: 9900
```

71.2.2. Multivariate N-Distinct Counts

A similar problem occurs with estimation of the cardinality of sets of multiple columns, such as the number of groups that would be generated by a `GROUP BY` clause. When `GROUP BY` lists a single column, the n-distinct estimate (which is visible as the estimated number of rows returned by the HashAggregate node) is very accurate:

```
EXPLAIN (ANALYZE, TIMING OFF) SELECT COUNT(*) FROM t GROUP BY a;
                                     QUERY PLAN

-------------------------------------------------------------------------
----------------------
 HashAggregate  (cost=195.00..196.00 rows=100 width=12) (actual rows=100 loops=1)
   Group Key: a
   ->  Seq Scan on t  (cost=0.00..145.00 rows=10000 width=4) (actual rows=10000
 loops=1)
```

But without multivariate statistics, the estimate for the number of groups in a query with two columns in `GROUP BY`, as in the following example, is off by an order of magnitude:

```
EXPLAIN (ANALYZE, TIMING OFF) SELECT COUNT(*) FROM t GROUP BY a, b;
                                     QUERY PLAN

-------------------------------------------------------------------------
-------------------------
 HashAggregate  (cost=220.00..230.00 rows=1000 width=16) (actual rows=100 loops=1)
   Group Key: a, b
   ->  Seq Scan on t  (cost=0.00..145.00 rows=10000 width=8) (actual rows=10000
 loops=1)
```

By redefining the statistics object to include n-distinct counts for the two columns, the estimate is much improved:

```
DROP STATISTICS stts;
CREATE STATISTICS stts (dependencies, ndistinct) ON a, b FROM t;
ANALYZE t;
EXPLAIN (ANALYZE, TIMING OFF) SELECT COUNT(*) FROM t GROUP BY a, b;
                                        QUERY PLAN

------------------------------------------------------------------------
-------------------------
 HashAggregate  (cost=220.00..221.00 rows=100 width=16) (actual rows=100 loops=1)
   Group Key: a, b
   ->  Seq Scan on t  (cost=0.00..145.00 rows=10000 width=8) (actual rows=10000
 loops=1)
```

71.2.3. MCV Lists

As explained in Section 71.2.1, functional dependencies are very cheap and efficient type of statistics, but their main limitation is their global nature (only tracking dependencies at the column level, not between individual column values).

This section introduces multivariate variant of MCV (most-common values) lists, a straightforward extension of the per-column statistics described in Section 71.1. These statistics address the limitation by storing individual values, but it is naturally more expensive, both in terms of building the statistics in `ANALYZE`, storage and planning time.

Let's look at the query from Section 71.2.1 again, but this time with a MCV list created on the same set of columns (be sure to drop the functional dependencies, to make sure the planner uses the newly created statistics).

```
DROP STATISTICS stts;
CREATE STATISTICS stts2 (mcv) ON a, b FROM t;
ANALYZE t;
EXPLAIN (ANALYZE, TIMING OFF) SELECT * FROM t WHERE a = 1 AND b = 1;
                                     QUERY PLAN
-------------------------------------------------------------------------------
 Seq Scan on t  (cost=0.00..195.00 rows=100 width=8) (actual rows=100 loops=1)
   Filter: ((a = 1) AND (b = 1))
   Rows Removed by Filter: 9900
```

The estimate is as accurate as with the functional dependencies, mostly thanks to the table being fairly small and having a simple distribution with a low number of distinct values. Before looking at the second query, which was not handled by functional dependencies particularly well, let's inspect the MCV list a bit.

Inspecting the MCV list is possible using `pg_mcv_list_items` set-returning function.

```
SELECT m.* FROM pg_statistic_ext join pg_statistic_ext_data on (oid = stxoid),
                pg_mcv_list_items(stxdmcv) m WHERE stxname = 'stts2';
 index |  values  | nulls | frequency | base_frequency
-------+----------+-------+-----------+----------------
     0 | {0, 0}   | {f,f} |      0.01 |         0.0001
     1 | {1, 1}   | {f,f} |      0.01 |         0.0001
   ...
    49 | {49, 49} | {f,f} |      0.01 |         0.0001
    50 | {50, 50} | {f,f} |      0.01 |         0.0001
   ...
    97 | {97, 97} | {f,f} |      0.01 |         0.0001
    98 | {98, 98} | {f,f} |      0.01 |         0.0001
    99 | {99, 99} | {f,f} |      0.01 |         0.0001
```

```
(100 rows)
```

This confirms there are 100 distinct combinations in the two columns, and all of them are about equally likely (1% frequency for each one). The base frequency is the frequency computed from per-column statistics, as if there were no multi-column statistics. Had there been any null values in either of the columns, this would be identified in the `nulls` column.

When estimating the selectivity, the planner applies all the conditions on items in the MCV list, and then sums the frequencies of the matching ones.

Compared to functional dependencies, MCV lists have two major advantages. Firstly, the list stores actual values, making it possible to decide which combinations are compatible.

```
EXPLAIN (ANALYZE, TIMING OFF) SELECT * FROM t WHERE a = 1 AND b = 10;
                                 QUERY PLAN
-----------------------------------------------------------------------------
 Seq Scan on t  (cost=0.00..195.00 rows=1 width=8) (actual rows=0 loops=1)
   Filter: ((a = 1) AND (b = 10))
   Rows Removed by Filter: 10000
```

Secondly, MCV lists handle a wider range of clause types, not just equality clauses like functional dependencies. For example, consider the following range query for the same table:

```
EXPLAIN (ANALYZE, TIMING OFF) SELECT * FROM t WHERE a <= 49 AND b > 49;
                                 QUERY PLAN
-----------------------------------------------------------------------------
 Seq Scan on t  (cost=0.00..195.00 rows=1 width=8) (actual rows=0 loops=1)
   Filter: ((a <= 49) AND (b > 49))
   Rows Removed by Filter: 10000
```

71.3. Planner Statistics and Security

Access to the table `pg_statistic` is restricted to superusers, so that ordinary users cannot learn about the contents of the tables of other users from it. Some selectivity estimation functions will use a user-provided operator (either the operator appearing in the query or a related operator) to analyze the stored statistics. For example, in order to determine whether a stored most common value is applicable, the selectivity estimator will have to run the appropriate = operator to compare the constant in the query to the stored value. Thus the data in `pg_statistic` is potentially passed to user-defined operators. An appropriately crafted operator can intentionally leak the passed operands (for example, by logging them or writing them to a different table), or accidentally leak them by showing their values in error messages, in either case possibly exposing data from `pg_statistic` to a user who should not be able to see it.

In order to prevent this, the following applies to all built-in selectivity estimation functions. When planning a query, in order to be able to use stored statistics, the current user must either have `SELECT` privilege on the table or the involved columns, or the operator used must be `LEAKPROOF` (more accurately, the function that the operator is based on). If not, then the selectivity estimator will behave as if no statistics are available, and the planner will proceed with default or fall-back assumptions.

If a user does not have the required privilege on the table or columns, then in many cases the query will ultimately receive a permission-denied error, in which case this mechanism is invisible in practice. But if the user is reading from a security-barrier view, then the planner might wish to check the statistics of an underlying table that is otherwise inaccessible to the user. In that case, the operator should be leak-proof or the statistics will not be used. There is no direct feedback about that, except that the plan might be suboptimal. If one suspects that this is the case, one could try running the query as a more privileged user, to see if a different plan results.

This restriction applies only to cases where the planner would need to execute a user-defined operator on one or more values from `pg_statistic`. Thus the planner is permitted to use generic statistical information, such as the fraction of null values or the number of distinct values in a column, regardless of access privileges.

Selectivity estimation functions contained in third-party extensions that potentially operate on statistics with user-defined operators should follow the same security rules.

Chapter 72. Backup Manifest Format

The backup manifest generated by pg_basebackup is primarily intended to permit the backup to be verified using pg_verifybackup. However, it is also possible for other tools to read the backup manifest file and use the information contained therein for their own purposes. To that end, this chapter describes the format of the backup manifest file.

A backup manifest is a JSON document encoded as UTF-8. (Although in general JSON documents are required to be Unicode, PostgreSQL permits the `json` and `jsonb` data types to be used with any supported server encoding. There is no similar exception for backup manifests.) The JSON document is always an object; the keys that are present in this object are described in the next section.

72.1. Backup Manifest Top-level Object

The backup manifest JSON document contains the following keys.

`PostgreSQL-Backup-Manifest-Version`

The associated value is always the integer 1.

`Files`

The associated value is always a list of objects, each describing one file that is present in the backup. No entries are present in this list for the WAL files that are needed in order to use the backup, or for the backup manifest itself. The structure of each object in the list is described in Section 72.2.

`WAL-Ranges`

The associated value is always a list of objects, each describing a range of WAL records that must be readable from a particular timeline in order to make use of the backup. The structure of these objects is further described in Section 72.3.

`Manifest-Checksum`

This key is always present on the last line of the backup manifest file. The associated value is a SHA256 checksum of all the preceding lines. We use a fixed checksum method here to make it possible for clients to do incremental parsing of the manifest. While a SHA256 checksum is significantly more expensive than a CRC32C checksum, the manifest should normally be small enough that the extra computation won't matter very much.

72.2. Backup Manifest File Object

The object which describes a single file contains either a `Path` key or an `Encoded-Path` key. Normally, the `Path` key will be present. The associated string value is the path of the file relative to the root of the backup directory. Files located in a user-defined tablespace will have paths whose first two components are `pg_tblspc` and the OID of the tablespace. If the path is not a string that is legal in UTF-8, or if the user requests that encoded paths be used for all files, then the `Encoded-Path` key will be present instead. This stores the same data, but it is encoded as a string of hexadecimal digits. Each pair of hexadecimal digits in the string represents a single octet.

The following two keys are always present:

`Size`

The expected size of this file, as an integer.

`Last-Modified`

The last modification time of the file as reported by the server at the time of the backup. Unlike the other fields stored in the backup, this field is not used by pg_verifybackup. It is included only for informational purposes.

If the backup was taken with file checksums enabled, the following keys will be present:

`Checksum-Algorithm`

The checksum algorithm used to compute a checksum for this file. Currently, this will be the same for every file in the backup manifest, but this may change in future releases. At present, the supported checksum algorithms are `CRC32C`, `SHA224`, `SHA256`, `SHA384`, and `SHA512`.

`Checksum`

The checksum computed for this file, stored as a series of hexadecimal characters, two for each byte of the checksum.

72.3. Backup Manifest WAL Range Object

The object which describes a WAL range always has three keys:

`Timeline`

The timeline for this range of WAL records, as an integer.

`Start-LSN`

The LSN at which replay must begin on the indicated timeline in order to make use of this backup. The LSN is stored in the format normally used by PostgreSQL; that is, it is a string consisting of two strings of hexadecimal characters, each with a length of between 1 and 8, separated by a slash.

`End-LSN`

The earliest LSN at which replay on the indicated timeline may end when making use of this backup. This is stored in the same format as `Start-LSN`.

Ordinarily, there will be only a single WAL range. However, if a backup is taken from a standby which switches timelines during the backup due to an upstream promotion, it is possible for multiple ranges to be present, each with a different timeline. There will never be multiple WAL ranges present for the same timeline.

Part VIII. Appendixes

Appendix A. Postgres Pro Error Codes

All messages emitted by the Postgres Pro server are assigned five-character error codes that follow the SQL standard's conventions for “SQLSTATE” codes. Applications that need to know which error condition has occurred should usually test the error code, rather than looking at the textual error message. The error codes are less likely to change across Postgres Pro releases, and also are not subject to change due to localization of error messages. Note that some, but not all, of the error codes produced by Postgres Pro are defined by the SQL standard; some additional error codes for conditions not defined by the standard have been invented or borrowed from other databases.

According to the standard, the first two characters of an error code denote a class of errors, while the last three characters indicate a specific condition within that class. Thus, an application that does not recognize the specific error code might still be able to infer what to do from the error class.

Table A.1 lists all the error codes defined in Postgres Pro Enterprise 14.18.1. (Some are not actually used at present, but are defined by the SQL standard.) The error classes are also shown. For each error class there is a “standard” error code having the last three characters `000`. This code is used only for error conditions that fall within the class but do not have any more-specific code assigned.

The symbol shown in the column “Condition Name” is the condition name to use in PL/pgSQL. Condition names can be written in either upper or lower case. (Note that PL/pgSQL does not recognize warning, as opposed to error, condition names; those are classes 00, 01, and 02.)

For some types of errors, the server reports the name of a database object (a table, table column, data type, or constraint) associated with the error; for example, the name of the unique constraint that caused a `unique_violation` error. Such names are supplied in separate fields of the error report message so that applications need not try to extract them from the possibly-localized human-readable text of the message. As of PostgreSQL 9.3, complete coverage for this feature exists only for errors in SQLSTATE class 23 (integrity constraint violation), but this is likely to be expanded in future.

Table A.1. Postgres Pro Error Codes

Error Code	Condition Name
Class 00 — Successful Completion	
00000	successful_completion
Class 01 — Warning	
01000	warning
0100C	dynamic_result_sets_returned
01008	implicit_zero_bit_padding
01003	null_value_eliminated_in_set_function
01007	privilege_not_granted
01006	privilege_not_revoked
01004	string_data_right_truncation
01P01	deprecated_feature
Class 02 — No Data (this is also a warning class per the SQL standard)	
02000	no_data
02001	no_additional_dynamic_result_sets_returned
Class 03 — SQL Statement Not Yet Complete	
03000	sql_statement_not_yet_complete
Class 08 — Connection Exception	
08000	connection_exception

Error Code	Condition Name
08003	connection_does_not_exist
08006	connection_failure
08001	sqlclient_unable_to_establish_sqlconnection
08004	sqlserver_rejected_establishment_of_sqlconnection
08007	transaction_resolution_unknown
08P01	protocol_violation
Class 09 — Triggered Action Exception	
09000	triggered_action_exception
Class 0A — Feature Not Supported	
0A000	feature_not_supported
Class 0B — Invalid Transaction Initiation	
0B000	invalid_transaction_initiation
Class 0F — Locator Exception	
0F000	locator_exception
0F001	invalid_locator_specification
Class 0L — Invalid Grantor	
0L000	invalid_grantor
0LP01	invalid_grant_operation
Class 0P — Invalid Role Specification	
0P000	invalid_role_specification
Class 0Z — Diagnostics Exception	
0Z000	diagnostics_exception
0Z002	stacked_diagnostics_accessed_without_active_handler
Class 20 — Case Not Found	
20000	case_not_found
Class 21 — Cardinality Violation	
21000	cardinality_violation
Class 22 — Data Exception	
22000	data_exception
2202E	array_subscript_error
22021	character_not_in_repertoire
22008	datetime_field_overflow
22012	division_by_zero
22005	error_in_assignment
2200B	escape_character_conflict
22022	indicator_overflow
22015	interval_field_overflow
2201E	invalid_argument_for_logarithm
22014	invalid_argument_for_ntile_function

Error Code	Condition Name
22016	invalid_argument_for_nth_value_function
2201F	invalid_argument_for_power_function
2201G	invalid_argument_for_width_bucket_function
22018	invalid_character_value_for_cast
22007	invalid_datetime_format
22019	invalid_escape_character
2200D	invalid_escape_octet
22025	invalid_escape_sequence
22P06	nonstandard_use_of_escape_character
22010	invalid_indicator_parameter_value
22023	invalid_parameter_value
22013	invalid_preceding_or_following_size
2201B	invalid_regular_expression
2201W	invalid_row_count_in_limit_clause
2201X	invalid_row_count_in_result_offset_clause
2202H	invalid_tablesample_argument
2202G	invalid_tablesample_repeat
22009	invalid_time_zone_displacement_value
2200C	invalid_use_of_escape_character
2200G	most_specific_type_mismatch
22004	null_value_not_allowed
22002	null_value_no_indicator_parameter
22003	numeric_value_out_of_range
2200H	sequence_generator_limit_exceeded
22026	string_data_length_mismatch
22001	string_data_right_truncation
22011	substring_error
22027	trim_error
22024	unterminated_c_string
2200F	zero_length_character_string
22P01	floating_point_exception
22P02	invalid_text_representation
22P03	invalid_binary_representation
22P04	bad_copy_file_format
22P05	untranslatable_character
2200L	not_an_xml_document
2200M	invalid_xml_document
2200N	invalid_xml_content
2200S	invalid_xml_comment

Error Code	Condition Name
2200T	invalid_xml_processing_instruction
22030	duplicate_json_object_key_value
22031	invalid_argument_for_sql_json_datetime_function
22032	invalid_json_text
22033	invalid_sql_json_subscript
22034	more_than_one_sql_json_item
22035	no_sql_json_item
22036	non_numeric_sql_json_item
22037	non_unique_keys_in_a_json_object
22038	singleton_sql_json_item_required
22039	sql_json_array_not_found
2203A	sql_json_member_not_found
2203B	sql_json_number_not_found
2203C	sql_json_object_not_found
2203D	too_many_json_array_elements
2203E	too_many_json_object_members
2203F	sql_json_scalar_required
Class 23 — Integrity Constraint Violation	
23000	integrity_constraint_violation
23001	restrict_violation
23502	not_null_violation
23503	foreign_key_violation
23505	unique_violation
23514	check_violation
23P01	exclusion_violation
Class 24 — Invalid Cursor State	
24000	invalid_cursor_state
Class 25 — Invalid Transaction State	
25000	invalid_transaction_state
25001	active_sql_transaction
25002	branch_transaction_already_active
25008	held_cursor_requires_same_isolation_level
25003	inappropriate_access_mode_for_branch_transaction
25004	inappropriate_isolation_level_for_branch_transaction
25005	no_active_sql_transaction_for_branch_transaction
25006	read_only_sql_transaction
25007	schema_and_data_statement_mixing_not_supported
25P01	no_active_sql_transaction
25P02	in_failed_sql_transaction

Error Code	Condition Name
25P03	idle_in_transaction_session_timeout
Class 26 — Invalid SQL Statement Name	
26000	invalid_sql_statement_name
Class 27 — Triggered Data Change Violation	
27000	triggered_data_change_violation
Class 28 — Invalid Authorization Specification	
28000	invalid_authorization_specification
28P01	invalid_password
Class 2B — Dependent Privilege Descriptors Still Exist	
2B000	dependent_privilege_descriptors_still_exist
2BP01	dependent_objects_still_exist
Class 2D — Invalid Transaction Termination	
2D000	invalid_transaction_termination
Class 2F — SQL Routine Exception	
2F000	sql_routine_exception
2F005	function_executed_no_return_statement
2F002	modifying_sql_data_not_permitted
2F003	prohibited_sql_statement_attempted
2F004	reading_sql_data_not_permitted
Class 34 — Invalid Cursor Name	
34000	invalid_cursor_name
Class 38 — External Routine Exception	
38000	external_routine_exception
38001	containing_sql_not_permitted
38002	modifying_sql_data_not_permitted
38003	prohibited_sql_statement_attempted
38004	reading_sql_data_not_permitted
Class 39 — External Routine Invocation Exception	
39000	external_routine_invocation_exception
39001	invalid_sqlstate_returned
39004	null_value_not_allowed
39P01	trigger_protocol_violated
39P02	srf_protocol_violated
39P03	event_trigger_protocol_violated
Class 3B — Savepoint Exception	
3B000	savepoint_exception
3B001	invalid_savepoint_specification
Class 3D — Invalid Catalog Name	
3D000	invalid_catalog_name

Error Code	Condition Name
Class 3F — Invalid Schema Name	
3F000	invalid_schema_name
Class 40 — Transaction Rollback	
40000	transaction_rollback
40002	transaction_integrity_constraint_violation
40001	serialization_failure
40003	statement_completion_unknown
40P01	deadlock_detected
Class 42 — Syntax Error or Access Rule Violation	
42000	syntax_error_or_access_rule_violation
42601	syntax_error
42501	insufficient_privilege
42846	cannot_coerce
42803	grouping_error
42P20	windowing_error
42P19	invalid_recursion
42830	invalid_foreign_key
42602	invalid_name
42622	name_too_long
42939	reserved_name
42804	datatype_mismatch
42P18	indeterminate_datatype
42P21	collation_mismatch
42P22	indeterminate_collation
42809	wrong_object_type
428C9	generated_always
42703	undefined_column
42883	undefined_function
42P01	undefined_table
42P02	undefined_parameter
42704	undefined_object
42701	duplicate_column
42P03	duplicate_cursor
42P04	duplicate_database
42723	duplicate_function
42P05	duplicate_prepared_statement
42P06	duplicate_schema
42P07	duplicate_table
42712	duplicate_alias

Error Code	Condition Name
42710	duplicate_object
42702	ambiguous_column
42725	ambiguous_function
42P08	ambiguous_parameter
42P09	ambiguous_alias
42P10	invalid_column_reference
42611	invalid_column_definition
42P11	invalid_cursor_definition
42P12	invalid_database_definition
42P13	invalid_function_definition
42P14	invalid_prepared_statement_definition
42P15	invalid_schema_definition
42P16	invalid_table_definition
42P17	invalid_object_definition
Class 44 — WITH CHECK OPTION Violation	
44000	with_check_option_violation
Class 53 — Insufficient Resources	
53000	insufficient_resources
53100	disk_full
53200	out_of_memory
53300	too_many_connections
53400	configuration_limit_exceeded
53500	cardinality_estimation_accuracy
Class 54 — Program Limit Exceeded	
54000	program_limit_exceeded
54001	statement_too_complex
54011	too_many_columns
54023	too_many_arguments
Class 55 — Object Not In Prerequisite State	
55000	object_not_in_prerequisite_state
55006	object_in_use
55P02	cant_change_runtime_param
55P03	lock_not_available
55P04	unsafe_new_enum_value_usage
Class 57 — Operator Intervention	
57000	operator_intervention
57014	query_canceled
57P01	admin_shutdown
57P02	crash_shutdown

Error Code	Condition Name
57P03	cannot_connect_now
57P04	database_dropped
57P05	idle_session_timeout
Class 58 — System Error (errors external to PostgreSQL itself)	
58000	system_error
58030	io_error
58P01	undefined_file
58P02	duplicate_file
Class 72 — Snapshot Failure	
72000	snapshot_too_old
Class F0 — Configuration File Error	
F0000	config_file_error
F0001	lock_file_exists
Class HV — Foreign Data Wrapper Error (SQL/MED)	
HV000	fdw_error
HV005	fdw_column_name_not_found
HV002	fdw_dynamic_parameter_value_needed
HV010	fdw_function_sequence_error
HV021	fdw_inconsistent_descriptor_information
HV024	fdw_invalid_attribute_value
HV007	fdw_invalid_column_name
HV008	fdw_invalid_column_number
HV004	fdw_invalid_data_type
HV006	fdw_invalid_data_type_descriptors
HV091	fdw_invalid_descriptor_field_identifier
HV00B	fdw_invalid_handle
HV00C	fdw_invalid_option_index
HV00D	fdw_invalid_option_name
HV090	fdw_invalid_string_length_or_buffer_length
HV00A	fdw_invalid_string_format
HV009	fdw_invalid_use_of_null_pointer
HV014	fdw_too_many_handles
HV001	fdw_out_of_memory
HV00P	fdw_no_schemas
HV00J	fdw_option_name_not_found
HV00K	fdw_reply_handle
HV00Q	fdw_schema_not_found
HV00R	fdw_table_not_found
HV00L	fdw_unable_to_create_execution

Error Code	Condition Name
HV00M	fdw_unable_to_create_reply
HV00N	fdw_unable_to_establish_connection
Class P0 — PL/pgSQL Error	
P0000	plpgsql_error
P0001	raise_exception
P0002	no_data_found
P0003	too_many_rows
P0004	assert_failure
Class XX — Internal Error	
XX000	internal_error
XX001	data_corrupted
XX002	index_corrupted

Appendix B. Date/Time Support

Postgres Pro uses an internal heuristic parser for all date/time input support. Dates and times are input as strings, and are broken up into distinct fields with a preliminary determination of what kind of information can be in the field. Each field is interpreted and either assigned a numeric value, ignored, or rejected. The parser contains internal lookup tables for all textual fields, including months, days of the week, and time zones.

This appendix includes information on the content of these lookup tables and describes the steps used by the parser to decode dates and times.

B.1. Date/Time Input Interpretation

Date/time input strings are decoded using the following procedure.

1. Break the input string into tokens and categorize each token as a string, time, time zone, or number.

    a. If the numeric token contains a colon (`:`), this is a time string. Include all subsequent digits and colons.

    b. If the numeric token contains a dash (`-`), slash (`/`), or two or more dots (`.`), this is a date string which might have a text month. If a date token has already been seen, it is instead interpreted as a time zone name (e.g., `America/New_York`).

    c. If the token is numeric only, then it is either a single field or an ISO 8601 concatenated date (e.g., `19990113` for January 13, 1999) or time (e.g., `141516` for 14:15:16).

    d. If the token starts with a plus (`+`) or minus (`-`), then it is either a numeric time zone or a special field.

2. If the token is an alphabetic string, match up with possible strings:

    a. See if the token matches any known time zone abbreviation. These abbreviations are supplied by the configuration file described in Section B.4.

    b. If not found, search an internal table to match the token as either a special string (e.g., `today`), day (e.g., `Thursday`), month (e.g., `January`), or noise word (e.g., `at`, `on`).

    c. If still not found, throw an error.

3. When the token is a number or number field:

    a. If there are eight or six digits, and if no other date fields have been previously read, then interpret as a "concatenated date" (e.g., `19990118` or `990118`). The interpretation is `YYYYMMDD` or `YYMMDD`.

    b. If the token is three digits and a year has already been read, then interpret as day of year.

    c. If four or six digits and a year has already been read, then interpret as a time (`HHMM` or `HHMMSS`).

    d. If three or more digits and no date fields have yet been found, interpret as a year (this forces yy-mm-dd ordering of the remaining date fields).

    e. Otherwise the date field ordering is assumed to follow the `DateStyle` setting: mm-dd-yy, dd-mm-yy, or yy-mm-dd. Throw an error if a month or day field is found to be out of range.

4. If BC has been specified, negate the year and add one for internal storage. (There is no year zero in the Gregorian calendar, so numerically 1 BC becomes year zero.)

5. If BC was not specified, and if the year field was two digits in length, then adjust the year to four digits. If the field is less than 70, then add 2000, otherwise add 1900.

Tip

Gregorian years AD 1–99 can be entered by using 4 digits with leading zeros (e.g., `0099` is AD 99).

B.2. Handling of Invalid or Ambiguous Timestamps

Ordinarily, if a date/time string is syntactically valid but contains out-of-range field values, an error will be thrown. For example, input specifying the 31st of February will be rejected.

During a daylight-savings-time transition, it is possible for a seemingly valid timestamp string to represent a nonexistent or ambiguous timestamp. Such cases are not rejected; the ambiguity is resolved by determining which UTC offset to apply. For example, supposing that the TimeZone parameter is set to `America/New_York`, consider

```
=> SELECT '2018-03-11 02:30'::timestamptz;
      timestamptz
------------------------
 2018-03-11 03:30:00-04
(1 row)
```

Because that day was a spring-forward transition date in that time zone, there was no civil time instant 2:30AM; clocks jumped forward from 2AM EST to 3AM EDT. Postgres Pro interprets the given time as if it were standard time (UTC-5), which then renders as 3:30AM EDT (UTC-4).

Conversely, consider the behavior during a fall-back transition:

```
=> SELECT '2018-11-04 01:30'::timestamptz;
      timestamptz
------------------------
 2018-11-04 01:30:00-05
(1 row)
```

On that date, there were two possible interpretations of 1:30AM; there was 1:30AM EDT, and then an hour later after clocks jumped back from 2AM EDT to 1AM EST, there was 1:30AM EST. Again, Postgres Pro interprets the given time as if it were standard time (UTC-5). We can force the other interpretation by specifying daylight-savings time:

```
=> SELECT '2018-11-04 01:30 EDT'::timestamptz;
      timestamptz
------------------------
 2018-11-04 01:30:00-04
(1 row)
```

The precise rule that is applied in such cases is that an invalid timestamp that appears to fall within a jump-forward daylight savings transition is assigned the UTC offset that prevailed in the time zone just before the transition, while an ambiguous timestamp that could fall on either side of a jump-back transition is assigned the UTC offset that prevailed just after the transition. In most time zones this is equivalent to saying that “the standard-time interpretation is preferred when in doubt”.

In all cases, the UTC offset associated with a timestamp can be specified explicitly, using either a numeric UTC offset or a time zone abbreviation that corresponds to a fixed UTC offset. The rule just given applies only when it is necessary to infer a UTC offset for a time zone in which the offset varies.

B.3. Date/Time Key Words

Table B.1 shows the tokens that are recognized as names of months.

Table B.1. Month Names

Month	Abbreviations
January	Jan
February	Feb
March	Mar
April	Apr
May	
June	Jun
July	Jul
August	Aug
September	Sep, Sept
October	Oct
November	Nov
December	Dec

Table B.2 shows the tokens that are recognized as names of days of the week.

Table B.2. Day of the Week Names

Day	Abbreviations
Sunday	Sun
Monday	Mon
Tuesday	Tue, Tues
Wednesday	Wed, Weds
Thursday	Thu, Thur, Thurs
Friday	Fri
Saturday	Sat

Table B.3 shows the tokens that serve various modifier purposes.

Table B.3. Date/Time Field Modifiers

Identifier	Description
`AM`	Time is before 12:00
`AT`	Ignored
`JULIAN, JD, J`	Next field is Julian Date
`ON`	Ignored
`PM`	Time is on or after 12:00
`T`	Next field is time

B.4. Date/Time Configuration Files

Since timezone abbreviations are not well standardized, Postgres Pro provides a means to customize the set of abbreviations accepted by the server. The timezone_abbreviations run-time parameter determines the active set of abbreviations. While this parameter can be altered by any database user, the possible values for it are under the control of the database administrator — they are in fact names of configuration files stored in `.../share/timezonesets/` of the installation directory. By adding or altering files in that directory, the administrator can set local policy for timezone abbreviations.

`timezone_abbreviations` can be set to any file name found in `.../share/timezonesets/`, if the file's name is entirely alphabetic. (The prohibition against non-alphabetic characters in `timezone_abbreviations` prevents reading files outside the intended directory, as well as reading editor backup files and other extraneous files.)

A timezone abbreviation file can contain blank lines and comments beginning with `#`. Non-comment lines must have one of these formats:

```
zone_abbreviation offset
zone_abbreviation offset D
zone_abbreviation time_zone_name
@INCLUDE file_name
@OVERRIDE
```

A *`zone_abbreviation`* is just the abbreviation being defined. An *`offset`* is an integer giving the equivalent offset in seconds from UTC, positive being east from Greenwich and negative being west. For example, -18000 would be five hours west of Greenwich, or North American east coast standard time. `D` indicates that the zone name represents local daylight-savings time rather than standard time.

Alternatively, a *`time_zone_name`* can be given, referencing a zone name defined in the IANA timezone database. The zone's definition is consulted to see whether the abbreviation is or has been in use in that zone, and if so, the appropriate meaning is used — that is, the meaning that was currently in use at the timestamp whose value is being determined, or the meaning in use immediately before that if it wasn't current at that time, or the oldest meaning if it was used only after that time. This behavior is essential for dealing with abbreviations whose meaning has historically varied. It is also allowed to define an abbreviation in terms of a zone name in which that abbreviation does not appear; then using the abbreviation is just equivalent to writing out the zone name.

> **Tip**
>
> Using a simple integer *`offset`* is preferred when defining an abbreviation whose offset from UTC has never changed, as such abbreviations are much cheaper to process than those that require consulting a time zone definition.

The `@INCLUDE` syntax allows inclusion of another file in the `.../share/timezonesets/` directory. Inclusion can be nested, to a limited depth.

The `@OVERRIDE` syntax indicates that subsequent entries in the file can override previous entries (typically, entries obtained from included files). Without this, conflicting definitions of the same timezone abbreviation are considered an error.

In an unmodified installation, the file `Default` contains all the non-conflicting time zone abbreviations for most of the world. Additional files `Australia` and `India` are provided for those regions: these files first include the `Default` file and then add or modify abbreviations as needed.

For reference purposes, a standard installation also contains files `Africa.txt`, `America.txt`, etc, containing information about every time zone abbreviation known to be in use according to the IANA timezone database. The zone name definitions found in these files can be copied and pasted into a custom configuration file as needed. Note that these files cannot be directly referenced as `timezone_abbreviations` settings, because of the dot embedded in their names.

> **Note**
>
> If an error occurs while reading the time zone abbreviation set, no new value is applied and the old set is kept. If the error occurs while starting the database, startup fails.

Caution

Time zone abbreviations defined in the configuration file override non-timezone meanings built into Postgres Pro. For example, the `Australia` configuration file defines `SAT` (for South Australian Standard Time). When this file is active, `SAT` will not be recognized as an abbreviation for Saturday.

Caution

If you modify files in `.../share/timezonesets/`, it is up to you to make backups — a normal database dump will not include this directory.

B.5. POSIX Time Zone Specifications

Postgres Pro can accept time zone specifications that are written according to the POSIX standard's rules for the `TZ` environment variable. POSIX time zone specifications are inadequate to deal with the complexity of real-world time zone history, but there are sometimes reasons to use them.

A POSIX time zone specification has the form

STD offset [*DST* [*dstoffset*] [, *rule*]]

(For readability, we show spaces between the fields, but spaces should not be used in practice.) The fields are:

- *STD* is the zone abbreviation to be used for standard time.
- *offset* is the zone's standard-time offset from UTC.
- *DST* is the zone abbreviation to be used for daylight-savings time. If this field and the following ones are omitted, the zone uses a fixed UTC offset with no daylight-savings rule.
- *dstoffset* is the daylight-savings offset from UTC. This field is typically omitted, since it defaults to one hour less than the standard-time *offset*, which is usually the right thing.
- *rule* defines the rule for when daylight savings is in effect, as described below.

In this syntax, a zone abbreviation can be a string of letters, such as `EST`, or an arbitrary string surrounded by angle brackets, such as `<UTC-05>`. Note that the zone abbreviations given here are only used for output, and even then only in some timestamp output formats. The zone abbreviations recognized in timestamp input are determined as explained in Section B.4.

The offset fields specify the hours, and optionally minutes and seconds, difference from UTC. They have the format *hh*[:*mm*[:*ss*]] optionally with a leading sign (+ or -). The positive sign is used for zones *west* of Greenwich. (Note that this is the opposite of the ISO-8601 sign convention used elsewhere in Postgres Pro.) *hh* can have one or two digits; *mm* and *ss* (if used) must have two.

The daylight-savings transition *rule* has the format

dstdate [/ *dsttime*] , *stddate* [/ *stdtime*]

(As before, spaces should not be included in practice.) The *dstdate* and *dsttime* fields define when daylight-savings time starts, while *stddate* and *stdtime* define when standard time starts. (In some cases, notably in zones south of the equator, the former might be later in the year than the latter.) The date fields have one of these formats:

n

A plain integer denotes a day of the year, counting from zero to 364, or to 365 in leap years.

Jn

In this form, *n* counts from 1 to 365, and February 29 is not counted even if it is present. (Thus, a transition occurring on February 29 could not be specified this way. However, days after February

have the same numbers whether it's a leap year or not, so that this form is usually more useful than the plain-integer form for transitions on fixed dates.)

`M`*m*`.`*n*`.`*d*

This form specifies a transition that always happens during the same month and on the same day of the week. *m* identifies the month, from 1 to 12. *n* specifies the *n*'th occurrence of the weekday identified by *d*. *n* is a number between 1 and 4, or 5 meaning the last occurrence of that weekday in the month (which could be the fourth or the fifth). *d* is a number between 0 and 6, with 0 indicating Sunday. For example, `M3.2.0` means “the second Sunday in March”.

> **Note**
>
> The `M` format is sufficient to describe many common daylight-savings transition laws. But note that none of these variants can deal with daylight-savings law changes, so in practice the historical data stored for named time zones (in the IANA time zone database) is necessary to interpret past time stamps correctly.

The time fields in a transition rule have the same format as the offset fields described previously, except that they cannot contain signs. They define the current local time at which the change to the other time occurs. If omitted, they default to `02:00:00`.

If a daylight-savings abbreviation is given but the transition *rule* field is omitted, the fallback behavior is to use the rule `M3.2.0,M11.1.0`, which corresponds to USA practice as of 2020 (that is, spring forward on the second Sunday of March, fall back on the first Sunday of November, both transitions occurring at 2AM prevailing time). Note that this rule does not give correct USA transition dates for years before 2007.

As an example, `CET-1CEST,M3.5.0,M10.5.0/3` describes current (as of 2020) timekeeping practice in Paris. This specification says that standard time has the abbreviation `CET` and is one hour ahead (east) of UTC; daylight savings time has the abbreviation `CEST` and is implicitly two hours ahead of UTC; daylight savings time begins on the last Sunday in March at 2AM CET and ends on the last Sunday in October at 3AM CEST.

The four timezone names `EST5EDT`, `CST6CDT`, `MST7MDT`, and `PST8PDT` look like they are POSIX zone specifications. However, they actually are treated as named time zones because (for historical reasons) there are files by those names in the IANA time zone database. The practical implication of this is that these zone names will produce valid historical USA daylight-savings transitions, even when a plain POSIX specification would not.

One should be wary that it is easy to misspell a POSIX-style time zone specification, since there is no check on the reasonableness of the zone abbreviation(s). For example, `SET TIMEZONE TO FOOBAR0` will work, leaving the system effectively using a rather peculiar abbreviation for UTC.

B.6. History of Units

The SQL standard states that “Within the definition of a ‘datetime literal’, the ‘datetime values’ are constrained by the natural rules for dates and times according to the Gregorian calendar”. Postgres Pro follows the SQL standard's lead by counting dates exclusively in the Gregorian calendar, even for years before that calendar was in use. This rule is known as the *proleptic Gregorian calendar*.

The Julian calendar was introduced by Julius Caesar in 45 BC. It was in common use in the Western world until the year 1582, when countries started changing to the Gregorian calendar. In the Julian calendar, the tropical year is approximated as 365 1/4 days = 365.25 days. This gives an error of about 1 day in 128 years.

The accumulating calendar error prompted Pope Gregory XIII to reform the calendar in accordance with instructions from the Council of Trent. In the Gregorian calendar, the tropical year is approximated as

365 + 97 / 400 days = 365.2425 days. Thus it takes approximately 3300 years for the tropical year to shift one day with respect to the Gregorian calendar.

The approximation 365+97/400 is achieved by having 97 leap years every 400 years, using the following rules:

Every year divisible by 4 is a leap year.
However, every year divisible by 100 is not a leap year.
However, every year divisible by 400 is a leap year after all.

So, 1700, 1800, 1900, 2100, and 2200 are not leap years. But 1600, 2000, and 2400 are leap years. By contrast, in the older Julian calendar all years divisible by 4 are leap years.

The papal bull of February 1582 decreed that 10 days should be dropped from October 1582 so that 15 October should follow immediately after 4 October. This was observed in Italy, Poland, Portugal, and Spain. Other Catholic countries followed shortly after, but Protestant countries were reluctant to change, and the Greek Orthodox countries didn't change until the start of the 20th century. The reform was observed by Great Britain and its dominions (including what is now the USA) in 1752. Thus 2 September 1752 was followed by 14 September 1752. This is why Unix systems that have the `cal` program produce the following:

```
$ cal 9 1752
   September 1752
 S  M Tu  W Th  F  S
       1  2 14 15 16
17 18 19 20 21 22 23
24 25 26 27 28 29 30
```

But, of course, this calendar is only valid for Great Britain and dominions, not other places. Since it would be difficult and confusing to try to track the actual calendars that were in use in various places at various times, Postgres Pro does not try, but rather follows the Gregorian calendar rules for all dates, even though this method is not historically accurate.

Different calendars have been developed in various parts of the world, many predating the Gregorian system. For example, the beginnings of the Chinese calendar can be traced back to the 14th century BC. Legend has it that the Emperor Huangdi invented that calendar in 2637 BC. The People's Republic of China uses the Gregorian calendar for civil purposes. The Chinese calendar is used for determining festivals.

B.7. Julian Dates

The *Julian Date* system is a method for numbering days. It is unrelated to the Julian calendar, though it is confusingly named similarly to that calendar. The Julian Date system was invented by the French scholar Joseph Justus Scaliger (1540–1609) and probably takes its name from Scaliger's father, the Italian scholar Julius Caesar Scaliger (1484–1558).

In the Julian Date system, each day has a sequential number, starting from JD 0 (which is sometimes called *the* Julian Date). JD 0 corresponds to 1 January 4713 BC in the Julian calendar, or 24 November 4714 BC in the Gregorian calendar. Julian Date counting is most often used by astronomers for labeling their nightly observations, and therefore a date runs from noon UTC to the next noon UTC, rather than from midnight to midnight: JD 0 designates the 24 hours from noon UTC on 24 November 4714 BC to noon UTC on 25 November 4714 BC.

Although Postgres Pro supports Julian Date notation for input and output of dates (and also uses Julian dates for some internal datetime calculations), it does not observe the nicety of having dates run from noon to noon. Postgres Pro treats a Julian Date as running from local midnight to local midnight, the same as a normal date.

This definition does, however, provide a way to obtain the astronomical definition when you need it: do the arithmetic in time zone `UTC+12`. For example,

```
=> SELECT extract(julian from '2021-06-23 7:00:00-04'::timestamptz at time zone 'UTC
+12');
           extract
-----------------------------
 2459388.9583333333333333333
(1 row)
=> SELECT extract(julian from '2021-06-23 8:00:00-04'::timestamptz at time zone 'UTC
+12');
               extract
--------------------------------------
 2459389.0000000000000000000000000000
(1 row)
=> SELECT extract(julian from date '2021-06-23');
 extract
---------
 2459389
(1 row)
```

Appendix C. SQL Key Words

Table C.1 lists all tokens that are key words in the SQL standard and in Postgres Pro Enterprise 14.18.1. Background information can be found in Section 4.1.1. (For space reasons, only the latest two versions of the SQL standard, and SQL-92 for historical comparison, are included. The differences between those and the other intermediate standard versions are small.)

SQL distinguishes between *reserved* and *non-reserved* key words. According to the standard, reserved key words are the only real key words; they are never allowed as identifiers. Non-reserved key words only have a special meaning in particular contexts and can be used as identifiers in other contexts. Most non-reserved key words are actually the names of built-in tables and functions specified by SQL. The concept of non-reserved key words essentially only exists to declare that some predefined meaning is attached to a word in some contexts.

In the Postgres Pro parser, life is a bit more complicated. There are several different classes of tokens ranging from those that can never be used as an identifier to those that have absolutely no special status in the parser, but are considered ordinary identifiers. (The latter is usually the case for functions specified by SQL.) Even reserved key words are not completely reserved in Postgres Pro, but can be used as column labels (for example, `SELECT 55 AS CHECK`, even though `CHECK` is a reserved key word).

In Table C.1 in the column for Postgres Pro we classify as “non-reserved” those key words that are explicitly known to the parser but are allowed as column or table names. Some key words that are otherwise non-reserved cannot be used as function or data type names and are marked accordingly. (Most of these words represent built-in functions or data types with special syntax. The function or type is still available but it cannot be redefined by the user.) Labeled “reserved” are those tokens that are not allowed as column or table names. Some reserved key words are allowable as names for functions or data types; this is also shown in the table. If not so marked, a reserved key word is only allowed as a column label. A blank entry in this column means that the word is treated as an ordinary identifier by PostgreSQL.

Furthermore, while most key words can be used as “bare” column labels without writing `AS` before them (as described in Section 7.3.2), there are a few that require a leading `AS` to avoid ambiguity. These are marked in the table as “requires `AS`”.

As a general rule, if you get spurious parser errors for commands that use any of the listed key words as an identifier, you should try quoting the identifier to see if the problem goes away.

It is important to understand before studying Table C.1 that the fact that a key word is not reserved in Postgres Pro does not mean that the feature related to the word is not implemented. Conversely, the presence of a key word does not indicate the existence of a feature.

Table C.1. SQL Key Words

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
A		non-reserved	non-reserved	
ABORT	non-reserved			
ABS		reserved	reserved	
ABSENT		non-reserved	non-reserved	
ABSOLUTE	non-reserved	non-reserved	non-reserved	reserved
ACCESS	non-reserved			
ACCORDING		non-reserved	non-reserved	
ACCOUNT	non-reserved			
ACOS		reserved		
ACTION	non-reserved	non-reserved	non-reserved	reserved
ADA		non-reserved	non-reserved	non-reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
ADD	non-reserved	non-reserved	non-reserved	reserved
ADMIN	non-reserved	non-reserved	non-reserved	
AFTER	non-reserved	non-reserved	non-reserved	
AGGREGATE	non-reserved			
ALL	reserved	reserved	reserved	reserved
ALLOCATE		reserved	reserved	reserved
ALSO	non-reserved			
ALTER	non-reserved	reserved	reserved	reserved
ALWAYS	non-reserved	non-reserved	non-reserved	
ANALYSE	reserved			
ANALYZE	reserved			
AND	reserved	reserved	reserved	reserved
ANY	reserved	reserved	reserved	reserved
APPLICATION	non-reserved			
ARE		reserved	reserved	reserved
ARRAY	reserved, requires AS	reserved	reserved	
ARRAY_AGG		reserved	reserved	
ARRAY_MAX_CARDINALITY		reserved	reserved	
AS	reserved, requires AS	reserved	reserved	reserved
ASC	reserved	non-reserved	non-reserved	reserved
ASENSITIVE	non-reserved	reserved	reserved	
ASIN		reserved		
ASSERTION	non-reserved	non-reserved	non-reserved	reserved
ASSIGNMENT	non-reserved	non-reserved	non-reserved	
ASYMMETRIC	reserved	reserved	reserved	
AT	non-reserved	reserved	reserved	reserved
ATAN		reserved		
ATOMIC	non-reserved	reserved	reserved	
ATTACH	non-reserved			
ATTRIBUTE	non-reserved	non-reserved	non-reserved	
ATTRIBUTES		non-reserved	non-reserved	
AUTHORIZATION	reserved (can be function or type)	reserved	reserved	reserved
AUTONOMOUS	reserved (can be function or type)			
AVG		reserved	reserved	reserved
BACKWARD	non-reserved			
BASE64		non-reserved	non-reserved	
BEFORE	non-reserved	non-reserved	non-reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
BEGIN	non-reserved	reserved	reserved	reserved
BEGIN_FRAME		reserved	reserved	
BEGIN_PARTITION		reserved	reserved	
BERNOULLI		non-reserved	non-reserved	
BETWEEN	non-reserved (cannot be function or type)	reserved	reserved	reserved
BIGINT	non-reserved (cannot be function or type)	reserved	reserved	
BINARY	reserved (can be function or type)	reserved	reserved	
BIT	non-reserved (cannot be function or type)			reserved
BIT_LENGTH				reserved
BLOB		reserved	reserved	
BLOCKED		non-reserved	non-reserved	
BOM		non-reserved	non-reserved	
BOOLEAN	non-reserved (cannot be function or type)	reserved	reserved	
BOTH	reserved	reserved	reserved	reserved
BREADTH	non-reserved	non-reserved	non-reserved	
BY	non-reserved	reserved	reserved	reserved
C		non-reserved	non-reserved	non-reserved
CACHE	non-reserved			
CALL	non-reserved	reserved	reserved	
CALLED	non-reserved	reserved	reserved	
CARDINALITY		reserved	reserved	
CASCADE	non-reserved	non-reserved	non-reserved	reserved
CASCADED	non-reserved	reserved	reserved	reserved
CASE	reserved	reserved	reserved	reserved
CAST	reserved	reserved	reserved	reserved
CATALOG	non-reserved	non-reserved	non-reserved	reserved
CATALOG_NAME		non-reserved	non-reserved	non-reserved
CEIL		reserved	reserved	
CEILING		reserved	reserved	
CHAIN	non-reserved	non-reserved	non-reserved	
CHAINING		non-reserved		
CHAR	non-reserved (cannot be function or type), requires AS	reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
CHARACTER	non-reserved (cannot be function or type), requires AS	reserved	reserved	reserved
CHARACTERISTICS	non-reserved	non-reserved	non-reserved	
CHARACTERS		non-reserved	non-reserved	
CHARACTER_LENGTH		reserved	reserved	reserved
CHARACTER_SET_CATALOG		non-reserved	non-reserved	non-reserved
CHARACTER_SET_NAME		non-reserved	non-reserved	non-reserved
CHARACTER_SET_SCHEMA		non-reserved	non-reserved	non-reserved
CHAR_LENGTH		reserved	reserved	reserved
CHECK	reserved	reserved	reserved	reserved
CHECKPOINT	non-reserved			
CLASS	non-reserved			
CLASSIFIER		reserved		
CLASS_ORIGIN		non-reserved	non-reserved	non-reserved
CLOB		reserved	reserved	
CLOSE	non-reserved	reserved	reserved	reserved
CLUSTER	non-reserved			
COALESCE	non-reserved (cannot be function or type)	reserved	reserved	reserved
COBOL		non-reserved	non-reserved	non-reserved
COLLATE	reserved	reserved	reserved	reserved
COLLATION	reserved (can be function or type)	non-reserved	non-reserved	reserved
COLLATION_CATALOG		non-reserved	non-reserved	non-reserved
COLLATION_NAME		non-reserved	non-reserved	non-reserved
COLLATION_SCHEMA		non-reserved	non-reserved	non-reserved
COLLECT		reserved	reserved	
COLUMN	reserved	reserved	reserved	reserved
COLUMNS	non-reserved	non-reserved	non-reserved	
COLUMN_NAME		non-reserved	non-reserved	non-reserved
COMMAND_FUNCTION		non-reserved	non-reserved	non-reserved
COMMAND_FUNCTION_CODE		non-reserved	non-reserved	
COMMENT	non-reserved			
COMMENTS	non-reserved			
COMMIT	non-reserved	reserved	reserved	reserved
COMMITTED	non-reserved	non-reserved	non-reserved	non-reserved
COMPRESSION	non-reserved			
CONCURRENTLY	reserved (can be function or type)			
CONDITION		reserved	reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
CONDITIONAL		non-reserved		
CONDITION_NUMBER		non-reserved	non-reserved	non-reserved
CONFIGURATION	non-reserved			
CONFLICT	non-reserved			
CONNECT		reserved	reserved	reserved
CONNECTION	non-reserved	non-reserved	non-reserved	reserved
CONNECTION_NAME		non-reserved	non-reserved	non-reserved
CONSTANT	non-reserved, requires AS			
CONSTRAINT	reserved	reserved	reserved	reserved
CONSTRAINTS	non-reserved	non-reserved	non-reserved	reserved
CONSTRAINT_CATALOG		non-reserved	non-reserved	non-reserved
CONSTRAINT_NAME		non-reserved	non-reserved	non-reserved
CONSTRAINT_SCHEMA		non-reserved	non-reserved	non-reserved
CONSTRUCTOR		non-reserved	non-reserved	
CONTAINS		reserved	reserved	
CONTENT	non-reserved	non-reserved	non-reserved	
CONTINUE	non-reserved	non-reserved	non-reserved	reserved
CONTROL		non-reserved	non-reserved	
CONVERSION	non-reserved			
CONVERT		reserved	reserved	reserved
COPY	non-reserved	reserved		
CORR		reserved	reserved	
CORRESPONDING		reserved	reserved	reserved
COS		reserved		
COSH		reserved		
COST	non-reserved			
COUNT		reserved	reserved	reserved
COVAR_POP		reserved	reserved	
COVAR_SAMP		reserved	reserved	
CREATE	reserved, requires AS	reserved	reserved	reserved
CROSS	reserved (can be function or type)	reserved	reserved	reserved
CSV	non-reserved			
CUBE	non-reserved	reserved	reserved	
CUME_DIST		reserved	reserved	
CURRENT	non-reserved	reserved	reserved	reserved
CURRENT_CATALOG	reserved	reserved	reserved	
CURRENT_DATE	reserved	reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
CURRENT_DEFAULT_TRANS-FORM_GROUP		reserved	reserved	
CURRENT_PATH		reserved	reserved	
CURRENT_ROLE	reserved	reserved	reserved	
CURRENT_ROW		reserved	reserved	
CURRENT_SCHEMA	reserved (can be function or type)	reserved	reserved	
CURRENT_TIME	reserved	reserved	reserved	reserved
CURRENT_TIMESTAMP	reserved	reserved	reserved	reserved
CURRENT_TRANSFORM_GROUP_ FOR_TYPE		reserved	reserved	
CURRENT_USER	reserved	reserved	reserved	reserved
CURSOR	non-reserved	reserved	reserved	reserved
CURSOR_NAME		non-reserved	non-reserved	non-reserved
CYCLE	non-reserved	reserved	reserved	
DATA	non-reserved	non-reserved	non-reserved	non-reserved
DATABASE	non-reserved			
DATALINK		reserved	reserved	
DATE		reserved	reserved	reserved
DATETIME_INTERVAL_CODE		non-reserved	non-reserved	non-reserved
DATETIME_INTERVAL_ PRECISION		non-reserved	non-reserved	non-reserved
DAY	non-reserved, re-quires AS	reserved	reserved	reserved
DB		non-reserved	non-reserved	
DEALLOCATE	non-reserved	reserved	reserved	reserved
DEC	non-reserved (can-not be function or type)	reserved	reserved	reserved
DECFLOAT		reserved		
DECIMAL	non-reserved (can-not be function or type)	reserved	reserved	reserved
DECLARE	non-reserved	reserved	reserved	reserved
DEFAULT	reserved	reserved	reserved	reserved
DEFAULTS	non-reserved	non-reserved	non-reserved	
DEFERRABLE	reserved	non-reserved	non-reserved	reserved
DEFERRED	non-reserved	non-reserved	non-reserved	reserved
DEFINE		reserved		
DEFINED		non-reserved	non-reserved	
DEFINER	non-reserved	non-reserved	non-reserved	
DEGREE		non-reserved	non-reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
DELETE	non-reserved	reserved	reserved	reserved
DELIMITER	non-reserved			
DELIMITERS	non-reserved			
DENSE_RANK		reserved	reserved	
DEPENDS	non-reserved			
DEPTH	non-reserved	non-reserved	non-reserved	
DEREF		reserved	reserved	
DERIVED		non-reserved	non-reserved	
DESC	reserved	non-reserved	non-reserved	reserved
DESCRIBE		reserved	reserved	reserved
DESCRIPTOR		non-reserved	non-reserved	reserved
DETACH	non-reserved			
DETERMINISTIC		reserved	reserved	
DIAGNOSTICS		non-reserved	non-reserved	reserved
DICTIONARY	non-reserved			
DISABLE	non-reserved			
DISCARD	non-reserved			
DISCONNECT		reserved	reserved	reserved
DISPATCH		non-reserved	non-reserved	
DISTINCT	reserved	reserved	reserved	reserved
DLNEWCOPY		reserved	reserved	
DLPREVIOUSCOPY		reserved	reserved	
DLURLCOMPLETE		reserved	reserved	
DLURLCOMPLETEONLY		reserved	reserved	
DLURLCOMPLETEWRITE		reserved	reserved	
DLURLPATH		reserved	reserved	
DLURLPATHONLY		reserved	reserved	
DLURLPATHWRITE		reserved	reserved	
DLURLSCHEME		reserved	reserved	
DLURLSERVER		reserved	reserved	
DLVALUE		reserved	reserved	
DO	reserved			
DOCUMENT	non-reserved	non-reserved	non-reserved	
DOMAIN	non-reserved	non-reserved	non-reserved	reserved
DOUBLE	non-reserved	reserved	reserved	reserved
DROP	non-reserved	reserved	reserved	reserved
DYNAMIC		reserved	reserved	
DYNAMIC_FUNCTION		non-reserved	non-reserved	non-reserved
DYNAMIC_FUNCTION_CODE		non-reserved	non-reserved	
EACH	non-reserved	reserved	reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
ELEMENT		reserved	reserved	
ELSE	reserved	reserved	reserved	reserved
EMPTY		reserved	non-reserved	
ENABLE	non-reserved			
ENCODING	non-reserved	non-reserved	non-reserved	
ENCRYPTED	non-reserved			
END	reserved	reserved	reserved	reserved
END-EXEC		reserved	reserved	reserved
END_FRAME		reserved	reserved	
END_PARTITION		reserved	reserved	
ENFORCED		non-reserved	non-reserved	
ENUM	non-reserved			
EQUALS		reserved	reserved	
ERROR		non-reserved		
ESCAPE	non-reserved	reserved	reserved	reserved
EVENT	non-reserved			
EVERY		reserved	reserved	
EXCEPT	reserved, requires AS	reserved	reserved	reserved
EXCEPTION				reserved
EXCLUDE	non-reserved	non-reserved	non-reserved	
EXCLUDING	non-reserved	non-reserved	non-reserved	
EXCLUSIVE	non-reserved			
EXEC		reserved	reserved	reserved
EXECUTE	non-reserved	reserved	reserved	reserved
EXISTS	non-reserved (cannot be function or type)	reserved	reserved	reserved
EXP		reserved	reserved	
EXPLAIN	non-reserved			
EXPRESSION	non-reserved	non-reserved	non-reserved	
EXTENSION	non-reserved			
EXTERNAL	non-reserved	reserved	reserved	reserved
EXTRACT	non-reserved (cannot be function or type)	reserved	reserved	reserved
FAILED_AUTH_KEEP_TIME	non-reserved			
FAILED_LOGIN_ATTEMPTS	non-reserved			
FALSE	reserved	reserved	reserved	reserved
FAMILY	non-reserved			
FETCH	reserved, requires AS	reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
FILE		non-reserved	non-reserved	
FILTER	non-reserved, requires AS	reserved	reserved	
FINAL		non-reserved	non-reserved	
FINALIZE	non-reserved			
FINISH		non-reserved		
FIRST	non-reserved	non-reserved	non-reserved	reserved
FIRST_VALUE		reserved	reserved	
FLAG		non-reserved	non-reserved	
FLOAT	non-reserved (cannot be function or type)	reserved	reserved	reserved
FLOOR		reserved	reserved	
FOLLOWING	non-reserved	non-reserved	non-reserved	
FOR	reserved, requires AS	reserved	reserved	reserved
FORCE	non-reserved			
FOREIGN	reserved	reserved	reserved	reserved
FORMAT		non-reserved		
FORTRAN		non-reserved	non-reserved	non-reserved
FORWARD	non-reserved			
FOUND		non-reserved	non-reserved	reserved
FRAME_ROW		reserved	reserved	
FREE		reserved	reserved	
FREEZE	reserved (can be function or type)			
FROM	reserved, requires AS	reserved	reserved	reserved
FS		non-reserved	non-reserved	
FULFILL		non-reserved		
FULL	reserved (can be function or type)	reserved	reserved	reserved
FUNCTION	non-reserved	reserved	reserved	
FUNCTIONS	non-reserved			
FUSION		reserved	reserved	
G		non-reserved	non-reserved	
GENERAL		non-reserved	non-reserved	
GENERATED	non-reserved	non-reserved	non-reserved	
GET		reserved	reserved	reserved
GLOBAL	non-reserved	reserved	reserved	reserved
GO		non-reserved	non-reserved	reserved
GOTO		non-reserved	non-reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
GRANT	reserved, requires AS	reserved	reserved	reserved
GRANTED	non-reserved	non-reserved	non-reserved	
GREATEST	non-reserved (cannot be function or type)			
GROUP	reserved, requires AS	reserved	reserved	reserved
GROUPING	non-reserved (cannot be function or type)	reserved	reserved	
GROUPS	non-reserved	reserved	reserved	
HANDLER	non-reserved			
HASH	non-reserved			
HAVING	reserved, requires AS	reserved	reserved	reserved
HEADER	non-reserved			
HEX		non-reserved	non-reserved	
HIERARCHY		non-reserved	non-reserved	
HOLD	non-reserved	reserved	reserved	
HOUR	non-reserved, requires AS	reserved	reserved	reserved
ID		non-reserved	non-reserved	
IDENTITY	non-reserved	reserved	reserved	reserved
IF	non-reserved			
IGNORE		non-reserved	non-reserved	
ILIKE	reserved (can be function or type)			
IMMEDIATE	non-reserved	non-reserved	non-reserved	reserved
IMMEDIATELY		non-reserved	non-reserved	
IMMUTABLE	non-reserved			
IMPLEMENTATION		non-reserved	non-reserved	
IMPLICIT	non-reserved			
IMPORT	non-reserved	reserved	reserved	
IN	reserved	reserved	reserved	reserved
INCLUDE	non-reserved			
INCLUDING	non-reserved	non-reserved	non-reserved	
INCREMENT	non-reserved	non-reserved	non-reserved	
INDENT		non-reserved	non-reserved	
INDEX	non-reserved			
INDEXES	non-reserved			
INDICATOR		reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
INHERIT	non-reserved			
INHERITS	non-reserved			
INITIAL		reserved		
INITIALLY	reserved	non-reserved	non-reserved	reserved
INLINE	non-reserved			
INNER	reserved (can be function or type)	reserved	reserved	reserved
INOUT	non-reserved (cannot be function or type)	reserved	reserved	
INPUT	non-reserved	non-reserved	non-reserved	reserved
INSENSITIVE	non-reserved	reserved	reserved	reserved
INSERT	non-reserved	reserved	reserved	reserved
INSTANCE		non-reserved	non-reserved	
INSTANTIABLE		non-reserved	non-reserved	
INSTEAD	non-reserved	non-reserved	non-reserved	
INT	non-reserved (cannot be function or type)	reserved	reserved	reserved
INTEGER	non-reserved (cannot be function or type)	reserved	reserved	reserved
INTEGRITY		non-reserved	non-reserved	
INTERSECT	reserved, requires AS	reserved	reserved	reserved
INTERSECTION		reserved	reserved	
INTERVAL	non-reserved (cannot be function or type)	reserved	reserved	reserved
INTO	reserved, requires AS	reserved	reserved	reserved
INVOKER	non-reserved	non-reserved	non-reserved	
IS	reserved (can be function or type)	reserved	reserved	reserved
ISNULL	reserved (can be function or type), requires AS			
ISOLATION	non-reserved	non-reserved	non-reserved	reserved
JOIN	reserved (can be function or type)	reserved	reserved	reserved
JSON		non-reserved		
JSON_ARRAY		reserved		
JSON_ARRAYAGG		reserved		
JSON_EXISTS		reserved		

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
JSON_OBJECT		reserved		
JSON_OBJECTAGG		reserved		
JSON_QUERY		reserved		
JSON_TABLE		reserved		
JSON_TABLE_PRIMITIVE		reserved		
JSON_VALUE		reserved		
K		non-reserved	non-reserved	
KEEP		non-reserved		
KEY	non-reserved	non-reserved	non-reserved	reserved
KEYS		non-reserved		
KEY_MEMBER		non-reserved	non-reserved	
KEY_TYPE		non-reserved	non-reserved	
LABEL	non-reserved			
LAG		reserved	reserved	
LANGUAGE	non-reserved	reserved	reserved	reserved
LARGE	non-reserved	reserved	reserved	
LAST	non-reserved	non-reserved	non-reserved	reserved
LAST_VALUE		reserved	reserved	
LATERAL	reserved	reserved	reserved	
LEAD		reserved	reserved	
LEADING	reserved	reserved	reserved	reserved
LEAKPROOF	non-reserved			
LEAST	non-reserved (cannot be function or type)			
LEFT	reserved (can be function or type)	reserved	reserved	reserved
LENGTH		non-reserved	non-reserved	non-reserved
LESS	non-reserved			
LEVEL	non-reserved	non-reserved	non-reserved	reserved
LIBRARY		non-reserved	non-reserved	
LIKE	reserved (can be function or type)	reserved	reserved	reserved
LIKE_REGEX		reserved	reserved	
LIMIT	reserved, requires AS	non-reserved	non-reserved	
LINK		non-reserved	non-reserved	
LIST	non-reserved			
LISTAGG		reserved		
LISTEN	non-reserved			
LN		reserved	reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
LOAD	non-reserved			
LOCAL	non-reserved	reserved	reserved	reserved
LOCALTIME	reserved	reserved	reserved	
LOCALTIMESTAMP	reserved	reserved	reserved	
LOCATION	non-reserved	non-reserved	non-reserved	
LOCATOR		non-reserved	non-reserved	
LOCK	non-reserved			
LOCKED	non-reserved			
LOG		reserved		
LOG10		reserved		
LOGGED	non-reserved			
LOWER		reserved	reserved	reserved
M		non-reserved	non-reserved	
MAP		non-reserved	non-reserved	
MAPPING	non-reserved	non-reserved	non-reserved	
MATCH	non-reserved	reserved	reserved	reserved
MATCHED		non-reserved	non-reserved	
MATCHES		reserved		
MATCH_NUMBER		reserved		
MATCH_RECOGNIZE		reserved		
MATERIALIZED	non-reserved			
MAX		reserved	reserved	reserved
MAXVALUE	non-reserved	non-reserved	non-reserved	
MEASURES		reserved		
MEMBER		reserved	reserved	
MERGE	non-reserved	reserved	reserved	
MESSAGE_LENGTH		non-reserved	non-reserved	non-reserved
MESSAGE_OCTET_LENGTH		non-reserved	non-reserved	non-reserved
MESSAGE_TEXT		non-reserved	non-reserved	non-reserved
METHOD	non-reserved	reserved	reserved	
MIN		reserved	reserved	reserved
MINUTE	non-reserved, requires AS	reserved	reserved	reserved
MINVALUE	non-reserved	non-reserved	non-reserved	
MOD		reserved	reserved	
MODE	non-reserved			
MODIFIES		reserved	reserved	
MODULE		reserved	reserved	reserved
MONTH	non-reserved, requires AS	reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
MORE		non-reserved	non-reserved	non-reserved
MOVE	non-reserved			
MULTISET		reserved	reserved	
MUMPS		non-reserved	non-reserved	non-reserved
NAME	non-reserved	non-reserved	non-reserved	non-reserved
NAMES	non-reserved	non-reserved	non-reserved	reserved
NAMESPACE		non-reserved	non-reserved	
NATIONAL	non-reserved (cannot be function or type)	reserved	reserved	reserved
NATURAL	reserved (can be function or type)	reserved	reserved	reserved
NCHAR	non-reserved (cannot be function or type)	reserved	reserved	reserved
NCLOB		reserved	reserved	
NESTED		non-reserved		
NESTING		non-reserved	non-reserved	
NEW	non-reserved	reserved	reserved	
NEXT	non-reserved	non-reserved	non-reserved	reserved
NFC	non-reserved	non-reserved	non-reserved	
NFD	non-reserved	non-reserved	non-reserved	
NFKC	non-reserved	non-reserved	non-reserved	
NFKD	non-reserved	non-reserved	non-reserved	
NIL		non-reserved	non-reserved	
NO	non-reserved	reserved	reserved	reserved
NONE	non-reserved (cannot be function or type)	reserved	reserved	
NORMALIZE	non-reserved (cannot be function or type)	reserved	reserved	
NORMALIZED	non-reserved	non-reserved	non-reserved	
NOT	reserved	reserved	reserved	reserved
NOTHING	non-reserved			
NOTIFY	non-reserved			
NOTNULL	reserved (can be function or type), requires AS			
NOWAIT	non-reserved			
NTH_VALUE		reserved	reserved	
NTILE		reserved	reserved	
NULL	reserved	reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
NULLABLE		non-reserved	non-reserved	non-reserved
NULLIF	non-reserved (cannot be function or type)	reserved	reserved	reserved
NULLS	non-reserved	non-reserved	non-reserved	
NUMBER		non-reserved	non-reserved	non-reserved
NUMERIC	non-reserved (cannot be function or type)	reserved	reserved	reserved
OBJECT	non-reserved	non-reserved	non-reserved	
OCCURRENCES_REGEX		reserved	reserved	
OCTETS		non-reserved	non-reserved	
OCTET_LENGTH		reserved	reserved	reserved
OF	non-reserved	reserved	reserved	reserved
OFF	non-reserved	non-reserved	non-reserved	
OFFSET	reserved, requires AS	reserved	reserved	
OIDS	non-reserved			
OLD	non-reserved	reserved	reserved	
OMIT		reserved		
ON	reserved, requires AS	reserved	reserved	reserved
ONE		reserved		
ONLY	reserved	reserved	reserved	reserved
OPEN		reserved	reserved	reserved
OPERATOR	non-reserved			
OPTION	non-reserved	non-reserved	non-reserved	reserved
OPTIONS	non-reserved	non-reserved	non-reserved	
OR	reserved	reserved	reserved	reserved
ORDER	reserved, requires AS	reserved	reserved	reserved
ORDERING		non-reserved	non-reserved	
ORDINALITY	non-reserved	non-reserved	non-reserved	
OTHERS	non-reserved	non-reserved	non-reserved	
OUT	non-reserved (cannot be function or type)	reserved	reserved	
OUTER	reserved (can be function or type)	reserved	reserved	reserved
OUTPUT		non-reserved	non-reserved	reserved
OVER	non-reserved, requires AS	reserved	reserved	
OVERFLOW		non-reserved		

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
OVERLAPS	reserved (can be function or type), requires AS	reserved	reserved	reserved
OVERLAY	non-reserved (cannot be function or type)	reserved	reserved	
OVERRIDING	non-reserved	non-reserved	non-reserved	
OWNED	non-reserved			
OWNER	non-reserved			
P		non-reserved	non-reserved	
PAD		non-reserved	non-reserved	reserved
PARALLEL	non-reserved			
PARAMETER		reserved	reserved	
PARAMETER_MODE		non-reserved	non-reserved	
PARAMETER_NAME		non-reserved	non-reserved	
PARAMETER_ORDINAL_POSITION		non-reserved	non-reserved	
PARAMETER_SPECIFIC_CATALOG		non-reserved	non-reserved	
PARAMETER_SPECIFIC_NAME		non-reserved	non-reserved	
PARAMETER_SPECIFIC_SCHEMA		non-reserved	non-reserved	
PARSER	non-reserved			
PARTIAL	non-reserved	non-reserved	non-reserved	reserved
PARTITION	non-reserved	reserved	reserved	
PARTITIONS	non-reserved			
PASCAL		non-reserved	non-reserved	non-reserved
PASS		non-reserved		
PASSING	non-reserved	non-reserved	non-reserved	
PASSTHROUGH		non-reserved	non-reserved	
PASSWORD	non-reserved			
PASSWORD_GRACE_TIME	non-reserved			
PASSWORD_LIFE_TIME	non-reserved			
PASSWORD_MIN_LEN	non-reserved			
PASSWORD_MIN_UNIQUE_CHARS	non-reserved			
PASSWORD_REQUIRE_COMPLEX	non-reserved			
PASSWORD_REUSE_MAX	non-reserved			
PASSWORD_REUSE_TIME	non-reserved			
PAST		non-reserved		
PATH		non-reserved	non-reserved	
PATTERN		reserved		
PER		reserved		
PERCENT		reserved	reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
PERCENTILE_CONT		reserved	reserved	
PERCENTILE_DISC		reserved	reserved	
PERCENT_RANK		reserved	reserved	
PERIOD		reserved	reserved	
PERMISSION		non-reserved	non-reserved	
PERMUTE		reserved		
PLACING	reserved	non-reserved	non-reserved	
PLAN		non-reserved		
PLANS	non-reserved			
PLI		non-reserved	non-reserved	non-reserved
POLICY	non-reserved			
PORTION		reserved	reserved	
POSITION	non-reserved (cannot be function or type)	reserved	reserved	reserved
POSITION_REGEX		reserved	reserved	
POWER		reserved	reserved	
PRECEDES		reserved	reserved	
PRECEDING	non-reserved	non-reserved	non-reserved	
PRECISION	non-reserved (cannot be function or type), requires AS	reserved	reserved	reserved
PREPARE	non-reserved	reserved	reserved	reserved
PREPARED	non-reserved			
PRESERVE	non-reserved	non-reserved	non-reserved	reserved
PRIMARY	reserved	reserved	reserved	reserved
PRIOR	non-reserved	non-reserved	non-reserved	reserved
PRIVATE		non-reserved		
PRIVILEGES	non-reserved	non-reserved	non-reserved	reserved
PROCEDURAL	non-reserved			
PROCEDURE	non-reserved	reserved	reserved	reserved
PROCEDURES	non-reserved			
PROFILE	non-reserved			
PROGRAM	non-reserved			
PRUNE		non-reserved		
PTF		reserved		
PUBLIC		non-reserved	non-reserved	reserved
PUBLICATION	non-reserved			
QUOTE	non-reserved			
QUOTES		non-reserved		
RANGE	non-reserved	reserved	reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
RANK		reserved	reserved	
READ	non-reserved	non-reserved	non-reserved	reserved
READS		reserved	reserved	
REAL	non-reserved (cannot be function or type)	reserved	reserved	reserved
REASSIGN	non-reserved			
RECHECK	non-reserved			
RECOVERY		non-reserved	non-reserved	
RECURSIVE	non-reserved	reserved	reserved	
REF	non-reserved	reserved	reserved	
REFERENCES	reserved	reserved	reserved	reserved
REFERENCING	non-reserved	reserved	reserved	
REFRESH	non-reserved			
REGR_AVGX		reserved	reserved	
REGR_AVGY		reserved	reserved	
REGR_COUNT		reserved	reserved	
REGR_INTERCEPT		reserved	reserved	
REGR_R2		reserved	reserved	
REGR_SLOPE		reserved	reserved	
REGR_SXX		reserved	reserved	
REGR_SXY		reserved	reserved	
REGR_SYY		reserved	reserved	
REINDEX	non-reserved			
RELATIVE	non-reserved	non-reserved	non-reserved	reserved
RELEASE	non-reserved	reserved	reserved	
RENAME	non-reserved			
REPEATABLE	non-reserved	non-reserved	non-reserved	non-reserved
REPLACE	non-reserved			
REPLICA	non-reserved			
REQUIRING		non-reserved	non-reserved	
RESET	non-reserved			
RESPECT		non-reserved	non-reserved	
RESTART	non-reserved	non-reserved	non-reserved	
RESTORE		non-reserved	non-reserved	
RESTRICT	non-reserved	non-reserved	non-reserved	reserved
RESULT		reserved	reserved	
RETURN	non-reserved	reserved	reserved	
RETURNED_CARDINALITY		non-reserved	non-reserved	
RETURNED_LENGTH		non-reserved	non-reserved	non-reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
RETURNED_OCTET_LENGTH		non-reserved	non-reserved	non-reserved
RETURNED_SQLSTATE		non-reserved	non-reserved	non-reserved
RETURNING	reserved, requires AS	non-reserved	non-reserved	
RETURNS	non-reserved	reserved	reserved	
REVOKE	non-reserved	reserved	reserved	reserved
RIGHT	reserved (can be function or type)	reserved	reserved	reserved
ROLE	non-reserved	non-reserved	non-reserved	
ROLLBACK	non-reserved	reserved	reserved	reserved
ROLLUP	non-reserved	reserved	reserved	
ROUTINE	non-reserved	non-reserved	non-reserved	
ROUTINES	non-reserved			
ROUTINE_CATALOG		non-reserved	non-reserved	
ROUTINE_NAME		non-reserved	non-reserved	
ROUTINE_SCHEMA		non-reserved	non-reserved	
ROW	non-reserved (cannot be function or type)	reserved	reserved	
ROWS	non-reserved	reserved	reserved	reserved
ROW_COUNT		non-reserved	non-reserved	non-reserved
ROW_NUMBER		reserved	reserved	
RULE	non-reserved			
RUNNING		reserved		
SAVEPOINT	non-reserved	reserved	reserved	
SCALAR		non-reserved		
SCALE		non-reserved	non-reserved	non-reserved
SCHEMA	non-reserved	non-reserved	non-reserved	reserved
SCHEMAS	non-reserved			
SCHEMA_NAME		non-reserved	non-reserved	non-reserved
SCOPE		reserved	reserved	
SCOPE_CATALOG		non-reserved	non-reserved	
SCOPE_NAME		non-reserved	non-reserved	
SCOPE_SCHEMA		non-reserved	non-reserved	
SCROLL	non-reserved	reserved	reserved	reserved
SEARCH	non-reserved	reserved	reserved	
SECOND	non-reserved, requires AS	reserved	reserved	reserved
SECTION		non-reserved	non-reserved	reserved
SECURITY	non-reserved	non-reserved	non-reserved	
SEEK		reserved		

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
SELECT	reserved	reserved	reserved	reserved
SELECTIVE		non-reserved	non-reserved	
SELF		non-reserved	non-reserved	
SENSITIVE		reserved	reserved	
SEQUENCE	non-reserved	non-reserved	non-reserved	
SEQUENCES	non-reserved			
SERIALIZABLE	non-reserved	non-reserved	non-reserved	non-reserved
SERVER	non-reserved	non-reserved	non-reserved	
SERVER_NAME		non-reserved	non-reserved	non-reserved
SESSION	non-reserved	non-reserved	non-reserved	reserved
SESSION_USER	reserved	reserved	reserved	reserved
SET	non-reserved	reserved	reserved	reserved
SETOF	non-reserved (cannot be function or type)			
SETS	non-reserved	non-reserved	non-reserved	
SHARE	non-reserved			
SHOW	non-reserved	reserved		
SIMILAR	reserved (can be function or type)	reserved	reserved	
SIMPLE	non-reserved	non-reserved	non-reserved	
SIN		reserved		
SINH		reserved		
SIZE		non-reserved	non-reserved	reserved
SKIP	non-reserved	reserved		
SMALLINT	non-reserved (cannot be function or type)	reserved	reserved	reserved
SNAPSHOT	non-reserved			
SOME	reserved	reserved	reserved	reserved
SOURCE		non-reserved	non-reserved	
SPACE		non-reserved	non-reserved	reserved
SPECIFIC		reserved	reserved	
SPECIFICTYPE		reserved	reserved	
SPECIFIC_NAME		non-reserved	non-reserved	
SPLIT	non-reserved			
SQL	non-reserved	reserved	reserved	reserved
SQLCODE				reserved
SQLERROR				reserved
SQLEXCEPTION		reserved	reserved	
SQLSTATE		reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
SQLWARNING		reserved	reserved	
SQRT		reserved	reserved	
STABLE	non-reserved			
STANDALONE	non-reserved	non-reserved	non-reserved	
START	non-reserved	reserved	reserved	
STATE		non-reserved	non-reserved	
STATEMENT	non-reserved	non-reserved	non-reserved	
STATIC		reserved	reserved	
STATISTICS	non-reserved			
STDDEV_POP		reserved	reserved	
STDDEV_SAMP		reserved	reserved	
STDIN	non-reserved			
STDOUT	non-reserved			
STORAGE	non-reserved			
STORED	non-reserved			
STRICT	non-reserved			
STRING		non-reserved		
STRIP	non-reserved	non-reserved	non-reserved	
STRUCTURE		non-reserved	non-reserved	
STYLE		non-reserved	non-reserved	
SUBCLASS_ORIGIN		non-reserved	non-reserved	non-reserved
SUBMULTISET		reserved	reserved	
SUBSCRIPTION	non-reserved			
SUBSET		reserved		
SUBSTRING	non-reserved (cannot be function or type)	reserved	reserved	reserved
SUBSTRING_REGEX		reserved	reserved	
SUCCEEDS		reserved	reserved	
SUM		reserved	reserved	reserved
SUPPORT	non-reserved			
SYMMETRIC	reserved	reserved	reserved	
SYSID	non-reserved			
SYSTEM	non-reserved	reserved	reserved	
SYSTEM_TIME		reserved	reserved	
SYSTEM_USER		reserved	reserved	reserved
T		non-reserved	non-reserved	
TABLE	reserved	reserved	reserved	reserved
TABLES	non-reserved			
TABLESAMPLE	reserved (can be function or type)	reserved	reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
TABLESPACE	non-reserved			
TABLE_NAME		non-reserved	non-reserved	non-reserved
TAN		reserved		
TANH		reserved		
TEMP	non-reserved			
TEMPLATE	non-reserved			
TEMPORARY	non-reserved	non-reserved	non-reserved	reserved
TEXT	non-reserved			
THAN	non-reserved			
THEN	reserved	reserved	reserved	reserved
THROUGH		non-reserved		
TIES	non-reserved	non-reserved	non-reserved	
TIME	non-reserved (cannot be function or type)	reserved	reserved	reserved
TIMESTAMP	non-reserved (cannot be function or type)	reserved	reserved	reserved
TIMEZONE_HOUR		reserved	reserved	reserved
TIMEZONE_MINUTE		reserved	reserved	reserved
TO	reserved, requires AS	reserved	reserved	reserved
TOKEN		non-reserved	non-reserved	
TOP_LEVEL_COUNT		non-reserved	non-reserved	
TRAILING	reserved	reserved	reserved	reserved
TRANSACTION	non-reserved	non-reserved	non-reserved	reserved
TRANSACTIONS_COMMITTED		non-reserved	non-reserved	
TRANSACTIONS_ROLLED_BACK		non-reserved	non-reserved	
TRANSACTION_ACTIVE		non-reserved	non-reserved	
TRANSFORM	non-reserved	non-reserved	non-reserved	
TRANSFORMS		non-reserved	non-reserved	
TRANSLATE		reserved	reserved	reserved
TRANSLATE_REGEX		reserved	reserved	
TRANSLATION		reserved	reserved	reserved
TREAT	non-reserved (cannot be function or type)	reserved	reserved	
TRIGGER	non-reserved	reserved	reserved	
TRIGGER_CATALOG		non-reserved	non-reserved	
TRIGGER_NAME		non-reserved	non-reserved	
TRIGGER_SCHEMA		non-reserved	non-reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
TRIM	non-reserved (cannot be function or type)	reserved	reserved	reserved
TRIM_ARRAY		reserved	reserved	
TRUE	reserved	reserved	reserved	reserved
TRUNCATE	non-reserved	reserved	reserved	
TRUSTED	non-reserved			
TYPE	non-reserved	non-reserved	non-reserved	non-reserved
TYPES	non-reserved			
UESCAPE	non-reserved	reserved	reserved	
UNBOUNDED	non-reserved	non-reserved	non-reserved	
UNCOMMITTED	non-reserved	non-reserved	non-reserved	non-reserved
UNCONDITIONAL		non-reserved		
UNDER		non-reserved	non-reserved	
UNENCRYPTED	non-reserved			
UNION	reserved, requires AS	reserved	reserved	reserved
UNIQUE	reserved	reserved	reserved	reserved
UNKNOWN	non-reserved	reserved	reserved	reserved
UNLIMITED	non-reserved			
UNLINK		non-reserved	non-reserved	
UNLISTEN	non-reserved			
UNLOCK	non-reserved			
UNLOGGED	non-reserved			
UNMATCHED		reserved		
UNNAMED		non-reserved	non-reserved	non-reserved
UNNEST		reserved	reserved	
UNTIL	non-reserved			
UNTYPED		non-reserved	non-reserved	
UPDATE	non-reserved	reserved	reserved	reserved
UPPER		reserved	reserved	reserved
URI		non-reserved	non-reserved	
USAGE		non-reserved	non-reserved	reserved
USER	reserved	reserved	reserved	reserved
USER_DEFINED_TYPE_CATALOG		non-reserved	non-reserved	
USER_DEFINED_TYPE_CODE		non-reserved	non-reserved	
USER_DEFINED_TYPE_NAME		non-reserved	non-reserved	
USER_DEFINED_TYPE_SCHEMA		non-reserved	non-reserved	
USER_INACTIVE_TIME	non-reserved			
USING	reserved	reserved	reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
UTF16		non-reserved		
UTF32		non-reserved		
UTF8		non-reserved		
VACUUM	non-reserved			
VALID	non-reserved	non-reserved	non-reserved	
VALIDATE	non-reserved			
VALIDATOR	non-reserved			
VALUE	non-reserved	reserved	reserved	reserved
VALUES	non-reserved (cannot be function or type)	reserved	reserved	reserved
VALUE_OF		reserved	reserved	
VARBINARY		reserved	reserved	
VARCHAR	non-reserved (cannot be function or type)	reserved	reserved	reserved
VARIADIC	reserved			
VARYING	non-reserved, requires AS	reserved	reserved	reserved
VAR_POP		reserved	reserved	
VAR_SAMP		reserved	reserved	
VERBOSE	reserved (can be function or type)			
VERSION	non-reserved	non-reserved	non-reserved	
VERSIONING		reserved	reserved	
VIEW	non-reserved	non-reserved	non-reserved	reserved
VIEWS	non-reserved			
VOLATILE	non-reserved			
WHEN	reserved	reserved	reserved	reserved
WHENEVER		reserved	reserved	reserved
WHERE	reserved, requires AS	reserved	reserved	reserved
WHITESPACE	non-reserved	non-reserved	non-reserved	
WIDTH_BUCKET		reserved	reserved	
WINDOW	reserved, requires AS	reserved	reserved	
WITH	reserved, requires AS	reserved	reserved	reserved
WITHIN	non-reserved, requires AS	reserved	reserved	
WITHOUT	non-reserved, requires AS	reserved	reserved	
WORK	non-reserved	non-reserved	non-reserved	reserved

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
WRAPPER	non-reserved	non-reserved	non-reserved	
WRITE	non-reserved	non-reserved	non-reserved	reserved
XML	non-reserved	reserved	reserved	
XMLAGG		reserved	reserved	
XMLATTRIBUTES	non-reserved (cannot be function or type)	reserved	reserved	
XMLBINARY		reserved	reserved	
XMLCAST		reserved	reserved	
XMLCOMMENT		reserved	reserved	
XMLCONCAT	non-reserved (cannot be function or type)	reserved	reserved	
XMLDECLARATION		non-reserved	non-reserved	
XMLDOCUMENT		reserved	reserved	
XMLELEMENT	non-reserved (cannot be function or type)	reserved	reserved	
XMLEXISTS	non-reserved (cannot be function or type)	reserved	reserved	
XMLFOREST	non-reserved (cannot be function or type)	reserved	reserved	
XMLITERATE		reserved	reserved	
XMLNAMESPACES	non-reserved (cannot be function or type)	reserved	reserved	
XMLPARSE	non-reserved (cannot be function or type)	reserved	reserved	
XMLPI	non-reserved (cannot be function or type)	reserved	reserved	
XMLQUERY		reserved	reserved	
XMLROOT	non-reserved (cannot be function or type)			
XMLSCHEMA		non-reserved	non-reserved	
XMLSERIALIZE	non-reserved (cannot be function or type)	reserved	reserved	
XMLTABLE	non-reserved (cannot be function or type)	reserved	reserved	
XMLTEXT		reserved	reserved	

Key Word	PostgreSQL	SQL:2016	SQL:2011	SQL-92
XMLVALIDATE		reserved	reserved	
YEAR	non-reserved, requires AS	reserved	reserved	reserved
YES	non-reserved	non-reserved	non-reserved	
ZONE	non-reserved	non-reserved	non-reserved	reserved

Appendix D. SQL Conformance

This section attempts to outline to what extent Postgres Pro conforms to the current SQL standard. The following information is not a full statement of conformance, but it presents the main topics in as much detail as is both reasonable and useful for users.

The formal name of the SQL standard is ISO/IEC 9075 “Database Language SQL”. A revised version of the standard is released from time to time; the most recent update appearing in 2016. The 2016 version is referred to as ISO/IEC 9075:2016, or simply as SQL:2016. The versions prior to that were SQL:2011, SQL:2008, SQL:2006, SQL:2003, SQL:1999, and SQL-92. Each version replaces the previous one, so claims of conformance to earlier versions have no official merit. Postgres Pro development aims for conformance with the latest official version of the standard where such conformance does not contradict traditional features or common sense. Many of the features required by the SQL standard are supported, though sometimes with slightly differing syntax or function. Further moves towards conformance can be expected over time.

SQL-92 defined three feature sets for conformance: Entry, Intermediate, and Full. Most database management systems claiming SQL standard conformance were conforming at only the Entry level, since the entire set of features in the Intermediate and Full levels was either too voluminous or in conflict with legacy behaviors.

Starting with SQL:1999, the SQL standard defines a large set of individual features rather than the ineffectively broad three levels found in SQL-92. A large subset of these features represents the “Core” features, which every conforming SQL implementation must supply. The rest of the features are purely optional.

The standard versions beginning with SQL:2003 are also split into a number of parts. Each is known by a shorthand name. Note that these parts are not consecutively numbered.

- ISO/IEC 9075-1 Framework (SQL/Framework)
- ISO/IEC 9075-2 Foundation (SQL/Foundation)
- ISO/IEC 9075-3 Call Level Interface (SQL/CLI)
- ISO/IEC 9075-4 Persistent Stored Modules (SQL/PSM)
- ISO/IEC 9075-9 Management of External Data (SQL/MED)
- ISO/IEC 9075-10 Object Language Bindings (SQL/OLB)
- ISO/IEC 9075-11 Information and Definition Schemas (SQL/Schemata)
- ISO/IEC 9075-13 Routines and Types using the Java Language (SQL/JRT)
- ISO/IEC 9075-14 XML-related specifications (SQL/XML)
- ISO/IEC 9075-15 Multi-dimensional arrays (SQL/MDA)

The Postgres Pro core covers parts 1, 2, 9, 11, and 14. Part 3 is covered by the ODBC driver, and part 13 is covered by the PL/Java plug-in, but exact conformance is currently not being verified for these components. There are currently no implementations of parts 4, 10, and 15 for Postgres Pro.

Postgres Pro supports most of the major features of SQL:2016. Out of 177 mandatory features required for full Core conformance, Postgres Pro conforms to at least 170. In addition, there is a long list of supported optional features. It might be worth noting that at the time of writing, no current version of any database management system claims full conformance to Core SQL:2016.

In the following two sections, we provide a list of those features that Postgres Pro supports, followed by a list of the features defined in SQL:2016 which are not yet supported in Postgres Pro. Both of these lists are approximate: There might be minor details that are nonconforming for a feature that is listed as supported, and large parts of an unsupported feature might in fact be implemented. The main body of the documentation always contains the most accurate information about what does and does not work.

> **Note**
>
> Feature codes containing a hyphen are subfeatures. Therefore, if a particular subfeature is not supported, the main feature is listed as unsupported even if some other subfeatures are supported.

D.1. Supported Features

Identifier	Core?	Description	Comment
B012		Embedded C	
B021		Direct SQL	
E011	Core	Numeric data types	
E011-01	Core	INTEGER and SMALLINT data types	
E011-02	Core	REAL, DOUBLE PRECISION, and FLOAT data types	
E011-03	Core	DECIMAL and NUMERIC data types	
E011-04	Core	Arithmetic operators	
E011-05	Core	Numeric comparison	
E011-06	Core	Implicit casting among the numeric data types	
E021	Core	Character data types	
E021-01	Core	CHARACTER data type	
E021-02	Core	CHARACTER VARYING data type	
E021-03	Core	Character literals	
E021-04	Core	CHARACTER_LENGTH function	trims trailing spaces from CHARACTER values before counting
E021-05	Core	OCTET_LENGTH function	
E021-06	Core	SUBSTRING function	
E021-07	Core	Character concatenation	
E021-08	Core	UPPER and LOWER functions	
E021-09	Core	TRIM function	
E021-10	Core	Implicit casting among the character string types	
E021-11	Core	POSITION function	
E021-12	Core	Character comparison	
E031	Core	Identifiers	
E031-01	Core	Delimited identifiers	
E031-02	Core	Lower case identifiers	
E031-03	Core	Trailing underscore	
E051	Core	Basic query specification	
E051-01	Core	SELECT DISTINCT	
E051-02	Core	GROUP BY clause	

Identifier	Core?	Description	Comment
E051-04	Core	GROUP BY can contain columns not in <select list>	
E051-05	Core	Select list items can be renamed	
E051-06	Core	HAVING clause	
E051-07	Core	Qualified * in select list	
E051-08	Core	Correlation names in the FROM clause	
E051-09	Core	Rename columns in the FROM clause	
E061	Core	Basic predicates and search conditions	
E061-01	Core	Comparison predicate	
E061-02	Core	BETWEEN predicate	
E061-03	Core	IN predicate with list of values	
E061-04	Core	LIKE predicate	
E061-05	Core	LIKE predicate ESCAPE clause	
E061-06	Core	NULL predicate	
E061-07	Core	Quantified comparison predicate	
E061-08	Core	EXISTS predicate	
E061-09	Core	Subqueries in comparison predicate	
E061-11	Core	Subqueries in IN predicate	
E061-12	Core	Subqueries in quantified comparison predicate	
E061-13	Core	Correlated subqueries	
E061-14	Core	Search condition	
E071	Core	Basic query expressions	
E071-01	Core	UNION DISTINCT table operator	
E071-02	Core	UNION ALL table operator	
E071-03	Core	EXCEPT DISTINCT table operator	
E071-05	Core	Columns combined via table operators need not have exactly the same data type	
E071-06	Core	Table operators in subqueries	
E081	Core	Basic Privileges	
E081-01	Core	SELECT privilege	
E081-02	Core	DELETE privilege	
E081-03	Core	INSERT privilege at the table level	
E081-04	Core	UPDATE privilege at the table level	
E081-05	Core	UPDATE privilege at the column level	
E081-06	Core	REFERENCES privilege at the table level	
E081-07	Core	REFERENCES privilege at the column level	
E081-08	Core	WITH GRANT OPTION	
E081-09	Core	USAGE privilege	
E081-10	Core	EXECUTE privilege	
E091	Core	Set functions	
E091-01	Core	AVG	
E091-02	Core	COUNT	

Identifier	Core?	Description	Comment
E091-03	Core	MAX	
E091-04	Core	MIN	
E091-05	Core	SUM	
E091-06	Core	ALL quantifier	
E091-07	Core	DISTINCT quantifier	
E101	Core	Basic data manipulation	
E101-01	Core	INSERT statement	
E101-03	Core	Searched UPDATE statement	
E101-04	Core	Searched DELETE statement	
E111	Core	Single row SELECT statement	
E121	Core	Basic cursor support	
E121-01	Core	DECLARE CURSOR	
E121-02	Core	ORDER BY columns need not be in select list	
E121-03	Core	Value expressions in ORDER BY clause	
E121-04	Core	OPEN statement	
E121-06	Core	Positioned UPDATE statement	
E121-07	Core	Positioned DELETE statement	
E121-08	Core	CLOSE statement	
E121-10	Core	FETCH statement implicit NEXT	
E121-17	Core	WITH HOLD cursors	
E131	Core	Null value support (nulls in lieu of values)	
E141	Core	Basic integrity constraints	
E141-01	Core	NOT NULL constraints	
E141-02	Core	UNIQUE constraints of NOT NULL columns	
E141-03	Core	PRIMARY KEY constraints	
E141-04	Core	Basic FOREIGN KEY constraint with the NO ACTION default for both referential delete action and referential update action	
E141-06	Core	CHECK constraints	
E141-07	Core	Column defaults	
E141-08	Core	NOT NULL inferred on PRIMARY KEY	
E141-10	Core	Names in a foreign key can be specified in any order	
E151	Core	Transaction support	
E151-01	Core	COMMIT statement	
E151-02	Core	ROLLBACK statement	
E152	Core	Basic SET TRANSACTION statement	
E152-01	Core	SET TRANSACTION statement: ISOLATION LEVEL SERIALIZABLE clause	
E152-02	Core	SET TRANSACTION statement: READ ONLY and READ WRITE clauses	
E153	Core	Updatable queries with subqueries	
E161	Core	SQL comments using leading double minus	

Identifier	Core?	Description	Comment
E171	Core	SQLSTATE support	
E182	Core	Host language binding	
F021	Core	Basic information schema	
F021-01	Core	COLUMNS view	
F021-02	Core	TABLES view	
F021-03	Core	VIEWS view	
F021-04	Core	TABLE_CONSTRAINTS view	
F021-05	Core	REFERENTIAL_CONSTRAINTS view	
F021-06	Core	CHECK_CONSTRAINTS view	
F031	Core	Basic schema manipulation	
F031-01	Core	CREATE TABLE statement to create persistent base tables	
F031-02	Core	CREATE VIEW statement	
F031-03	Core	GRANT statement	
F031-04	Core	ALTER TABLE statement: ADD COLUMN clause	
F031-13	Core	DROP TABLE statement: RESTRICT clause	
F031-16	Core	DROP VIEW statement: RESTRICT clause	
F031-19	Core	REVOKE statement: RESTRICT clause	
F032		CASCADE drop behavior	
F033		ALTER TABLE statement: DROP COLUMN clause	
F034		Extended REVOKE statement	
F034-01		REVOKE statement performed by other than the owner of a schema object	
F034-02		REVOKE statement: GRANT OPTION FOR clause	
F034-03		REVOKE statement to revoke a privilege that the grantee has WITH GRANT OPTION	
F041	Core	Basic joined table	
F041-01	Core	Inner join (but not necessarily the INNER keyword)	
F041-02	Core	INNER keyword	
F041-03	Core	LEFT OUTER JOIN	
F041-04	Core	RIGHT OUTER JOIN	
F041-05	Core	Outer joins can be nested	
F041-07	Core	The inner table in a left or right outer join can also be used in an inner join	
F041-08	Core	All comparison operators are supported (rather than just =)	
F051	Core	Basic date and time	
F051-01	Core	DATE data type (including support of DATE literal)	
F051-02	Core	TIME data type (including support of TIME literal) with fractional seconds precision of at least 0	
F051-03	Core	TIMESTAMP data type (including support of TIMESTAMP literal) with fractional seconds precision of at least 0 and 6	

Identifier	Core?	Description	Comment
F051-04	Core	Comparison predicate on DATE, TIME, and TIMESTAMP data types	
F051-05	Core	Explicit CAST between datetime types and character string types	
F051-06	Core	CURRENT_DATE	
F051-07	Core	LOCALTIME	
F051-08	Core	LOCALTIMESTAMP	
F052		Intervals and datetime arithmetic	
F053		OVERLAPS predicate	
F081	Core	UNION and EXCEPT in views	
F111		Isolation levels other than SERIALIZABLE	
F111-01		READ UNCOMMITTED isolation level	
F111-02		READ COMMITTED isolation level	
F111-03		REPEATABLE READ isolation level	
F131	Core	Grouped operations	
F131-01	Core	WHERE, GROUP BY, and HAVING clauses supported in queries with grouped views	
F131-02	Core	Multiple tables supported in queries with grouped views	
F131-03	Core	Set functions supported in queries with grouped views	
F131-04	Core	Subqueries with GROUP BY and HAVING clauses and grouped views	
F131-05	Core	Single row SELECT with GROUP BY and HAVING clauses and grouped views	
F171		Multiple schemas per user	
F181	Core	Multiple module support	
F191		Referential delete actions	
F200		TRUNCATE TABLE statement	
F201	Core	CAST function	
F202		TRUNCATE TABLE: identity column restart option	
F221	Core	Explicit defaults	
F222		INSERT statement: DEFAULT VALUES clause	
F231		Privilege tables	
F231-01		TABLE_PRIVILEGES view	
F231-02		COLUMN_PRIVILEGES view	
F231-03		USAGE_PRIVILEGES view	
F251		Domain support	
F261	Core	CASE expression	
F261-01	Core	Simple CASE	
F261-02	Core	Searched CASE	
F261-03	Core	NULLIF	
F261-04	Core	COALESCE	
F262		Extended CASE expression	

Identifier	Core?	Description	Comment
F271		Compound character literals	
F281		LIKE enhancements	
F302		INTERSECT table operator	
F302-01		INTERSECT DISTINCT table operator	
F302-02		INTERSECT ALL table operator	
F304		EXCEPT ALL table operator	
F311	Core	Schema definition statement	
F311-01	Core	CREATE SCHEMA	
F311-02	Core	CREATE TABLE for persistent base tables	
F311-03	Core	CREATE VIEW	
F311-04	Core	CREATE VIEW: WITH CHECK OPTION	
F311-05	Core	GRANT statement	
F321		User authorization	
F341		Usage tables	
F361		Subprogram support	
F381		Extended schema manipulation	
F381-01		ALTER TABLE statement: ALTER COLUMN clause	
F381-02		ALTER TABLE statement: ADD CONSTRAINT clause	
F381-03		ALTER TABLE statement: DROP CONSTRAINT clause	
F382		Alter column data type	
F383		Set column not null clause	
F384		Drop identity property clause	
F385		Drop column generation expression clause	
F386		Set identity column generation clause	
F391		Long identifiers	
F392		Unicode escapes in identifiers	
F393		Unicode escapes in literals	
F394		Optional normal form specification	
F401		Extended joined table	
F401-01		NATURAL JOIN	
F401-02		FULL OUTER JOIN	
F401-04		CROSS JOIN	
F402		Named column joins for LOBs, arrays, and multisets	
F404		Range variable for common column names	
F411		Time zone specification	differences regarding literal interpretation
F421		National character	
F431		Read-only scrollable cursors	
F431-01		FETCH with explicit NEXT	
F431-02		FETCH FIRST	
F431-03		FETCH LAST	

Identifier	Core?	Description	Comment
F431-04		FETCH PRIOR	
F431-05		FETCH ABSOLUTE	
F431-06		FETCH RELATIVE	
F441		Extended set function support	
F442		Mixed column references in set functions	
F471	Core	Scalar subquery values	
F481	Core	Expanded NULL predicate	
F491		Constraint management	
F501	Core	Features and conformance views	
F501-01	Core	SQL_FEATURES view	
F501-02	Core	SQL_SIZING view	
F502		Enhanced documentation tables	
F531		Temporary tables	
F555		Enhanced seconds precision	
F561		Full value expressions	
F571		Truth value tests	
F591		Derived tables	
F611		Indicator data types	
F641		Row and table constructors	
F651		Catalog name qualifiers	
F661		Simple tables	
F672		Retrospective check constraints	
F690		Collation support	but no character set support
F692		Extended collation support	
F701		Referential update actions	
F711		ALTER domain	
F731		INSERT column privileges	
F751		View CHECK enhancements	
F761		Session management	
F762		CURRENT_CATALOG	
F763		CURRENT_SCHEMA	
F771		Connection management	
F781		Self-referencing operations	
F791		Insensitive cursors	
F801		Full set function	
F850		Top-level <order by clause> in <query expression>	
F851		<order by clause> in subqueries	
F852		Top-level <order by clause> in views	
F855		Nested <order by clause> in <query expression>	
F856		Nested <fetch first clause> in <query expression>	

Identifier	Core?	Description	Comment
F857		Top-level <fetch first clause> in <query expression>	
F858		<fetch first clause> in subqueries	
F859		Top-level <fetch first clause> in views	
F860		<fetch first row count> in <fetch first clause>	
F861		Top-level <result offset clause> in <query expression>	
F862		<result offset clause> in subqueries	
F863		Nested <result offset clause> in <query expression>	
F864		Top-level <result offset clause> in views	
F865		<offset row count> in <result offset clause>	
F867		FETCH FIRST clause: WITH TIES option	
S071		SQL paths in function and type name resolution	
S092		Arrays of user-defined types	
S095		Array constructors by query	
S096		Optional array bounds	
S098		ARRAY_AGG	
S111		ONLY in query expressions	
S201		SQL-invoked routines on arrays	
S201-01		Array parameters	
S201-02		Array as result type of functions	
S211		User-defined cast functions	
S301		Enhanced UNNEST	
S404		TRIM_ARRAY	
T031		BOOLEAN data type	
T071		BIGINT data type	
T121		WITH (excluding RECURSIVE) in query expression	
T122		WITH (excluding RECURSIVE) in subquery	
T131		Recursive query	
T132		Recursive query in subquery	
T133		Enhanced cycle mark values	SQL:202x draft
T141		SIMILAR predicate	
T151		DISTINCT predicate	
T152		DISTINCT predicate with negation	
T171		LIKE clause in table definition	
T172		AS subquery clause in table definition	
T173		Extended LIKE clause in table definition	
T174		Identity columns	
T177		Sequence generator support: simple restart option	
T178		Identity columns: simple restart option	
T191		Referential action RESTRICT	
T201		Comparable data types for referential constraints	

Identifier	Core?	Description	Comment
T211-01		Triggers activated on UPDATE, INSERT, or DELETE of one base table	
T211-02		BEFORE triggers	
T211-03		AFTER triggers	
T211-04		FOR EACH ROW triggers	
T211-05		Ability to specify a search condition that must be true before the trigger is invoked	
T211-07		TRIGGER privilege	
T212		Enhanced trigger capability	
T213		INSTEAD OF triggers	
T241		START TRANSACTION statement	
T261		Chained transactions	
T271		Savepoints	
T281		SELECT privilege with column granularity	
T285		Enhanced derived column names	
T312		OVERLAY function	
T321-01	Core	User-defined functions with no overloading	
T321-02	Core	User-defined stored procedures with no overloading	
T321-03	Core	Function invocation	
T321-04	Core	CALL statement	
T321-06	Core	ROUTINES view	
T321-07	Core	PARAMETERS view	
T323		Explicit security for external routines	
T325		Qualified SQL parameter references	
T331		Basic roles	
T332		Extended roles	
T341		Overloading of SQL-invoked functions and procedures	
T351		Bracketed SQL comments (/*...*/ comments)	
T431		Extended grouping capabilities	
T432		Nested and concatenated GROUPING SETS	
T433		Multiargument GROUPING function	
T434		GROUP BY DISTINCT	
T441		ABS and MOD functions	
T461		Symmetric BETWEEN predicate	
T491		LATERAL derived table	
T501		Enhanced EXISTS predicate	
T521		Named arguments in CALL statement	
T523		Default values for INOUT parameters of SQL-invoked procedures	
T524		Named arguments in routine invocations other than a CALL statement	
T525		Default values for parameters of SQL-invoked functions	

Identifier	Core?	Description	Comment
T551		Optional key words for default syntax	
T581		Regular expression substring function	
T591		UNIQUE constraints of possibly null columns	
T611		Elementary OLAP operations	
T612		Advanced OLAP operations	
T613		Sampling	
T614		NTILE function	
T615		LEAD and LAG functions	
T617		FIRST_VALUE and LAST_VALUE function	
T620		WINDOW clause: GROUPS option	
T621		Enhanced numeric functions	
T622		Trigonometric functions	
T623		General logarithm functions	
T624		Common logarithm functions	
T631	Core	IN predicate with one list element	
T651		SQL-schema statements in SQL routines	
T653		SQL-schema statements in external routines	
T655		Cyclically dependent routines	
T831		SQL/JSON path language: strict mode	
T832		SQL/JSON path language: item method	
T833		SQL/JSON path language: multiple subscripts	
T834		SQL/JSON path language: wildcard member accessor	
T835		SQL/JSON path language: filter expressions	
T836		SQL/JSON path language: starts with predicate	
T837		SQL/JSON path language: regex_like predicate	
X010		XML type	
X011		Arrays of XML type	
X014		Attributes of XML type	
X016		Persistent XML values	
X020		XMLConcat	
X031		XMLElement	
X032		XMLForest	
X034		XMLAgg	
X035		XMLAgg: ORDER BY option	
X036		XMLComment	
X037		XMLPI	
X040		Basic table mapping	
X041		Basic table mapping: nulls absent	
X042		Basic table mapping: null as nil	
X043		Basic table mapping: table as forest	
X044		Basic table mapping: table as element	

Identifier	Core?	Description	Comment
X045		Basic table mapping: with target namespace	
X046		Basic table mapping: data mapping	
X047		Basic table mapping: metadata mapping	
X048		Basic table mapping: base64 encoding of binary strings	
X049		Basic table mapping: hex encoding of binary strings	
X050		Advanced table mapping	
X051		Advanced table mapping: nulls absent	
X052		Advanced table mapping: null as nil	
X053		Advanced table mapping: table as forest	
X054		Advanced table mapping: table as element	
X055		Advanced table mapping: with target namespace	
X056		Advanced table mapping: data mapping	
X057		Advanced table mapping: metadata mapping	
X058		Advanced table mapping: base64 encoding of binary strings	
X059		Advanced table mapping: hex encoding of binary strings	
X060		XMLParse: character string input and CONTENT option	
X061		XMLParse: character string input and DOCUMENT option	
X070		XMLSerialize: character string serialization and CONTENT option	
X071		XMLSerialize: character string serialization and DOCUMENT option	
X072		XMLSerialize: character string serialization	
X090		XML document predicate	
X120		XML parameters in SQL routines	
X121		XML parameters in external routines	
X221		XML passing mechanism BY VALUE	
X301		XMLTable: derived column list option	
X302		XMLTable: ordinality column option	
X303		XMLTable: column default option	
X304		XMLTable: passing a context item	must be XML DOCUMENT
X400		Name and identifier mapping	
X410		Alter column data type: XML type	

D.2. Unsupported Features

The following features defined in SQL:2016 are not implemented in this release of Postgres Pro. In a few cases, equivalent functionality is available.

Identifier	Core?	Description	Comment
B011		Embedded Ada	
B013		Embedded COBOL	

Identifier	Core?	Description	Comment
B014		Embedded Fortran	
B015		Embedded MUMPS	
B016		Embedded Pascal	
B017		Embedded PL/I	
B031		Basic dynamic SQL	
B032		Extended dynamic SQL	
B032-01		<describe input statement>	
B033		Untyped SQL-invoked function arguments	
B034		Dynamic specification of cursor attributes	
B035		Non-extended descriptor names	
B041		Extensions to embedded SQL exception declarations	
B051		Enhanced execution rights	
B111		Module language Ada	
B112		Module language C	
B113		Module language COBOL	
B114		Module language Fortran	
B115		Module language MUMPS	
B116		Module language Pascal	
B117		Module language PL/I	
B121		Routine language Ada	
B122		Routine language C	
B123		Routine language COBOL	
B124		Routine language Fortran	
B125		Routine language MUMPS	
B126		Routine language Pascal	
B127		Routine language PL/I	
B128		Routine language SQL	
B200		Polymorphic table functions	
B201		More than one PTF generic table parameter	
B202		PTF Copartitioning	
B203		More than one copartition specification	
B204		PRUNE WHEN EMPTY	
B205		Pass-through columns	
B206		PTF descriptor parameters	
B207		Cross products of partitionings	
B208		PTF component procedure interface	
B209		PTF extended names	
B211		Module language Ada: VARCHAR and NUMERIC support	
B221		Routine language Ada: VARCHAR and NUMERIC support	

Identifier	Core?	Description	Comment
F054		TIMESTAMP in DATE type precedence list	
F121		Basic diagnostics management	
F121-01		GET DIAGNOSTICS statement	
F121-02		SET TRANSACTION statement: DIAGNOSTICS SIZE clause	
F122		Enhanced diagnostics management	
F123		All diagnostics	
F263		Comma-separated predicates in simple CASE expression	
F291		UNIQUE predicate	
F301		CORRESPONDING in query expressions	
F312		MERGE statement	consider INSERT ... ON CONFLICT DO UPDATE
F313		Enhanced MERGE statement	
F314		MERGE statement with DELETE branch	
F403		Partitioned joined tables	
F451		Character set definition	
F461		Named character sets	
F492		Optional table constraint enforcement	
F521		Assertions	
F671		Subqueries in CHECK	intentionally omitted
F673		Reads SQL-data routine invocations in CHECK constraints	
F693		SQL-session and client module collations	
F695		Translation support	
F696		Additional translation documentation	
F721		Deferrable constraints	foreign and unique keys only
F741		Referential MATCH types	no partial match yet
F812	Core	Basic flagging	
F813		Extended flagging	
F821		Local table references	
F831		Full cursor update	
F831-01		Updatable scrollable cursors	
F831-02		Updatable ordered cursors	
F841		LIKE_REGEX predicate	
F842		OCCURRENCES_REGEX function	
F843		POSITION_REGEX function	
F844		SUBSTRING_REGEX function	
F845		TRANSLATE_REGEX function	
F846		Octet support in regular expression operators	
F847		Nonconstant regular expressions	

Identifier	Core?	Description	Comment
F866		FETCH FIRST clause: PERCENT option	
R010		Row pattern recognition: FROM clause	
R020		Row pattern recognition: WINDOW clause	
R030		Row pattern recognition: full aggregate support	
S011	Core	Distinct data types	
S011-01	Core	USER_DEFINED_TYPES view	
S023		Basic structured types	
S024		Enhanced structured types	
S025		Final structured types	
S026		Self-referencing structured types	
S027		Create method by specific method name	
S028		Permutable UDT options list	
S041		Basic reference types	
S043		Enhanced reference types	
S051		Create table of type	partially supported
S081		Subtables	
S091		Basic array support	partially supported
S091-01		Arrays of built-in data types	
S091-02		Arrays of distinct types	
S091-03		Array expressions	
S094		Arrays of reference types	
S097		Array element assignment	
S151		Type predicate	see pg_typeof()
S161		Subtype treatment	
S162		Subtype treatment for references	
S202		SQL-invoked routines on multisets	
S231		Structured type locators	
S232		Array locators	
S233		Multiset locators	
S241		Transform functions	
S242		Alter transform statement	
S251		User-defined orderings	
S261		Specific type method	
S271		Basic multiset support	
S272		Multisets of user-defined types	
S274		Multisets of reference types	
S275		Advanced multiset support	
S281		Nested collection types	
S291		Unique constraint on entire row	
S401		Distinct types based on array types	
S402		Distinct types based on distinct types	

Identifier	Core?	Description	Comment
S403		ARRAY_MAX_CARDINALITY	
T011		Timestamp in Information Schema	
T021		BINARY and VARBINARY data types	
T022		Advanced support for BINARY and VARBINARY data types	
T023		Compound binary literal	
T024		Spaces in binary literals	
T041		Basic LOB data type support	
T041-01		BLOB data type	
T041-02		CLOB data type	
T041-03		POSITION, LENGTH, LOWER, TRIM, UPPER, and SUBSTRING functions for LOB data types	
T041-04		Concatenation of LOB data types	
T041-05		LOB locator: non-holdable	
T042		Extended LOB data type support	
T043		Multiplier T	
T044		Multiplier P	
T051		Row types	
T053		Explicit aliases for all-fields reference	
T061		UCS support	
T076		DECFLOAT data type	
T101		Enhanced nullability determination	
T111		Updatable joins, unions, and columns	
T175		Generated columns	mostly supported
T176		Sequence generator support	supported except for NEXT VALUE FOR
T180		System-versioned tables	
T181		Application-time period tables	
T211		Basic trigger capability	
T211-06		Support for run-time rules for the interaction of triggers and constraints	
T211-08		Multiple triggers for the same event are executed in the order in which they were created in the catalog	intentionally omitted
T231		Sensitive cursors	
T251		SET TRANSACTION statement: LOCAL option	
T272		Enhanced savepoint management	
T301		Functional dependencies	partially supported
T321	Core	Basic SQL-invoked routines	
T321-05	Core	RETURN statement	
T322		Declared data type attributes	
T324		Explicit security for SQL routines	
T326		Table functions	

Identifier	Core?	Description	Comment
T471		Result sets return value	
T472		DESCRIBE CURSOR	
T495		Combined data change and retrieval	different syntax
T502		Period predicates	
T511		Transaction counts	
T522		Default values for IN parameters of SQL-invoked procedures	supported except DEFAULT key word in invocation
T561		Holdable locators	
T571		Array-returning external SQL-invoked functions	
T572		Multiset-returning external SQL-invoked functions	
T601		Local cursor references	
T616		Null treatment option for LEAD and LAG functions	
T618		NTH_VALUE function	function exists, but some options missing
T619		Nested window functions	
T625		LISTAGG	
T641		Multiple column assignment	only some syntax variants supported
T652		SQL-dynamic statements in SQL routines	
T654		SQL-dynamic statements in external routines	
T811		Basic SQL/JSON constructor functions	
T812		SQL/JSON: JSON_OBJECTAGG	
T813		SQL/JSON: JSON_ARRAYAGG with ORDER BY	
T814		Colon in JSON_OBJECT or JSON_OBJECTAGG	
T821		Basic SQL/JSON query operators	
T822		SQL/JSON: IS JSON WITH UNIQUE KEYS predicate	
T823		SQL/JSON: PASSING clause	
T824		JSON_TABLE: specific PLAN clause	
T825		SQL/JSON: ON EMPTY and ON ERROR clauses	
T826		General value expression in ON ERROR or ON EMPTY clauses	
T827		JSON_TABLE: sibling NESTED COLUMNS clauses	
T828		JSON_QUERY	
T829		JSON_QUERY: array wrapper options	
T830		Enforcing unique keys in SQL/JSON constructor functions	
T838		JSON_TABLE: PLAN DEFAULT clause	
T839		Formatted cast of datetimes to/from character strings	
M001		Datalinks	
M002		Datalinks via SQL/CLI	
M003		Datalinks via Embedded SQL	

Identifier	Core?	Description	Comment
M004		Foreign data support	partially supported
M005		Foreign schema support	
M006		GetSQLString routine	
M007		TransmitRequest	
M009		GetOpts and GetStatistics routines	
M010		Foreign data wrapper support	different API
M011		Datalinks via Ada	
M012		Datalinks via C	
M013		Datalinks via COBOL	
M014		Datalinks via Fortran	
M015		Datalinks via M	
M016		Datalinks via Pascal	
M017		Datalinks via PL/I	
M018		Foreign data wrapper interface routines in Ada	
M019		Foreign data wrapper interface routines in C	different API
M020		Foreign data wrapper interface routines in COBOL	
M021		Foreign data wrapper interface routines in Fortran	
M022		Foreign data wrapper interface routines in MUMPS	
M023		Foreign data wrapper interface routines in Pascal	
M024		Foreign data wrapper interface routines in PL/I	
M030		SQL-server foreign data support	
M031		Foreign data wrapper general routines	
X012		Multisets of XML type	
X013		Distinct types of XML type	
X015		Fields of XML type	
X025		XMLCast	
X030		XMLDocument	
X038		XMLText	
X065		XMLParse: BLOB input and CONTENT option	
X066		XMLParse: BLOB input and DOCUMENT option	
X068		XMLSerialize: BOM	
X069		XMLSerialize: INDENT	
X073		XMLSerialize: BLOB serialization and CONTENT option	
X074		XMLSerialize: BLOB serialization and DOCUMENT option	
X075		XMLSerialize: BLOB serialization	
X076		XMLSerialize: VERSION	
X077		XMLSerialize: explicit ENCODING option	
X078		XMLSerialize: explicit XML declaration	
X080		Namespaces in XML publishing	
X081		Query-level XML namespace declarations	

Identifier	Core?	Description	Comment
X082		XML namespace declarations in DML	
X083		XML namespace declarations in DDL	
X084		XML namespace declarations in compound statements	
X085		Predefined namespace prefixes	
X086		XML namespace declarations in XMLTable	
X091		XML content predicate	
X096		XMLExists	XPath 1.0 only
X100		Host language support for XML: CONTENT option	
X101		Host language support for XML: DOCUMENT option	
X110		Host language support for XML: VARCHAR mapping	
X111		Host language support for XML: CLOB mapping	
X112		Host language support for XML: BLOB mapping	
X113		Host language support for XML: STRIP WHITESPACE option	
X114		Host language support for XML: PRESERVE WHITES-PACE option	
X131		Query-level XMLBINARY clause	
X132		XMLBINARY clause in DML	
X133		XMLBINARY clause in DDL	
X134		XMLBINARY clause in compound statements	
X135		XMLBINARY clause in subqueries	
X141		IS VALID predicate: data-driven case	
X142		IS VALID predicate: ACCORDING TO clause	
X143		IS VALID predicate: ELEMENT clause	
X144		IS VALID predicate: schema location	
X145		IS VALID predicate outside check constraints	
X151		IS VALID predicate with DOCUMENT option	
X152		IS VALID predicate with CONTENT option	
X153		IS VALID predicate with SEQUENCE option	
X155		IS VALID predicate: NAMESPACE without ELEMENT clause	
X157		IS VALID predicate: NO NAMESPACE with ELEMENT clause	
X160		Basic Information Schema for registered XML Schemas	
X161		Advanced Information Schema for registered XML Schemas	
X170		XML null handling options	
X171		NIL ON NO CONTENT option	
X181		XML(DOCUMENT(UNTYPED)) type	
X182		XML(DOCUMENT(ANY)) type	
X190		XML(SEQUENCE) type	
X191		XML(DOCUMENT(XMLSCHEMA)) type	

Identifier	Core?	Description	Comment
X192		XML(CONTENT(XMLSCHEMA)) type	
X200		XMLQuery	
X201		XMLQuery: RETURNING CONTENT	
X202		XMLQuery: RETURNING SEQUENCE	
X203		XMLQuery: passing a context item	
X204		XMLQuery: initializing an XQuery variable	
X205		XMLQuery: EMPTY ON EMPTY option	
X206		XMLQuery: NULL ON EMPTY option	
X211		XML 1.1 support	
X222		XML passing mechanism BY REF	parser accepts BY REF but ignores it; passing is always BY VALUE
X231		XML(CONTENT(UNTYPED)) type	
X232		XML(CONTENT(ANY)) type	
X241		RETURNING CONTENT in XML publishing	
X242		RETURNING SEQUENCE in XML publishing	
X251		Persistent XML values of XML(DOCUMENT(UNTYPED)) type	
X252		Persistent XML values of XML(DOCUMENT(ANY)) type	
X253		Persistent XML values of XML(CONTENT(UNTYPED)) type	
X254		Persistent XML values of XML(CONTENT(ANY)) type	
X255		Persistent XML values of XML(SEQUENCE) type	
X256		Persistent XML values of XML(DOCUMENT(XM-LSCHEMA)) type	
X257		Persistent XML values of XML(CONTENT(XM-LSCHEMA)) type	
X260		XML type: ELEMENT clause	
X261		XML type: NAMESPACE without ELEMENT clause	
X263		XML type: NO NAMESPACE with ELEMENT clause	
X264		XML type: schema location	
X271		XMLValidate: data-driven case	
X272		XMLValidate: ACCORDING TO clause	
X273		XMLValidate: ELEMENT clause	
X274		XMLValidate: schema location	
X281		XMLValidate with DOCUMENT option	
X282		XMLValidate with CONTENT option	
X283		XMLValidate with SEQUENCE option	
X284		XMLValidate: NAMESPACE without ELEMENT clause	
X286		XMLValidate: NO NAMESPACE with ELEMENT clause	
X300		XMLTable	XPath 1.0 only
X305		XMLTable: initializing an XQuery variable	

D.3. XML Limits and Conformance to SQL/XML

Significant revisions to the XML-related specifications in ISO/IEC 9075-14 (SQL/XML) were introduced with SQL:2006. Postgres Pro's implementation of the XML data type and related functions largely follows the earlier 2003 edition, with some borrowing from later editions. In particular:

- Where the current standard provides a family of XML data types to hold “document” or “content” in untyped or XML Schema-typed variants, and a type `XML(SEQUENCE)` to hold arbitrary pieces of XML content, Postgres Pro provides the single `xml` type, which can hold “document” or “content”. There is no equivalent of the standard's “sequence” type.
- Postgres Pro provides two functions introduced in SQL:2006, but in variants that use the XPath 1.0 language, rather than XML Query as specified for them in the standard.

This section presents some of the resulting differences you may encounter.

D.3.1. Queries Are Restricted to XPath 1.0

The Postgres Pro-specific functions `xpath()` and `xpath_exists()` query XML documents using the XPath language. Postgres Pro also provides XPath-only variants of the standard functions `XMLEXISTS` and `XMLTABLE`, which officially use the XQuery language. For all of these functions, Postgres Pro relies on the libxml2 library, which provides only XPath 1.0.

There is a strong connection between the XQuery language and XPath versions 2.0 and later: any expression that is syntactically valid and executes successfully in both produces the same result (with a minor exception for expressions containing numeric character references or predefined entity references, which XQuery replaces with the corresponding character while XPath leaves them alone). But there is no such connection between these languages and XPath 1.0; it was an earlier language and differs in many respects.

There are two categories of limitation to keep in mind: the restriction from XQuery to XPath for the functions specified in the SQL standard, and the restriction of XPath to version 1.0 for both the standard and the Postgres Pro-specific functions.

D.3.1.1. Restriction of XQuery to XPath

Features of XQuery beyond those of XPath include:

- XQuery expressions can construct and return new XML nodes, in addition to all possible XPath values. XPath can create and return values of the atomic types (numbers, strings, and so on) but can only return XML nodes that were already present in documents supplied as input to the expression.
- XQuery has control constructs for iteration, sorting, and grouping.
- XQuery allows declaration and use of local functions.

Recent XPath versions begin to offer capabilities overlapping with these (such as functional-style `for-each` and `sort`, anonymous functions, and `parse-xml` to create a node from a string), but such features were not available before XPath 3.0.

D.3.1.2. Restriction of XPath to 1.0

For developers familiar with XQuery and XPath 2.0 or later, XPath 1.0 presents a number of differences to contend with:

- The fundamental type of an XQuery/XPath expression, the `sequence`, which can contain XML nodes, atomic values, or both, does not exist in XPath 1.0. A 1.0 expression can only produce a node-set (containing zero or more XML nodes), or a single atomic value.
- Unlike an XQuery/XPath sequence, which can contain any desired items in any desired order, an XPath 1.0 node-set has no guaranteed order and, like any set, does not allow multiple appearances of the same item.

> **Note**
>
> The libxml2 library does seem to always return node-sets to Postgres Pro with their members in the same relative order they had in the input document. Its documentation does not commit to this behavior, and an XPath 1.0 expression cannot control it.

- While XQuery/XPath provides all of the types defined in XML Schema and many operators and functions over those types, XPath 1.0 has only node-sets and the three atomic types `boolean`, `double`, and `string`.
- XPath 1.0 has no conditional operator. An XQuery/XPath expression such as `if ( hat ) then hat/@size else "no hat"` has no XPath 1.0 equivalent.
- XPath 1.0 has no ordering comparison operator for strings. Both `"cat" < "dog"` and `"cat" > "dog"` are false, because each is a numeric comparison of two `NaN`s. In contrast, `=` and `!=` do compare the strings as strings.
- XPath 1.0 blurs the distinction between *value comparisons* and *general comparisons* as XQuery/XPath define them. Both `sale/@hatsize = 7` and `sale/@customer = "alice"` are existentially quantified comparisons, true if there is any `sale` with the given value for the attribute, but `sale/@taxable = false()` is a value comparison to the *effective boolean value* of a whole node-set. It is true only if no `sale` has a `taxable` attribute at all.
- In the XQuery/XPath data model, a *document node* can have either document form (i.e., exactly one top-level element, with only comments and processing instructions outside of it) or content form (with those constraints relaxed). Its equivalent in XPath 1.0, the *root node*, can only be in document form. This is part of the reason an `xml` value passed as the context item to any Postgres Pro XPath-based function must be in document form.

The differences highlighted here are not all of them. In XQuery and the 2.0 and later versions of XPath, there is an XPath 1.0 compatibility mode, and the W3C lists of *function library changes* and *language changes* applied in that mode offer a more complete (but still not exhaustive) account of the differences. The compatibility mode cannot make the later languages exactly equivalent to XPath 1.0.

D.3.1.3. Mappings between SQL and XML Data Types and Values

In SQL:2006 and later, both directions of conversion between standard SQL data types and the XML Schema types are specified precisely. However, the rules are expressed using the types and semantics of XQuery/XPath, and have no direct application to the different data model of XPath 1.0.

When Postgres Pro maps SQL data values to XML (as in `xmlelement`), or XML to SQL (as in the output columns of `xmltable`), except for a few cases treated specially, Postgres Pro simply assumes that the XML data type's XPath 1.0 string form will be valid as the text-input form of the SQL datatype, and conversely. This rule has the virtue of simplicity while producing, for many data types, results similar to the mappings specified in the standard.

Where interoperability with other systems is a concern, for some data types, it may be necessary to use data type formatting functions (such as those in Section 9.8) explicitly to produce the standard mappings.

D.3.2. Incidental Limits of the Implementation

This section concerns limits that are not inherent in the libxml2 library, but apply to the current implementation in Postgres Pro.

D.3.2.1. Only `BY VALUE` Passing Mechanism Is Supported

The SQL standard defines two *passing mechanisms* that apply when passing an XML argument from SQL to an XML function or receiving a result: `BY REF`, in which a particular XML value retains its node identity, and `BY VALUE`, in which the content of the XML is passed but node identity is not preserved.

A mechanism can be specified before a list of parameters, as the default mechanism for all of them, or after any parameter, to override the default.

To illustrate the difference, if *x* is an XML value, these two queries in an SQL:2006 environment would produce true and false, respectively:

```
SELECT XMLQUERY('$a is $b' PASSING BY REF x AS a, x AS b NULL ON EMPTY);
SELECT XMLQUERY('$a is $b' PASSING BY VALUE x AS a, x AS b NULL ON EMPTY);
```

Postgres Pro will accept `BY VALUE` or `BY REF` in an `XMLEXISTS` or `XMLTABLE` construct, but it ignores them. The `xml` data type holds a character-string serialized representation, so there is no node identity to preserve, and passing is always effectively `BY VALUE`.

D.3.2.2. Cannot Pass Named Parameters to Queries

The XPath-based functions support passing one parameter to serve as the XPath expression's context item, but do not support passing additional values to be available to the expression as named parameters.

D.3.2.3. No `XML(SEQUENCE)` Type

The Postgres Pro `xml` data type can only hold a value in `DOCUMENT` or `CONTENT` form. An XQuery/XPath expression context item must be a single XML node or atomic value, but XPath 1.0 further restricts it to be only an XML node, and has no node type allowing `CONTENT`. The upshot is that a well-formed `DOCUMENT` is the only form of XML value that Postgres Pro can supply as an XPath context item.

Appendix E. Release Notes

The release notes contain the significant changes in each Postgres Pro Enterprise release, with major features and migration issues listed at the top. The release notes do not contain changes that affect only a few users or changes that are internal and therefore not user-visible. For example, the optimizer is improved in almost every release, but the improvements are usually observed by users as simply faster queries.

E.1. Postgres Pro Enterprise 14.18.1

Release Date: 2025-06-03

E.1.1. Overview

This release is based on PostgreSQL 14.18 and Postgres Pro Enterprise 14.17.1. All changes inherited from PostgreSQL 14.18 are listed in PostgreSQL 14.18 Release Notes. As compared with Postgres Pro Enterprise 14.17.1, this version also provides the following changes:

- Added the enable_alternative_sorting_cost_model configuration parameter, which allows you to enable or disable the query planner's use of alternative model for estimating the cost of tuple sorting.
- Implemented performance optimization when working with table metadata, which allows obtaining information about attributes using the system cache instead of direct reading from the system catalog.
- Introduced the following changes to the implementation of crash_info:
  - Added handling of `SIGILL` signals to `crash_info` processing.
  - Added details, like process start time and query text at planning, to `crash_info` output files.
  - Fixed incorrect function names in the first 2-3 lines of `crash_info` backtrace stacks.
  - Fixed possible data truncation at the end of SQL query dump files. Previously, a buffer overflow during SQL query dumping could result in incomplete writes, causing truncated data at the end of files produced by `crash_info`.
  - Fixed handling of crash information signals (sent using the kill command) by backends. Previously, the first signal would flush `crash_info` information to the log, but the process would continue running without producing a core dump, even if configured, and only the second signal would terminate the backend and generate the core dump as expected.
- Fixed the following issues for CFS:
  - Fixed compatibility of CFS with the `ALTER TABLESPACE ... SET/RESET` commands.
  - Fixed an issue with memory allocation within a critical section in the implementation of `VACUUM ANALYZE` for compressed tables.
- Fixed the following bugs related to autonomous transactions:
  - Fixed a segmentation fault, which could occur when using postgres_fdw with autonomous transactions.
  - Fixed loss of temporary tables from parent transaction on autonomous transaction rollback.
  - Fixed an issue with empty `xact_start` columns in the `pg_stat_activity` view for backends executing autonomous transactions.
- Fixed an issue with missing statistics about vacuuming when multiple index vacuum workers are used.
- Fixed an issue when the checkpointer process could get stuck, repeatedly throwing “invalid memory alloc request size” errors. This could occur when using a huge `shared_buffers` setting, causing checkpointer memory allocation requests to exceed the allowed limit.

- Fixed misuse of spinlocks in the automatic page repair worker.
- Added the daterange_inclusive extension, which allows you to include the upper bound of a time range in output.
- Added the pg_failover_slots extension as a separate pre-built package. pg_failover_slots is designed for automatic creation and synchronization of logical replication slots on physical replicas.
- Added the *pg_probackup3* solution for backup and recovery of Postgres Pro database clusters. Refer to the pg_probackup3 *release notes* for more details.
- Added the pgpro_bindump module to manage backup and restore operations. This module implements specialized replication commands for an extended replication protocol, has its own format for archiving files, and does not require SSH connection. It is designed specifically for use with the *pg_probackup3* utility.
- Added the pgpro_datactl utility to manage Postgres Pro data files, which includes a module for unpacking and analyzing CFS files.
- Added the new pgpro_tune utility for automatic tuning of Postgres Pro configuration parameters for all operating systems, except for Windows.
- Added a new `PGPRO_TUNE` environment variable to initdb, which specifies whether to use pgpro_tune without modifying command-line options directly.
- Deprecated the experimental vops extension.
- Removed the `--tune` option from `pg-setup`. Use the new pgpro_tune utility instead.
- Upgraded multimaster to version 1.3.0, which provides the following enhancements and bug fixes:
  - Improved the way nodes delete old synchronization points. Previously, every node deleted only a part of the synchronization point table and replicated changes to other nodes. This could cause synchronization issues and inability to delete old synchronization points. Now, every node deletes all synchronization points and does not replicate changes to other nodes.
  - Fixed potential node hanging during catchup when attempting to process aborted DDL transactions in a cluster of three or more nodes.
- Upgraded oracle_fdw to provide the following enhancements and bug fixes:
  - Increased line size for EXPLAIN output as some Oracle catalog queries have long filter conditions. The line size was increased to the value of 3000.
  - Fixed a crash with column options on non-existing columns. If the Oracle table has fewer columns than the Postgres Pro and one of these extra columns has a column option set, oracle_fdw would write past the end of an array, leading to memory corruption and crashes. Now options for such columns are ignored.
- Fixed an issue with updating pageinspect. In rare cases, depending on the sequence of previous updates, upgrading the database cluster and then attempting to update the pageinspect extension using `ALTER EXTENSION pageinspect UPDATE TO` could result in an error. To avoid such issues, it is strongly recommended to drop and recreate the extension using `DROP EXTENSION` followed by `CREATE EXTENSION` after upgrading the cluster. Since pageinspect does not create dependent objects, this approach is safe.
- Upgraded pg_proaudit to provide the following enhancements and bug fixes:
  - Added new object types: `CATALOG RELATION` and `CATALOG FUNCTION`.
  - Added new event fields: UUID, XID, and VXID. Now it is possible to identify an event by its UUID and transaction IDs (if applicable).
  - The behavior of the `pg_proaudit.log_catalog_access` configuration parameter was corrected to reflect the new logic of logging for system catalog objects.
  - Changed the logic of handling disconnection events. Now these events are associated with the corresponding authentication events, so the disconnection events will be logged even in the case when the rule is removed after authentication, but before disconnect.

  - Fixed an issue where the `DISCONNECT` event type was not logged for a user who was a member of the role that was set in the logging rule.
  - Fixed the bug that caused a log entry to be written to an incorrect log file when log file rotation was configured.
  - Fixed an issue with pg_proaudit failing to log schema creation events.
  - Corrected the behavior of the `logger` process when deleting a role from a parallel session configured by the rule.
- Upgraded pg_probackup to version 2.8.9 Enterprise, which provides the following new features, optimizations, and bug fixes:
  - Added the `maintain` command to resolve issues that can occur during a forced backup termination.
  - Added the `--lock-lifetime` option that sets the timeout for locks. This option is useful for computational environments with a slow network.
  - Stabilized retaining the initial permissions for directories when running the `init` command.
  - Stabilized the `checkdb` command on a remote host.
  - Improved the stability of the point-in-time recovery (PITR) with validation.
  - Fixed the “SignatureDoesNotMatch” error that could occur when connecting to the VK Cloud S3 storage.
  - Fixed an incorrect behavior that could occur when launching the wait for a WAL streaming thread in the ARCHIVE WAL delivery mode.
- Upgraded pgpro_pwr to version 4.9, which mainly provides optimizations and bug fixes. Notable changes are as follows:
  - Added support for pgpro_stats 1.9.
  - Added a possibility to define the mode of collecting relation sizes globally through the `pgpro_pwr.relsize_collect_mode` extension parameter or for a server through the `set_server_size_sampling` function parameter.
  - Enabled fine-tuning the server statistics collection by calling the `set_server_setting` function. It allows you to define which statistics should be collected.
  - Added a preview of storage parameters for tables and indexes in the “Schema object statistics” report section.
- Upgraded pgpro_scheduler to version 2.11.2 to fix an issue where repeated jobs could be executed at additional time if days of the week were set using the `crontab` format. pgpro_scheduler now checks all job time settings and runs jobs at the specified time.
- Upgraded pgpro_stats to version 1.9, which provides the following bug fixes and improvements:
  - Enhanced session tracing to provide more information. Specifically, the new `time_info` filter attribute controls inclusion of additional information in the session-tracing output, and the `pgpro_stats.trace_query_text_size` configuration parameter can limit the size of the query in the session-tracing output.
  - Aligned the names of the `explain_*` filter attributes of the session tracer with the names of session-tracing configuration parameters.
  - Changed the format of the statistics dump file and the corresponding save/load routines.
  - Implemented turning off the session tracer functionality when no session-tracing filters are specified.
  - Prohibited inclusion of both pgpro_stats and pg_stat_statements in the list of `shared_preload_libraries`. If both are included, the database server will not start.

- Upgraded the pg_wait_sampling extension to provide the following bug fixes:
  - Fixed an issue where GUC variables could be overridden when using parallel workers.
  - Fixed an issue with malformed samples caused by a race condition when `pg_wait_sampling.sample_cpu` is disabled.

E.1.2. Migration to Version 14.18.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

ABI versions may change between minor releases of Postgres Pro. If this is the case, and you see the `ABI mismatch` error when trying to run your extension, make sure to install a new version of the extension supplied with a new release of Postgres Pro, or recompile your third-party extension to be able to use it with the current version of Postgres Pro.

When upgrading your high-availability cluster from Postgres Pro Enterprise versions 14.12.x or lower, first disable automatic failover if it was enabled and upgrade all the standby servers, then upgrade the primary server, promote a standby, and restart the former primary (possibly with pg_rewind).

If you take backups using pg_probackup and you have previously upgraded it to version 2.8.0 Enterprise or 2.8.1 Enterprise, make sure to upgrade it to version 2.8.2 Enterprise or higher and retake a full backup after upgrade, since backups taken using those versions might be corrupted. If you suspect that your backups taken with versions 2.8.0 or 2.8.1 may be corrupted, you can validate them using version 2.8.2.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

Starting from Postgres Pro Enterprise 14.10.1, the privileges of `CREATEROLE` are restricted, and modification of other roles requires the role requesting the change to have the `ADMIN OPTION` permission.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.2. Postgres Pro Enterprise 14.17.1

Release Date: 2025-03-05

E.2.1. Overview

This release is based on PostgreSQL 14.17 and Postgres Pro Enterprise 14.15.1. All changes inherited from PostgreSQL 14.17 are listed in PostgreSQL 14.17 Release Notes. As compared with Postgres Pro Enterprise 14.15.1, this version also provides the following changes:

- Added details, like current working directory, the `PGDATA` directory, etc., to `crash_info` output files.
- Added the increased security requirements for the CREATE PROFILE command. Now the `PASSWORD_REQUIRE_COMPLEX` parameter requires characters from three different groups. Also, all characters of languages without case distinction (Hindi, Chinese, etc.) in the UTF-8 encoding are considered lowercase.

- Implemented the following enhancements and bug fixes for CFS:
  - Changed the default value for the cfs_gc_threshold configuration parameter from 50 to 30 percent.
  - Fixed an issue with CFS garbage collector being blocked by the backup process. If backup took ran too long, this could lead to write locks, preventing writes to compressed tablespaces. Now both processes lock only specific data files briefly, avoiding mutual blocking.
  - Fixed an issue with missing compression settings for tablespaces on standby servers by adding a new WAL record type. Previously, standby servers did not receive such compression settings because `ALTER TABLESPACE ... SET (compression=true)` was not logged in WAL.
  - Fixed the `cfs_start_gc` function to reject invalid values of the `n_workers` argument.
- Fixed an issue with upgrading Postgres Pro Standard to Postgres Pro Enterprise using pg_upgrade, which could fail if the old cluster had an epoch greater than 1 with an error like "could not open file".
- Fixed the pg_upgrade `--check` option to correctly check that pg_upgrade is run on a standby. Previously, it would fail with errors like "cannot assign TransactionIds during recovery".
- Fixed a segmentation fault caused by foreign data wrapper invalidation during autonomous transactions if an autonomous transaction reset global variables while registered callback functions remained active. Now callback functions check for global variables and invalidation data is preserved for parent transactions.
- Fixed an issue that caused the server to crash with PANIC instead of returning an appropriate error when deleting tuples from a page where the difference between the minimum transaction ID and the current transaction ID exceeded 2^31.
- Fixed `pg_multixact` bloating by introducing "soft" limits that trigger autovacuum earlier.
- Fixed an issue where `crash_info` could fail to write diagnostic files when handling a stack overflow. Previously, the signal handler ran on the same stack that had overflowed, which could prevent it from executing due to lack of available stack space. Now the handler runs on an alternate signal stack.
- Fixed a memory context issue, which could previously cause emitting garbage in logs instead of the host and port details when disconnecting from the remote server.
- Fixed an issue that could occur when a custom scan was used, which could cause an incorrect state of the query plan and could result in an error when pgpro_stats was involved.
- Fixed an issue where roles without explicitly set `VALID UNTIL` attribute and associated with a profile that had PASSWORD_GRACE_TIME set to 0 and `PASSWORD_LIFE_TIME` set to `UNLIMITED` incorrectly received password expiration warnings. Now they are correctly considered valid indefinitely.
- Upgraded the apache_age extension to version 1.5.1.
- Optimized fasttrun to skip unnecessary truncate operations on empty temporary relations.
- Upgraded mamonsu to version 3.5.11 to provide support for pgpro_stats version 1.8.
- Upgraded multimaster to add the ability to specify the catchup mode for reconnected nodes using the `multimaster.catchup_algorithm` configuration parameter. Supported the `parallel` catchup mode, in which non-conflicting replicated transactions are applied in parallel.
- Upgraded pgbadger to version 13.0.
- Upgraded pgbouncer to version 1.24.0.
- Upgraded pg_hint_plan to version 1.4.3.2.
- Upgraded pg_portal_modify to version 0.3.5.
- Upgraded pg_proaudit to provide the following enhancements and bug fixes:
  - Added a new event field: session user name. Now an event contains the information about both `session_user` and `current_user` attributes of an SQL session.

    - Added support for new event classes: `ALL_DDL_NONTEMP` and `ALL_DML_NONTEMP`. The scope of these classes is limited to the objects that are not contained in `pg_temp_nnn` temporary schemas.
    - Fixed logging of `SELECT FOR UPDATE` and `SELECT FOR KEY SHARE` events as `SELECT`, rather than `UPDATE`.
- Upgraded pg_probackup to version 2.8.7 Enterprise, which provides the following optimizations and bug fixes:
    - Reduced the log level for "checking WAL file name" messages that are issued when the `show` with the `--archive` option is executed from `INFO` to `VERBOSE`.
    - Updated the `add-instance` command logic to make the `-D` option that specifies the path to the catalog mandatory. `add-instance` no longer relies on the `PGDATA` environment variable for the catalog location, but requires explicitly specifying the path to the catalog as the command option.
    - Improved the garbage collection mechanism in CFS used when a backup copy is created. File-system level locks resolve an issue with the concurrent access to files from compressed tablespaces during copying to a backup and during the defragmentation.
    - Fixed an issue of the multi-threaded file copying technique that prevents repeated copying of one file. This issue could previously stop the backup creation under high load on the server.
- Upgraded pgpro_pwr to version 4.8, which provides new features and bug fixes. Notable changes are as follows:
    - Added tracking of extension versions installed in the cluster through a new report section.
    - Added a possibility to hide data for certain databases in the report. To this end, a new parameter that accepts an array of databases to be excluded was added to report generation functions.
- Upgraded pgpro_scheduler to version 2.11.1 to fix a segmentation fault, which could occur when pgpro_scheduler did not terminate its processes when the associated extension or schema was dropped. Now it terminates with an error instead of crashing.
- Upgraded pgpro_stats to version 1.8.1, which provides the following bug fixes and improvements:
    - Fixed an issue that could occur during session tracing and cause errors "could not write file ""pg_stat/pgpro_stats_filters.trace.tmp"": No such file or directory". Concurrent writing from different sessions to a trace file is fixed now, so processes can write to the trace file in parallel without collisions.
    - Implemented an optimization that lowers the locking time in some cases when copying metrics from the local memory to the shared memory.
- Upgraded pg_variables. The `DISCARD ALL` command now discards all packages and variables in pg_variables.
- Upgraded the rum module to update an error message for an error that can occur in the case when a `SELECT` query uses `ORDER BY`.

E.2.2. Migration to Version 14.17.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

ABI versions may change between minor releases of Postgres Pro. If this is the case, and you see the `ABI mismatch` error when trying to run your extension, make sure to install a new version of the extension supplied with a new release of Postgres Pro, or recompile your third-party extension to be able to use it with the current version of Postgres Pro.

When upgrading your high-availability cluster from Postgres Pro Enterprise versions 14.12.x or lower, first disable automatic failover if it was enabled and upgrade all the standby servers, then upgrade the primary server, promote a standby, and restart the former primary (possibly with pg_rewind).

If you take backups using pg_probackup and you have previously upgraded it to version 2.8.0 Enterprise or 2.8.1 Enterprise, make sure to upgrade it to version 2.8.2 Enterprise or higher and retake a full backup

after upgrade, since backups taken using those versions might be corrupted. If you suspect that your backups taken with versions 2.8.0 or 2.8.1 may be corrupted, you can validate them using version 2.8.2.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the VACUUM command before the upgrade.

Starting from Postgres Pro Enterprise 14.10.1, the privileges of CREATEROLE are restricted, and modification of other roles requires the role requesting the change to have the ADMIN OPTION permission.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.3. Postgres Pro Enterprise 14.15.1

Release Date: 2024-12-06

E.3.1. Overview

This release is based on PostgreSQL 14.15 and Postgres Pro Enterprise 14.13.2. All changes inherited from PostgreSQL 14.15 are listed in PostgreSQL 14.15 Release Notes. As compared with Postgres Pro Enterprise 14.13.2, this version also provides the following changes:

- Added the ability to form the MergeAppend operation instead of Append, which allows omitting additional sorting needed to ensure that the data is in fact sorted. Now MergeAppend is formed specifying the columns to sort by. The new ability applies only when the enable_appendorpath option is set to ON.
- Improved performance of CFS by reducing the number of invalidation messages for tables, which previously caused multiple file reopen events. Now invalidation is targeted at the specific segments affected by the garbage collector.
- Allowed transformation of correlated IN subqueries into joins.
- Implemented the ability to dump the state of a single backend process by sending the dump signal.
- Added a validation step to check for non-zero values in unused header fields of *.cfm files by pg_upgrade.
- Changed the error level to calculate the statistics on vacuum interrupts to ERROR (PGERROR) only. Calculating vacuum interrupts for the PANIC error level could cause unpredictable system behavior, and the statistics could not be calculated anyway because of the server crash.
- Fixed cfs_gc_relation to return the actual number of processed segments of the relation.
- Fixed an issue with upgrading from PostgreSQL or Postgres Pro Standard to Postgres Pro Enterprise using pg_upgrade when a multitransaction offset counter overflow occurred.
- Fixed the processing of 64-bit transaction IDs with proper encoding and decoding of the transaction ID.
- Fixed an issue with upgrading from PostgreSQL or Postgres Pro Standard to Postgres Pro Enterprise using pg_upgrade that could occur when attempting to convert heap pages to the double

xmax page format in cases where there was insufficient free space to accommodate the special area. In the presence of multitransactions, this could lead to errors like “MultiXactId XXXXX has not been created yet” or “could not access status of transaction XXXXXX”, depending on the server version. No data loss is expected as the actual conversion did not occur. Pages will now be safely converted upon first access.

- Fixed a memory leak that could occur when the EXPLAIN command's output produced over 64 columns.
- Fixed a segmentation fault, which could occur while executing the COPY TO command when using the online_analyze module.
- Fixed an issue where EXPLAIN ANALYZE showed incorrect counts of inserted and conflicted tuples during row inserts with conflicting primary keys when using ON CONFLICT DO NOTHING.
- Fixed an issue that could slow down query execution. The reason was that the optimizer selected a suboptimal index due to the lack of its cost estimation after removing redundant clauses with the enable_appendorpath option set to ON.
- Upgraded aqo to include the following optimizations and bug fixes:
  - Enhanced aqo wide search (aqo.wide_search = on) to utilize data from multiple neighbors simultaneously. Also, revised its interaction with aqo.min_neighbors_for_predicting to allow queries with fewer than the specified number of data samples to participate in wide search. Previously, such queries were excluded from consideration.
  - Fixed an array index out-of-bounds issue in the aqo smart statement timeout update logic, as well as incorrect statistics insertion into aqo_query_stats when the arrays were full. In previous releases, using aqo_query_stat_update with arrays of size 20 or more could lead to subsequent statistics updates being written to uncontrolled memory segments. Make sure to install the Postgres Pro on both primary and standby servers to avoid similar memory corruption problems.
- Upgraded mamonsu to version 3.5.9, which provides optimizations and bug fixes. Notable changes are as follows:
  - Added support for systems where *setuptools* version greater than 67.7.2 is installed.
  - Ended the use of dotted user:group specification at the RPM pre-install stage.
- Upgraded multimaster to version 1.2.0. Significantly increased catchup performance by enabling asynchronous commit operations on a lagging node syncing with the donor node, controlled by the multimaster.enable_async_3pc_on_catchup parameter.
- Upgraded oracle_fdw to version 2.7.0.
- Upgraded orafce to version 4.13.5.
- Upgraded pg_filedump to version 17.1, which specifically fixed an issue that could cause pg_filedump to crash with a segmentation fault when handling incomplete pages.
- Upgraded pg_hint_plan to version 1.4.3.
- Upgraded pg_integrity_check to display actual checksum values, if the checksums differ, only with the --verbose option.
- Upgraded pg_portal_modify to version 0.3.4.
- Upgraded pg_proaudit to provide the following optimizations and bug fixes:
  - Added logging of security events related to operations with profiles: CREATE PROFILE, ALTER PROFILE, and DROP PROFILE.
  - Changed the distribution of security events related to functions and stored procedures among the groups of security events: the ALL_DDL group now includes no events related to functions

and stored procedures, ALL_PROC includes CREATE, ALTER, and DROP, while ALL_DML includes EXECUTE.

- Fixed compatibility with the connection pooler. Previously, issues could be encountered when logging AUTHENTICATE and DISCONNECT security events.
- Fixed logging of security events on partitioned tables by pg_proaudit. Now the SELECT/UPDATE/INSERT/DELETE/TRUNCATE events on a partitioned table get logged if logging rules imply logging of appropriate events for this table. Previously, only events on individual partitions were logged.

- Upgraded pg_probackup to version 2.8.5 Enterprise, which provides the following optimizations and bug fixes:
  - Enabled the output of the version command in the JSON format using --format=json.
  - Added the --all option to the amcheck command, which allows performing all the checks in a single command.
  - Added support for the include parameter in the configuration file. The contents of the file specified in include gets added to the configuration file instead of this parameter.
  - Added a possibility to specify an individual number of threads for execution of a backup and its subsequent validation by specifying the --backup-threads and --validate-threads option, respectively.
  - Changed the priority of setting PGDATA and BACKUP_PATH. Now the values from the command-line options take precedence.
  - Added validation of WAL files for backups to be merged by the merge command.
  - An error message that was issued when the validate command run with the --wal option found an archive in the DEGRADED status has been replaced with a warning since backups in this status do not affect the restore correctness as a whole.
  - Added support for the --s3-config-file option of restore_command. postgresql.auto.conf must include the restore_command with the --s3-config-file option if the backup was created with this option.
  - The default value of PG_PROBACKUP_S3_IGNORE_CERT_VER is set to on according to the documentation.
  - Fixed an issue that could occur if the command line was too long.
  - Fixed an issue that could occur during validation or restore when the PITR from a previous timeline was performed.
  - Fixed an issue that could occur when the S3 connection port was specified both in PG_PROBACKUP_S3_PORT and PG_PROBACKUP_S3_HOST. Now the value specified in PG_PROBACKUP_S3_HOST, together with the address, has higher priority.
- Upgraded pgpro_controldata to version 17.1.0.
- Upgraded pgpro_stats to version 1.8, which supports Postgres Pro 17. Notable changes are as follows:
  - Updated pgpro_stats_statements and pgpro_stats_totals views to include fields added to pg_stat_statements. Related functions were updated accordingly.
  - Streamlined access to views and functions. Specifically, access to the pgpro_stats_archiver, pgpro_stats_vacuum_database, pgpro_stats_vacuum_tables, and pgpro_stats_vacuum_indexes views was granted to all users. Previously, these views required explicitly granting access rights. Access to execution of the pgpro_stats_trace_reset function, which could previously be executed by any user, was restricted to superusers.
  - Eliminated an excessive check of holding the lock when accessing the hash table of session-tracing filters.

    - Fixed processing of the `pgpro_stats.stats_temp_directory` configuration parameter. Previously after the server restart for changes to this parameter value to take effect, the fatal error "pfree called with invalid pointer" could occur when processing this parameter.
- Upgraded pgpro_pwr to version 4.7, which provides new features, optimizations and bug fixes. Notable changes are as follows:
    - A *subsample* feature to collect relatively fast changing data.
    - New report tables, specifically regarding session states.
    - Support for new Postgres Pro 17 statistics.
    - A possibility not to reset statistics of the statistics collecting extension during taking a sample.
    - The change of the type for the field that tracks transaction IDs in a certain table from `xid` to `text`. The use of the `xid` type could previously cause a failure of pg_upgrade when upgrading from Postgres Pro Standard to Postgres Pro Enterprise.
- Upgraded pgpro_scheduler to version 2.10, which provides the following changes:
    - Fixed an issue with automatic restart of one-time jobs after job interruption.
    - Fixed `schedule.get_active_jobs` to properly return the list of currently executed cron jobs.
    - Fixed an issue where errors occurring during job execution were not properly logged due to a primary key constraint preventing multiple log entries.
    - Fixed an issue where `at job executor` would fail when the `database manager` prematurely released the shared memory segment before the worker had connected to it.
    - Fixed an issue where `schedule.timetable` did not display the next execution time of cron jobs with either `next_time_statement` or an array of dates. Fixed an issue with calculating next execution time for cron jobs that caused job instances to be skipped.
    - Fixed an issue causing database crashes due to segmentation faults in the job executor background worker.
- Upgraded pg_repack to version 1.5.1.
- Upgraded pg_wait_sampling to provide tracking of subquery IDs and utility statements and to add the new `pg_wait_sampling.sample_cpu` parameter, which allows specifying the sampling mode that determines whether to perform sampling of on-CPU backends.
- Upgraded the PLV8 extension to version 3.2.3.
- Ensured compatibility of `postgres_fdw` with autonomous transactions.
- Upgraded PTRACK to prevent possible issues with PTRACK backups by setting the `ptrack.map` file for automatic deletion when PTRACK is disabled.
- Upgraded tds_fdw to version 2.0.4.
- Achieved compatibility with *TimescaleDB*, which is an open-source database designed to make SQL scalable for time-series data.

E.3.2. Migration to Version 14.15.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

ABI versions may change between minor releases of Postgres Pro. If this is the case, and you see the `ABI mismatch` error when trying to run your extension, make sure to install a new version of the extension supplied with a new release of Postgres Pro, or recompile your third-party extension to be able to use it with the current version of Postgres Pro.

When upgrading your high-availability cluster from Postgres Pro Enterprise versions 14.12.x or lower, first disable automatic failover if it was enabled and upgrade all the standby servers, then upgrade the primary server, promote a standby, and restart the former primary (possibly with pg_rewind).

If you take backups using pg_probackup and you have previously upgraded it to version 2.8.0 Enterprise or 2.8.1 Enterprise, make sure to upgrade it to version 2.8.2 Enterprise or higher and retake a full backup after upgrade, since backups taken using those versions might be corrupted. If you suspect that your backups taken with versions 2.8.0 or 2.8.1 may be corrupted, you can validate them using version 2.8.2.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

Starting from Postgres Pro Enterprise 14.10.1, the privileges of `CREATEROLE` are restricted, and modification of other roles requires the role requesting the change to have the `ADMIN OPTION` permission.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.4. Postgres Pro Enterprise 14.13.2

Release Date: 2024-10-24

E.4.1. Overview

This release is based on Postgres Pro Enterprise 14.13.1 and provides the following changes:

- Introduced various optimizations in the implementation of improved performance for subsystems on top of SLRU, including more consistent use of `int64` and acquiring the correct SLRU bank lock. The latter fixes an issue with zeroed `pg_serial` pages, which could manifest itself in “could not access status of transaction” errors.
- Fixed an issue to avoid potential stack overflow in scenarios involving a large number of subtransactions. Now when handling the process of committing a transaction, iteration is used instead of tail recursion.
- Fixed an issue that caused a terminated CFS worker to respawn with a duplicate with the same worker ID. This led to multiple instances of the same worker competing for the recovery of compressed segments.
- Fixed a race condition in committing serializable transactions.
- Fixed an issue in `pg_serial`, which could arise when the transaction counter reached values over 2^{32}.
- Fixed a memory leak in `walsender` in multimaster.

E.4.2. Migration to Version 14.13.2

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.5. Postgres Pro Enterprise 14.13.1

Release Date: 2024-09-06

E.5.1. Overview

This release is based on PostgreSQL 14.13 and Postgres Pro Enterprise 14.12.2. All changes inherited from PostgreSQL 14.13 are listed in PostgreSQL 14.13 Release Notes. As compared with Postgres Pro Enterprise 14.12.2, this version also provides the following changes:

- Enhanced performance of segment search by implementing a new search strategy, allowing faster detection of the last segment.
- Implemented the interaction of the PASSWORD_GRACE_TIME profile parameter with the `VALID UNTIL` role attribute. Now if both of them are set, the warning about password expiration will be displayed.
- Prevented potential authentication delays due to locking by not updating role's last login time if the role's profile `USER_INACTIVE_TIME` is set to unlimited (see Section 54.39 for details).
- Optimized the logic of pruning, which is now delayed until a page is nearly full, rather than relying solely on the fill factor. This reduces the frequency of pruning during `UPDATE` operations, leading to better performance in tables with frequent updates.
- Fixed the following issues in CFS:
  - Fixed issues related to processing of data structures in CFS by pg_rewind. Previously, pg_rewind did not fully support CFS, which could result in data corruption.
  - Fixed an issue in CFS, which could cause GC worker to fail with warning “CFS GC failed to read block 0 of file X at position 0 size 0: Success”. It happened due to incorrect handling of the first MB of the data file containing only zero pages.
- Fixed a segmentation fault that could occur when a connection to the built-in connection pooler was reset before a new session was created in the backend.
- Fixed an issue with freezing 64-bit multitransaction IDs, which could manifest itself in PANIC-level errors like “xid XXX does not fit into valid range for base YYY” during autovacuum.
- Fixed an issue related to suboptimal handling of `pd_prune_xid`. This issue did not result in any significant operation problems but caused unnecessary page pruning, which might have produced extra WAL records.
- Fixed an issue, which could manifest itself in errors like “invalid FSM request size”. The code was adjusted to reflect the changes in heap page structure, removing reliance on a constant related to maximum free heap page space where it is no longer applicable.
- Fixed a bug that caused the optimizer to ignore columns from query conditions. Previously, when partially using a composite index, the number of rows could be overestimated, which led to an incorrect plan creation. The bug occurred due to a malfunction of the multi-column statistics elements.
- Fixed a bug in `ANALYZE` that could occur because it was impossible to display the `pg_statistic` system catalog. For the fix to work, if your database has indexes with `INCLUDE` columns, after upgrading Postgres Pro, it is recommended to do another `ANALYZE` for these columns.
- Added support for ALT 11.
- Upgraded the mchar extension to fix a bug that caused the `mchar` and `mvarchar` data types to ignore control characters during string comparison.
- Implemented the ability to slow down transaction execution on the donor node in multimaster using the `multimaster.tx_delay_on_slow_catchup` configuration parameter. This is useful when a lagging node is catching up to the donor node and cannot apply changes as quickly.
- Upgraded pg_filedump to version 17.0, which provides optimizations and bug fixes. In particular, contents of meta pages for GIN and SP-GiST indexes are now displayed correctly, and an issue of lacking memory for encoding and decompression is resolved.
- Upgraded pg_proaudit to provide the following optimizations and bug fixes:

  - Improved performance and added the `pg_proaudit.max_rules_count` parameter, which allows specifying the maximum number of rules allowed.
  - Corrected support of database names including uppercase symbols by the `pg_proaudit_set_rule` function.
- Upgraded pg_probackup to version 2.8.3 Enterprise, which provides the following bug fixes:
  - Fixed backup validation for databases containing an OID larger than 10^9. Previously, the validation status could be displayed incorrectly in such cases.
  - Fixed a bug that could occur when pg_probackup was run as a user included in the `postgres` group in case the database used CFS.
- Fixed incorrect behavior of pg_wait_sampling when used with the extended query protocol.

E.5.2. Migration to Version 14.13.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

> **Important**
>
> When upgrading your high-availability cluster from Postgres Pro Enterprise versions 14.12.x or lower, first disable automatic failover if it was enabled and upgrade all the standby servers, then upgrade the primary server, promote a standby, and restart the former primary (possibly with pg_rewind).

If you take backups using pg_probackup and you have previously upgraded it to version 2.8.0 Enterprise or 2.8.1 Enterprise, make sure to upgrade it to version 2.8.2 Enterprise or higher and retake a full backup after upgrade, since backups taken using those versions might be corrupted. If you suspect that your backups taken with versions 2.8.0 or 2.8.1 may be corrupted, you can validate them using version 2.8.2.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

Starting from Postgres Pro Enterprise 14.10.1, the privileges of `CREATEROLE` are restricted, and modification of other roles requires the role requesting the change to have the `ADMIN OPTION` permission.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.6. Postgres Pro Enterprise 14.12.2

Release Date: 2024-07-01

E.6.1. Overview

This release is based on Postgres Pro Enterprise 14.12.1 and provides the following changes:

- Fixed two issues that could occur after upgrading from PostgreSQL or Postgres Pro Standard using pg_upgrade: fixed `xid` base calculation during heap page pruning and `xmax` calculation during

page conversion from 32-bit to 64-bit format. These issues didn't result in data loss or corruption but raised PANIC-level errors.

- Fixed a segmentation fault caused by improper memory management in CFS, which could occur in some corner cases where CFS garbage collector was disabled or a standby server restored WAL records for a long time (e.g. it was lagging far behind).
- Fixed a bug in the backend composite type cache management. This bug could result in a segmentation fault or produce errors like “ERROR: record type has not been registered” during the process of selectivity estimation in query planning under the following conditions:
  - The query contained at least one `JOIN` operator.
  - The enable_compound_index_stats configuration parameter was enabled.
  - The tables involved in the query had multi-column `INCLUDE` indexes.
- Upgraded orafce to version 4.10.3.
- Upgraded orafce to version 4.10.3.
- Upgraded pg_probackup to version 2.8.2 Enterprise, which provides the following bug fixes:
  - Fixed an OID parsing issue where databases and tablespaces with relfilenodes greater than a billion were not included in backups.
  - Fixed an issue in enabling pg_probackup logging with the `--log-level-file` parameter, where the parameter value was written to the configuration file, but no directory for log files was created.

E.6.2. Migration to Version 14.12.2

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

> **Important**
>
> If you take backups using pg_probackup and you have previously upgraded it to version 2.8.0 Enterprise or 2.8.1 Enterprise, make sure to upgrade it to version 2.8.2 Enterprise or higher and retake a full backup after upgrade, since backups taken using those versions might be corrupted. If you suspect that your backups taken with versions 2.8.0 or 2.8.1 may be corrupted, you can validate them using version 2.8.2.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.7. Postgres Pro Enterprise 14.12.1

Release Date: 2024-05-27

E.7.1. Overview

This release is based on PostgreSQL 14.12 and Postgres Pro Enterprise 14.11.3. All changes inherited from PostgreSQL 14.12 are listed in PostgreSQL 14.12 Release Notes. As compared with Postgres Pro Enterprise 14.11.3, this version also provides the following changes:

- Disabled the system startup timeout by setting the `TimeoutSec` parameter to 0 in systemd. Previously, big databases could fail to start within the specified timeout.
- Reduced logging level during a specified restore point creation at a checkpoint timeout for inactive bases only. It allows removing excessive log messages.
- Improved performance of subsystems on top of SLRU. This includes improvements for the LWLocks that changed the locking mode for the SLRU banks, so that each bank uses a separate LWLock. This results in increased scalability. Also, a new concurrency model for SLRU implementation that uses atomic reads and writes is proposed.

- Added the cfs_log_verbose configuration parameter that controls the CFS log level of defragmentation messages. It allows reducing the number of CFS messages in the log file.
- Added the cfs_gc_lock_file configuration parameter that sets the path to the lock file to be used to ensure running only one garbage collection worker at a time for several Postgres Pro servers.
- Added the xml_parse_huge configuration parameter that allows allocating up to 1 GB of memory for processing XML data.
- Fixed a bug resulting in error “cache lookup failed for collation 128”. Now, for the additional `INCLUDE` index columns, collation is ignored.
- Fixed two planner issues. An expression duplication issue previously caused underestimation of node selectivity and cost in some cases, which could lead to a choice of a suboptimal plan. Another issue — the selectivity overestimation for an `AppendOr` node was caused by its subnode selectivity overestimation and led to the plan cost overestimation.
- Fixed an issue of not streaming certain data to a subscriber by a logical replication after executing the `ALTER PUBLICATION pub ADD TABLE tab` command. The root cause of the issue was an insufficient interlocking between `ALTER PUBLICATION` and taking a snapshot.
- Fixed an issue with the automatic aggressive vacuum being triggered too often. Now, an aggressive vacuum scan will only occur for any table with multixact-age strictly greater than autovacuum_multixact_freeze_max_age.
- Added support for Astra Linux 1.8 and ended support for Astra Linux Orel 2.12, Astra Linux Smolensk 1.6.
- Added support for Red OS Murom 8 and ended support for Red OS Murom 7.2.
- Added support for Ubuntu 24.04.
- Upgraded mamonsu to version 3.5.8, which provides optimizations and bugfixes. Notable changes are as follows:
  - Added support for the Zabbix 6.4 API: handling of deprecated parameters for authentication requests.
  - Removed caching of the `pgsql.connections[max_connections]` metric.
  - Updated the default log rotation rules.
  - Prepared for support of Python 3.12.
  - Changed metric names of the pg_locks plugin. Be aware that the changes could break custom user-defined triggers and processing functions that use the *`item.name`* parameter.
  - Fixed type mismatch for pgpro_stats and pg_wait_sampling.
  - Fixed privileges for the `mamonsu` role created by `bootstrap`.
- Upgraded orafce to version 4.10.0.
- Upgraded pg_probackup to version 2.8.0 Enterprise, which provides new features, optimizations and bug fixes. Notable changes are as follows:
  - Added a possibility to limit the rate of disk writes using the option `--write-rate-limit=bitrate (Mbps, Gbps)`.
  - Decreased the memory consumption when restoring long sequences of increments twice on average.
  - Added checksum validation for CFS files by `checkdb`.
  - Added a possibility to validate only a WAL archive.
  - Extended the use of the `--dry-run` option for all pg_probackup commands.
  - Made creation of a temporary slot during backups in the STREAM mode the default behavior unless it is specified otherwise.

    - Changed the default compression algorithm to `zstd`. If `zstd` is not supported by the system, `lz4` has the next priority. The `--compress` option now sets the default values for `--compress-level` and `--compress-algorithm`.
    - Added a possibility to specify several hosts to connect to an S3 storage.
    - Implemented a new locking technique, which enables using the locks with S3 and NFS protocols.
- Added the `pgv_exists_elem` function to pg_variables that checks whether an element with a key exists in a general collection.
- Upgraded pgpro_stats to version 1.7.1, which provides optimizations and bug fixes. Notable changes are as follows:
    - Added saving non-normalized plans to pgpro_stats for queries where previously no plans were saved.
    - Fixed an issue that hindered the monitoring when the `pgpro_stats_statements` view contained quite a few rows with the same values of `plan` and `queryid`, but different values of `planid`. The issue was caused by an error in parsing the plan tree containing a `T_Memoise` node.
- Fixed an error “ERROR: query failed: ERROR: tablespace "XXXX" does not exist” that could occur when the `pg_repack` command was trying to reorganize tables in a tablespace whose name started with a digit. The root cause of the issue was that pg_repack expected extra quotes.
- Added the `--save-fullpage` option to pg_waldump. It allows saving full-page images included in WAL records into a given target directory.

E.7.2. Migration to Version 14.12.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

Starting from Postgres Pro Enterprise 14.10.1, the privileges of `CREATEROLE` are restricted, and modification of other roles requires the role requesting the change to have the `ADMIN OPTION` permission.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.8. Postgres Pro Enterprise 14.11.3

Release Date: 2024-04-08

E.8.1. Overview

This release is based on Postgres Pro Enterprise 14.11.2 and provides the following changes:

- Increased the maximum value of the `slru_buffers_size_scale` configuration parameter to 9. In some high-load environments, the former maximum value was not sufficient and could result in query queuing and locks.

- Fixed incorrect HOT chain conversion from 32-bit to 64-bit after upgrading Postgres Pro Enterprise using pg_upgrade. The previous fix for this type of problem failed to account for changing the offset information after checking dead tuples.
- Fixed inconsistency of the `XMAX` value and the `XMAX_INVALID` hint bit of the tuple, which manifested itself in "missing chunk number 0 for toast value XXX in pg_toast_XXX" errors.
- Upgraded pgpro_pwr to version 4.5.
- Upgraded pg_probackup to version 2.7.3 Enterprise, which provides optimizations and bug fixes. Notable changes are as follows:
  - Added the `--waldir` option to the `catchup` command, which allows you to specify the directory to write WAL files to.
  - Fixed incremental restore of tables larger than 1GB. Checksum computation for file pages was fixed, so the tables will no longer be reread from the backup during restore.
  - Fixed an abnormal termination of pg_probackup upon a forced termination of a backup.
  - Fixed slow validation and restore of large databases by fixing file comparison. Previously, the file sorting algorithm used for the comparison could result in quadratic complexity.
  - Fixed an issue that could occur during a backup in the root of an S3 bucket.

E.8.2. Migration to Version 14.11.3

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.9. Postgres Pro Enterprise 14.11.2

Release Date: 2024-03-06

E.9.1. Overview

This release is based on Postgres Pro Enterprise 14.11.1 and provides the following changes:

- Fixed an issue of reusing subplans or alternative plans already released from memory that were previously passed by reference. This is solved by prohibiting the cleaning of expressions in memory. The issue could manifest itself in "unrecognized node" errors.
- Fixed incorrect handling of equivalence classes, which could cause aqo to ignore some plan nodes in complex queries.

E.9.2. Migration to Version 14.11.2

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.10. Postgres Pro Enterprise 14.11.1

Release Date: 2024-02-21

E.10.1. Overview

This release is based on PostgreSQL 14.11 and Postgres Pro Enterprise 14.10.1. All changes inherited from PostgreSQL 14.11 are listed in PostgreSQL 14.11 Release Notes. As compared with Postgres Pro Enterprise 14.10.1, this version also provides the following changes:

- Added configuration parameters to enable getting information on crashes of a backend. The crash_info parameter turns on this functionality, while crash_info_dump and crash_info_location specify the contents and location of crash information files, respectively.
- Added a new configuration parameter cfs_gc_respond_time, which allows specifying the time interval that CFS waits for the lock to be released from a file processed by garbage collector before writing a warning to the log.
- Optimized memory consumption during selectivity estimation for each array element as compared to vanilla PostgreSQL.
- Updated the default values of default_toast_compression and wal_compression to `lz4`. It speeds up WAL and TOAST processing and reduces disk space utilization.
- Fixed incorrect HOT chain conversion from 32-bit to 64-bit after upgrading Postgres Pro Enterprise using pg_upgrade. Previously, it resulted in the vacuum infinite loop. The number of vacuum retries is now limited to one per tuple. When exceeded, an error is written to the log.
- Fixed segmentation fault that could occur when executing queries or using the planner with pg_pathman running. pg_pathman did not pay attention to new fields in the `RangeTblEntry` (RTE) structure, which were not correctly initialized. By making a regular copy of a parent RTE, pg_pathman also copied pointers to parent equivalence classes or their members. This inconsistency affected query planning and caused the error.
- Fixed the race condition between the autovacuum worker and backend processes when clearing orphaned tables, which could manifest itself in “cache lookup failed for relation” errors. Now autovacuum locks the namespaces when clearing orphaned tables.
- Fixed an issue that could occur during installation of a Postgres Pro server on Debian-based systems included in a domain with the `postgres` user.
- Fixed the output of pg-setup , which erroneously displayed the locale from the `LANG` environment variable at cluster initialization. Now the message about locale is not displayed at this stage.
- Fixed an issue that could occur when a CFS garbage collection worker process failed. Because the worker did not restart automatically, the server restart was needed to continue. Now the worker gets restarted after 10 seconds of its unavailability.
- Fixed the retention of deleted files in CFS by reducing the lifetime of temporary CFS files that occur during the garbage collector work or during the `VACUUM FULL` operation.
- Ended support for Rosa Enterprise Linux Server 7.
- Ended support for ROSA COBALT (server edition) based on Rosa platform 7.
- Upgraded apache_age to version 1.5.0.
- Upgraded orafce to version 4.9.2.
- Upgraded pg_filedump to version 16.1.
- Upgraded pg_probackup to version 2.7.2 Enterprise, which provides optimizations and bug fixes. Notable changes are as follows:
  - Optimized the use of memory during backups in the remote mode.
  - Fixed an issue that occurred during an incremental backup when a table that was not yet copied got removed from CFS.
  - Fixed the order of processing WAL files by the `archive-push` command when the number of WAL files exceeds the specified `--batch-size`.
  - Fixed an error “WAL segment is absent” that could occur when the size of a WAL record being logged exceeded the size of a WAL segment.
  - Fixed a bug that occurred when creating a versioned bucket in VK Cloud.
  - Fixed segmentation fault that occurred during execution of the `merge` command in S3.
- Upgraded pg_repack to version 1.5.0.

- Upgraded pg_variables, which now provides iterator functionality for any collections, as well as functions to work with general collection variables. These functions allow accessing collection elements by a key that can have either integer or text type. These enhancements facilitate migration of Oracle code that processes collections.
- Upgraded pg_proaudit to version 2.0, which provides the following major changes and enhancements:
  - Added new functions `pg_proaudit_set_rule` and `pg_proaudit_remove_rule` that allow creating and removing logging rules, respectively. These functions replaced `pg_proaudit_set_object`, `pg_proaudit_set_role`, `pg_proaudit_reset_object`, and `pg_proaudit_reset_role`.
  - Implemented the ability to log groups of events by specifying the respective value in the *event_type* argument.
  - Added the `comment` column in the `pg_proaudit_settings` view that displays the comment to describe the created logging rule.
  - Implemented the ability to log security events related to objects of the `PREPARED STATEMENT` type as well as events of the `DEALLOCATE`, `EXECUTE`, and `PREPARE` types.
  - Fixed an issue with incorrect logging of the `CREATE DATABASE`, `CREATE GROUP`, `CREATE ROLE`, `CREATE TABLESPACE`, and `CREATE USER` security events. Previously, these events were logged as `SUCCESS` after the syntax check and before the command execution itself. Now `SUCCESS` is written in the log when the command execution finishes, and if the command fails, it is marked as `FAILURE`.
- Upgraded pgpro_stats to version 1.7, which provides optimizations and bug fixes:
  - Similarly to a pg_stat_statements fix, changed pgpro_stats to read its “query texts” file in units of at most 1GB. Such large query text files are very unusual, but if they do occur, the previous coding would fail on Windows 64 (which rejects individual read requests of more than 2GB).
  - Implemented backward compatibility of `pgpro_stats_statements` and `pgpro_stats_totals` functions. Now a newer version of the pgpro_stats shared library can be safely used with old declarations of SQL functions. Previously such cases caused a server crash.
  - Fixed an issue that prevented output of database vacuuming statistics in the `pgpro_stats_vacuum_database` view.
- Upgraded pgpro_pwr to version 4.4, which supports pgpro_stats 1.7, as well as adds more interactive features and substring-based filtering to the report.
- Upgraded the PLV8 extension to version 3.2.2.

E.10.2. Migration to Version 14.11.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

Starting from Postgres Pro Enterprise 14.10.1, the privileges of `CREATEROLE` are restricted, and modification of other roles requires the role requesting the change to have the `ADMIN OPTION` permission.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.11. Postgres Pro Enterprise 14.10.1

Release Date: 2023-11-23

E.11.1. Overview

This release is based on PostgreSQL 14.10 and Postgres Pro Enterprise 14.9.3. All changes inherited from PostgreSQL 14.10 are listed in PostgreSQL 14.10 Release Notes. As compared with Postgres Pro Enterprise 14.9.3, this version also provides the following changes:

- Added new configuration parameters pgpro_build, pgpro_edition, and pgpro_version, which report the Postgres Pro source code commit ID, edition, and server version respectively.
- Optimized memory consumption and time of performing a large number of expressions x=c_i (c_i are constants, i>= 500) joined by OR. The optimization is based on a replacement with ANY, such as replacement of x=1 OR x=2 OR x=3 with x=ANY([1,2,3]).
- Restricted the privileges of `CREATEROLE` and its ability to modify other roles. Previously roles with `CREATEROLE` privileges could change many aspects of any non-superuser role. Such changes, including adding members, now require the role requesting the change to have `ADMIN OPTION` permission. For example, they can now change the `CREATEDB`, `REPLICATION`, and `BYPASSRLS` properties only if they also have those permissions.
- Fixed an issue with physical replication, which could cause PANIC-level errors on replicas. Previously, pages with tuples recreated by a multitransaction were erroneously reinitialized, which resulted in `pd_multi_base` being set to zero.
- Fixed an issue with page pruning after upgrading Postgres Pro Enterprise cluster using pg_upgrade, which could manifest itself in “cannot fit xid into page” errors. Now updating transactions in multitransactions are taken in account so `pd_xid_base` for pages is calculated correctly.
- Fixed displaying client connection information in `pg_stat_activity` when using the built-in connection pooler. Previously, the `client_addr` values were not updated for new sessions.
- Fixed an internal issue that could arise when an index relation was moved to a different namespace similarly to a plain relation.
- Fixed too long planning that could take place when `JOIN` and index increased the number of variants to consider. Planning time was reduced by indexing equivalence classes and members of them.
- Added support for ALT SP Release 10.
- Added the apache-age extension that provides graph database functionality.
- Upgraded oracle_fdw to version 2.6.0.
- Upgraded orafce to version 4.6.1.
- Upgraded pg_filedump to version 16.0.
- Upgraded pgbouncer to version 1.20.1.
- Upgraded pg_integrity_check, which now provides three new options.
- Upgraded pg_proaudit to version 1.2, which provides the following changes:
  - Changed the name of the `CONNECT` events recorded by `pg_proaudit` to `AUTHENTICATE`.
  - Removed the `pg_proaudit.syslog_facility` and `pg_proaudit.syslog_ident` configuration parameters. Instead, the syslog_ident and syslog_facility parameters can be used.
  - Records in the syslog are now marked with `AUDIT` for clear identification.
  - Added the `db_name` argument for functions that add and delete the logging settings. This argument allows specifying the name of the database for which security events need to be logged. Also, the `role_oid` argument can now be passed with `NULL` to enable logging actions for all users.

- Upgraded pgpro_controldata to version 16.1.0.
- Upgraded pg_hint_plan to version 1.4.2.
- Upgraded pgpro_stats to version 1.6.3, which in particular fixed a code issue that prevented data generation for the `pgpro_stats_vacuum_tables` view. Accordingly the “Database vacuum statistics” table was not included in the pgpro_pwr report.
- Upgraded pg_probackup to version 2.6.7 Enterprise, which in particular improved stability of the `catchup` command.
- Upgraded PTRACK to version 2.5.1 Enterprise.
- Fixed a segmentation fault, which could occur when the background worker of the `database manager` type was not created, but pgpro_scheduler assumed the opposite and continued operation.
- Upgraded tds_fdw to version 2.0.3.

E.11.2. Migration to Version 14.10.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

Starting from Postgres Pro Enterprise 14.10.1, the privileges of `CREATEROLE` are restricted, and modification of other roles requires the role requesting the change to have the `ADMIN OPTION` permission.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.12. Postgres Pro Enterprise 14.9.3

Release Date: 2023-10-05

E.12.1. Overview

This release is based on Postgres Pro Enterprise 14.9.2 and provides the following changes:

- Added log_next_xid_assign_threshold that allows to enable logging during WAL replay when the next XID is greater than the current XID by the specified value.
- Fixed an issue with handling pages when upgrading Postgres Pro Enterprise cluster using pg_upgrade. This issue could manifest itself in “cannot fit xid into page” errors and lead to data corruption.
- Fixed an issue with an upgrade of Postgres Pro Enterprise cluster using pg_upgrade. Now empty free space map pages are not converted.

E.12.2. Migration to Version 14.9.3

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.13. Postgres Pro Enterprise 14.9.2

Release Date: 2023-09-15

E.13.1. Overview

This release is based on Postgres Pro Enterprise 14.9.1 and provides the following changes:

- Fixed two issues that could arise after upgrading Postgres Pro Enterprise using pg_upgrade. The first one resulted in incorrect conversion of multixacts from 32-bit to 64-bit transaction ID. Multixact values were erroneously incremented by 1 and files in `pg_multixact/members` and `pg_multixact/offsets` subdirectories were misaligned in some cases, which manifested itself in "found multixact XXX from before relminmxid..." errors. The second issue caused incorrect HOT chain conversion from 32-bit to 64-bit and lead to the deletion of the intermediate tuples in HOT chain, yet did not affect data.
- Fixed race conditions during resource locking caused by an oversight in a recent optimization of the CFS garbage collector, which could result in data loss. One of the symptoms was leftover `pg_depend` links referencing dropped temporary tables.
- Fixed a memory leak in mchar.

E.13.2. Migration to Version 14.9.2

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

It is strongly recommended to avoid migrating a cluster with 32-bit transaction IDs to Postgres Pro Enterprise versions below 14.9.2, if there are multitransactions in your database, as it may cause data corruption.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.14. Postgres Pro Enterprise 14.9.1

Release Date: 2023-08-23

E.14.1. Overview

This release is based on PostgreSQL 14.9 and Postgres Pro Enterprise 14.8.1. All changes inherited from PostgreSQL 14.9 are listed in PostgreSQL 14.9 Release Notes. As compared with Postgres Pro Enterprise 14.8.1, this version also provides the following changes:

- Added the generic_plan_fuzz_factor configuration parameter. This parameter sets the plan cost calculation coefficient of the planner, which increases the probability that the generic or custom plan will be selected more often.
- Added the enable_appendorpath configuration parameter, which enables the `Append` plan for `OR` clauses. It is useful for applications with auto-generated queries.
- Fixed logical replication to a Postgres Pro Enterprise server from servers of different editions: PostgreSQL or Postgres Pro Standard of the same or a previous version.

- Fixed a segmentation fault, which occurred during `SELECT` queries and was caused by an oversight in the previous bugfix related to self join removal optimization.
- Fixed an issue with calculating the page base for 64-bit XIDs. In some rare cases, it could lead to a transaction failure or to an incorrect `xmin`, which manifested itself in errors, such as “Fatal xid base calculation error”.
- Fixed an issue that could cause the `pg_database_size` function to return incorrect database size, which was different from the actual disk space, when using the CFS. Previously, the size of CFS sparse files was calculated using the logical file size rather than the physical file size in data blocks.
- Fixed states of non-CFS background workers displayed in the `pg_stat_activity` view. The worker status is now set correctly after garbage collection.
- Fixed an issue in pgpro_scheduler with supervisor scheduler removing the `database manager` data before its initialization, which could lead to the manager exiting with an error “Scheduler manager XX: cannot find information about self in scheduler_state”.
- Added support for Debian 12 and ended support for Debian 9.
- Fixed an outdated recommendation to customize a unit file in the `postgrespro-ent-14.service` file comments.
- Fixed the optimizer estimation of the number of tuples with the same hash key. The optimizer did not take into account that in a join by a large number of columns, the number of unique hash keys must rapidly grow, considered the number of hash keys to be small and finally chose merge join instead of hash join.
- Fixed usage of the `joinsel` component, which is needed for a more accurate cardinality estimation by several columns. If for some reason (for example, because of insufficient detailed statistics) `joinsel` cannot make a good prediction, Postgres Pro will not use `joinsel` in this particular case, but estimate cardinality using a regular algorithm. If `joinsel` has to estimate cardinality by a single column, a regular algorithm will also be used instead.
- Fixed a bug that did not allow storing data of the `mchar`, `mvarchar` types larger than 250 MB. Now up to 1 GB of data of these types can be stored correctly.
- Upgraded pg_probackup to version 2.6.5 Enterprise, which provides the following optimizations and bug fixes:
  - An attempt of a partial restore to a non-empty `PGDATA` directory now completes with an error, but a possibility of such a restore is retained with the `--destroy-all-other-dbs` flag specified.
  - Fixed inclusion of allocated but empty pages in an incremental backup.
  - Fixed point-in-time recovery issues:
    - Restore on the recovery time specified by the `pg_probackup show` command
    - Restore from backups with the `--recovery-target-timeline` and `--no-validate` options
  - Improved processing of files in compressed tablespaces by the PTRACK module.
  - Renamed the `--skip-if-exist` flag to `--skip-if-exists`.
- Upgraded pg_hint_plan to include a bugfix related to hint stack corruption.
- Upgraded pgpro_pwr to version 4.2, which adds interactive features to the report.
- Upgraded PTRACK to version 2.5 Enterprise.

E.14.2. Migration to Version 14.9.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.15. Postgres Pro Enterprise 14.8.1

Release Date: 2023-06-06

E.15.1. Overview

This release is based on PostgreSQL 14.8 and Postgres Pro Enterprise 14.7.1. All changes inherited from PostgreSQL 14.8 are listed in PostgreSQL 14.8 Release Notes. As compared with Postgres Pro Enterprise 14.7.1, this version also provides the following changes:

- Implemented lock deduplication that allows to effectively store in memory and track all exclusive locks held by a standby server's startup process during WAL replay.
- Fixed pruning logic to slightly improve performance.
- Optimized CFS garbage collector: reduced CPU costs and reads from disk during file analysis.
- Added the unicode_nul_character_replacement_in_jsonb configuration parameter to replace `'\u0000'` with the specified unicode character when calling a function processing JSONB.
- Improved performance of DDL operations on temporary tables. When `max_connections` is high, the costs to acquire locks for the tables that are marked `ON COMMIT DELETE ROWS` are now reduced due to the change of the locking mechanism.
- Added an operation log, which stores information about system events such as an upgrade, execution of pg_resetwal and so on, which is highly useful for vendor's technical support. Recording to the operation log is only done at the system level, and SQL functions are used to read it. (See Section 9.27.12.)
- Fixed an issue in the connection pooler, which could cause backend termination if the client aborted the connection during authentication.
- Fixed an issue with much larger CFS data files on the replica compared to the primary. Now the replica writes the files in the same way as the primary when consistent recovery state is reached.
- Fixed an internal error that occurred during a self join removal. Previously, it was not taken into account that when an expression “A.x=B.x” was transformed to “A.x IS NOT NULL”, it was necessary to correct meta parameters of the transformed expression because of its different semantics. In particular, the initial expression can be used in cases such as selection of an attribute to sort by or being a `JOIN` parametrization expression, but this is inapplicable for the transformed expression.
- Removed the deprecated configuration parameter `cfs_gc_verify_file` from `postgresql.conf`. The configuration parameter `cfs_encryption` is deprecated and will be removed in a future release.
- Added support for ROSA Chrome 2021.2.
- Ended support for Ubuntu 18.04.
- Upgraded mamonsu to version 3.5.3, which provides new features and bugfixes. Notable changes are as follows:
  - Removed the limitation that did not allow a user different from `mamonsu` to read and edit the configuration file `agent.conf`. Specifically, the pg_probackup plugin now works correctly when the `mamonsu` user owns the pg_probackup backup directory.
  - Removed metrics that conflict native Zabbix agents from Zabbix configuration file being exported.

  - Fixed mamonsu choice of the default extension to collect statistics. Now when pgpro_stats and pg_stat_statements are both installed, pgpro_stats is correctly treated as the default one.
  - Added a check that the server where mamonsu WAL plugin runs is not in recovery.
- Excluded `CREATE TABLESPACE` and `DROP TABLESPACE` from multimaster replication. These commands should be executed separately on each peer node.
- Upgraded pg_hint_plan to version 1.4.1, which provides the `hints_anywhere` parameter that allows to place hints anywhere in the query.
- Upgraded pg_probackup to version 2.6.4 Enterprise, which provides optimizations and bug fixes. Lower versions are incompatible with Postgres Pro Enterprise 14.8.1. Notable changes are as follows:
  - Included the `catchup` command, which was previously provided only in a test mode, in the production delivery.
  - Added optimizations for incremental backups that reduce disk read amount almost twice.
  - Improved error and warning messaging and unified the error message style.
  - Fixed issues and improved the reliability of CFS table `merge` and `backup` operations.
  - Fixed usability issues with the `show` command, in particular: fixed displaying the recovery time, which could sometimes not be displayed after a successful backup; made the backup time be displayed in a table view even if the backup ended with an error.
  - Fixed an error in specifying the relative path after restoring a cluster from a backup.
  - Corrected an improper assignment of backup IDs that took place in some cases.
  - Added an option to skip creation or initialization of an existing backup instance.
  - Fixed an issue with inclusion of the whole data in an incremental backup rather than only the changed data.
- Upgraded pgpro_stats to version 1.6, which provides new features and bugfixes:
  - Implemented tracing of application sessions, based on filters, which trigger logging the execution of queries that match filtering conditions. You can use pgpro_stats functions to create, update or delete query filters. (See Section G.3.8.1 for details.)
  - Added functions for superuser to create views that emulate pg_stat_statements and *pg_stat_kcache* extensions. Specifically, `pg_stat_statements`, `pg_stat_statements_info`, `pg_stat_kcache` and `pg_stat_kcache_detail` views can be created. Once they are created, you can work with them as if the appropriate extension is installed. (See Section G.3.6.1 for details.)
  - Added `pgpro_stats_archiver` view, which extends the pg_stat_archiver view by adding two fields, showing overall time that the archiver process was active and overall execution time of the archive command.
  - Implemented backward compatibility of the vacuum statistics interface. Now a newer version of the pgpro_stats shared library can be safely used with old declarations of SQL functions. Previously such cases caused a server crash.
  - Fixed possible server crashes that could occur due to `PGDATA` overflow when in pgpro_stats, one or several long queries were executed. Now instead of storing query texts in a temporary file located in the `PGDATA/pg_stat_tmp` directory, it is possible to choose the directory with the external file to store query texts by setting the value of the `pgpro_stats.stats_temp_directory` configuration parameter. If you wish, you can set this value equal to the value of the system configuration parameter `stats_temp_directory`. But keep in mind that `pgpro_stats.stats_temp_directory` can only be set at the server start.
- Upgraded pgpro_pwr to version 4.1.3, which supports pgpro_stats 1.6 and provides the following new features:
  - Added report tables “Top tables by removed all-visible/all-frozed marks”.

  - Added a few new fields to the “Cluster Statistics” report table.
- Upgraded PTRACK to version 2.4.3.
- Upgraded orafce to version 4.2.6.

E.15.2. Migration to Version 14.8.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

When upgrading to Postgres Pro Enterprise versions starting with 14.8.1, make sure to upgrade pg_probackup Enterprise to version 2.6.4 or higher since lower versions are incompatible with these Postgres Pro Enterprise versions.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.16. Postgres Pro Enterprise 14.7.1

Release Date: 2023-03-07

E.16.1. Overview

This release is based on PostgreSQL 14.7 and Postgres Pro Enterprise 14.6.1. All changes inherited from PostgreSQL 14.7 are listed in PostgreSQL 14.7 Release Notes. As compared with Postgres Pro Enterprise 14.6.1, this version also provides the following changes:

- Added enable_large_mem_buffers that allows to copy and dump large `bytea` and `text` values. This parameter can be defined only for the current session. `--enable-large-mem-buffers` option for pg_dump and pg_dumpall was also added. pg_restore can restore such values by default now.
- Improved performance impacted by numerous cache resets by reducing the number of invalidation messages regarding temporary tables sent from backends to each other.
- Fixed a segmentation fault, which might have occurred in PL/pgSQL when trying to remove a separate field of a composite type upon completion of an autonomous transaction.
- Added support for ROSA COBALT Server 7.9 and ended support for ROSA COBALT Server 7.3.
- Fixed suboptimal memory usage in optimizing a query that included a pretty large number of `UNION ALL` subqueries. This planner issue was due to a vanilla PostgreSQL issue with replacing placeholder variables in a special case of flattening `UNION ALL` leaf queries.
- Fixed performance degradation that was observed when running queries on a replica where old_snapshot_threshold > 0. It appeared that the issue could be encountered not only there, but was more obvious on replicas.
- Upgraded aqo to version 1.6, which provides the following new features:
  - Introduced *smart statement timeout*, which is needed to limit the execution time when manually training aqo on special queries with a poor cardinality forecast and which aqo can dynamically change during this training.
  - Added `aqo_query_stat_update`, `aqo_data_update` and `aqo_query_texts_update` functions to update or insert a record in data files underlying the respective view.
  - Added `aqo_memory_usage` function to display the memory size required for aqo.
  - Renamed `aqo_enable_query` and `aqo_disable_query` functions to `aqo_enable_class` and `aqo_disable_class`, respectively.

- Fixed an issue with autovacuum not running on unused primaries in multimaster. Now logical replication correctly updates information in `pg_stat`.
- Upgraded pg_probackup to version 2.6.1 Enterprise, which provides the following features:
  - Optimized pg_probackup input/output engine to improve performance.
  - Added Simple Storage Service (S3) support for storing data in private clouds. S3 interface was tested with MinIO object storage and VK Cloud storage. Note that pg_probackup provides complete processing of S3 interface logging.
  - Added CFS (Compressed File System) support for incremental backups in `DELTA`, `PAGE`, and `PTRACK` modes. `PTRACK` mode requires PTRACK 2.4.0 or higher and is recommended as the fastest mode for incremental backups.
  - Added support for lz4 and zstd compression algorithm.
  - Ended support for Postgres Pro 9.6.
- Upgraded PTRACK to version 2.4.1.
- Upgraded pgbouncer to version 1.18.
- Upgraded pgpro_scheduler to version 2.9, which provides the following changes:
  - Fixed the `schedule.resubmit` function to save the state of the executed job correctly. Also, this function can now accept 0 as the time interval, in this case the job is resubmmitted immediately after execution.
  - Fixed an issue with the `schedule.timetable` function, which previously caused an error when the function was called by any superuser other than `postgres`.
- Updraded pgpro_stats to version 1.5, which provides new features and bugfixes:
  - Added computation of statistics on removal of all-frozen and all-visible marks in the visibility map.
  - Added the `pgpro_stats_vacuum_database` view, showing statistics about vacuuming each database in a cluster.
  - Fixed possible crash of a server where `pgpro_stats.track` was set to `all` that could occur when pgpro_stats processed a function body as a multistatement query.
  - Fixed inappropriate issuing of an “unrecognized expression node type: ...” warning in case a query plan contained a GatherMerge node.
  - Fixed too long execution of a query containing texts of JSON or XML documents of a special kind. The slowdown was possible because normalization of the query plan text could mistakenly include replacement of constants inside those documents.
- Upgraded pgpro_pwr to version 4.1.2.
- Upgraded the PLV8 extension to version 3.1.5.

E.16.2. Migration to Version 14.7.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.17. Postgres Pro Enterprise 14.6.1

Release Date: 2022-12-16

E.17.1. Overview

This release is based on PostgreSQL 14.6 and Postgres Pro Enterprise 14.5.2. All changes inherited from PostgreSQL 14.6 are listed in PostgreSQL 14.6 Release Notes. As compared with Postgres Pro Enterprise 14.5.2, this version also provides the following changes:

- Added ignore_event_trigger that allows to disable event triggers temporarily.
- Added slru_buffers_size_scale that allows to scale the size of SLRU shared memory buffers. Note that the buffer sizes changed due to this improvement.
- Improved garbage collection logic in CFS. Now percent of garbage is calculated based on file size rounded to 4 kB (typical filesystem block size) instead of raw file size, which prevents frequent defragmentation of small files.
- Added support for Elbrus CPU architecture through ALT 9/10 for e2kv3/e2kv4, ALT 8.2 SP for e2kv3/e2kv4 and Astra Linux Leningrad 8.1 operating systems. You are recommended to use the 5.4.182-mcst-e8c-alt3.22.1 Linux kernel or newer when running ALT 10 for e2kv3/e2kv4.
- Fixed an issue with password authentication when using the connection pooler, which manifested itself in “authentication identifier set more than once” errors.
- Fixed an issue with physical replication, which could lead to a replica crash in rare cases. Previously, WAL records on update and init of heap pages did not contain `pd_multi_base` so incorrect `xmax` values could be set.
- Fixed huge selectivity overestimation observed in rare cases, which could result in a sequential scan of a whole relation instead of a quick index scan, so certain queries were executed much more slowly than expected. The issue was due to an oversight in a recent optimization of selectivity estimation.
- Fixed bursts in the `checkpoint_req` counter of the `pg_stat_bgwriter` view on a replica that occurred from time to time due to a series of unsuccessful attempts to create a restartpoint. The fix checks in advance whether an attempt to create a restartpoint will fail and thus prevents from making obviously unsuccessful attempts. Note that the issue did not cause excessive consumption of system resources even before it was fixed.
- Fixed compatibility of in_memory with autonomous transactions.
- Fixed an issue in psql, which mistakenly treated the `\duS` and `\duS+` meta-commands as invalid. Both meta-commands list database roles, including system roles, with a different level of detail, and correctly processed `\dgS+` and `\du+S` (respectively) could be used instead even before the issue was fixed.
- Upgraded aqo to version 1.5, which contains bugfixes and the following changes:
  - Switched to storing the knowledge base on disk outside of the database. Previously it was stored in Postgres Pro tables.
  - Made aqo relocatable.
  - Added functions to analyze the quality of query planning.
  - Added a possibility to learn from partially completed queries, namely, from those that timed out (see statement_timeout).
  - Made aqo use the same query ID as other extensions. So aqo and pg_stat_statements can be used simultaneously, sharing the same query IDs.
  - Enabled aqo work with temporary tables.
  - Fixed a few memory leaks.
  - Added alpha version of a new feature: search by neighbors (off by default). It allows applying knowledge to newly added queries with a different structure.
- Upgraded mamonsu to version 3.5.2, which provides new features and bugfixes. Notable changes are as follows:

    - Added autovacuum utilization metrics.
    - Added Zabbix macros based on plugin parameters from the configuration file, so that triggers can now be dynamically changed directly in Zabbix without updating the configuration file and restarting mamonsu.
- The multimaster extension is considered as ready-to-use. Notable changes are as follows:
    - Implemented transaction deadlock prevention mechanism managed by the `multimaster.deadlock_prevention` configuration parameter. It allows to avoid situations when transactions might not actually run in case of many conflicts due to long deadlock resolution time.
    - Fixed states of `multimaster` apply workers displayed in the `pg_stat_activity` view. After applying transactions, the worker status is now set to `Idle` instead of `Active`.
    - Fixed an issue, which could result in isolation of all `multimaster` cluster nodes after dropping any node and adding a new node to the cluster.
- Added the oracle_fdw extension to Windows versions of Postgres Pro.
- Upgraded pg_probackup to version 2.5.10, which provides optimizations and bugfixes. Notable changes are as follows:
    - Optimized `*.cfm` files backup by truncating trailing zeroes.
    - Fixed an issue with `checkdb --amcheck`, which previously completed with an error when the checked database contained partitioned indexes.
    - Fixed a backup failure on a replica that occurred because the version of the pg_probackup agent running there was different from that on the primary.
- Upgraded pgpro_pwr to version 4.1, which mainly adds JIT-related statistics to report tables.
- Upgraded pgpro_scheduler to version 2.8. This version introduces the schedule.timetable() function, which returns all the jobs, both scheduled and one-time, within the specified time interval.
- Upgraded pgpro_stats to version 1.4.3, which provides bugfixes. In particular:
    - Fixed possible server crashes that could occur during query text normalization when an extended protocol was used.
- Added tds_fdw extension that provides a foreign data wrapper to connect to Microsoft SQL Server and other databases that use the Tabular Data Stream (TDS) protocol.

E.17.2. Migration to Version 14.6.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.18. Postgres Pro Enterprise 14.5.2

Release Date: 2022-10-06

E.18.1. Overview

This release is based on Postgres Pro Enterprise 14.5.1. and provides the following changes:

- Fixed a bug in the logic of epoch shifting. The previous bug fix, which involved delta page replication, might have interfered with another issue, resulting in data corruption. Now full page replication is triggered.

- Fixed a segmentation fault, which could occur on a replica due to inconsistent page fragmentation. During pruning, actions on dead tuples could differ on the primary and the standby upon WAL replay, causing page inconsistency.
- Fixed an issue with queries that could time out due to long lock waits. Previously, index type names were locked in temporary tables during index creation.

E.18.2. Migration to Version 14.5.2

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

> **Important**
>
> If you have previously migrated to Postgres Pro Enterprise 14.5.1, or suspect data corruption on your replica, it is strongly recommended that you recreate the replica.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.19. Postgres Pro Enterprise 14.5.1

Release Date: 2022-09-08

E.19.1. Overview

This release is based on PostgreSQL 14.5 and Postgres Pro Enterprise 14.4.1. All changes inherited from PostgreSQL 14.5 are listed in PostgreSQL 14.5 Release Notes. As compared with Postgres Pro Enterprise 14.4.1, this version also provides the following changes:

- Fixed a segmentation fault, which occurred during logical replication when a trigger fired on data modification on the replica, and an error was thrown inside the trigger function.
- Fixed various issues in pg_upgrade. In particular, now free space maps and visibility maps are handled correctly during the upgrade.
- Fixed a bug in the logic of epoch shifting, which didn't take into account the `XMAX_INVALID` hint bit of the tuple. Previously, it could lead to a sudden increase of the current transaction ID.
- Resolved an issue that caused an error “duplicate key value violates unique constraint” when indexing a database in multiple threads. Now the chosen name of a type being created for the index gets locked to avoid choosing the same name in a parallel process.
- Resolved an issue in the planner's use of the compound indexes statistics: the optimizer reduced the cost prediction accuracy for a query plan if in the `WHERE` clause of the query, values of different types were compared (for example: `integer` and `numeric`, `text` and `name`). Sometimes, for certain combinations of the compared types and values, the issue could cause a server crash.
- Added support for Red Hat Enterprise Linux 9 and its derivatives: Rocky Linux 9, Oracle Linux 9, and AlmaLinux 9.
- Upgraded mamonsu to version 3.5.1. Notable changes are as follows:
  - Enabled mamonsu plugins to use pgpro_stats to collect statistics.
  - Resolved the security issue of exposing passwords through the configuration file. Only `mamonsu` user can access `agent.conf` now.
  - Fixed metrics computation that caused “float division by zero” errors in the mamonsu STATEMENTS plugin.
- Upgraded pg_probackup to version 2.5.7, which provides the following new features and bugfixes:

  - Enabled output of logs in the JSON format by adding new logging options.
  - Added an option to explicitly specify the directory where the `restore` command should restore WAL records.
  - Changed the level of detail of logging some messages of pg_probackup commands to add user convenience to reading logs.
  - Fixed pg_probackup hanging that could occur when the `ControlMaster` option was specified in the SSH `config` file. Now the value of `ControlMaster` is explicitly set to “no”.
- Upgraded pgpro_pwr to version 4.0.
- Added the oracle_fdw package for Red OS Murom 7.3.

E.19.2. Migration to Version 14.5.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

If you are migrating to the current major version of Postgres Pro Enterprise using pg_upgrade, and you want to keep the existing visibility map representation in pageinspect, you should run the `VACUUM` command before the upgrade.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.20. Postgres Pro Enterprise 14.4.1

Release Date: 2022-06-21

E.20.1. Overview

This release is based on PostgreSQL 14.4 and Postgres Pro Enterprise 14.2.1. All changes inherited from PostgreSQL 14.4 are listed in PostgreSQL 14.4 Release Notes. As compared with Postgres Pro Enterprise 14.2.1, this version also provides the following changes:

- Changed the algorithm of composite type name generation. This fixes an issue in the code of vanilla PostgreSQL, which strictly limits the number of tables with the same long prefix in names.
- Added support for Ubuntu 22.04.
- Ended support for OSnova 2.0.
- Made the pg_freespacemap `pg_freespace` function display the correct amount of free space on pages for tables in CFS tablespaces. The function is now implemented in C instead of SQL used before.
- Upgraded pg_probackup to version 2.5.6, which provides the following new features and bugfixes as compared to version 2.5.5:
  - Added the `--dry-run` flag to the `catchup` command to allow you to estimate the size of data files to be transferred, but make no changes on disk.
  - Changed the level of detail of logging some `catchup` messages for user convenience of log reading.
  - Fixed a bug that prevented correct rereading of a block after a message “File: ... blknum ... have wrong checksum, try again” was issued.
- Upgraded PTRACK to version 2.3.0, optimizing PTRACK map loading, which previously in some cases could considerably slow down overall database loading. A substantial speed-up is observed for large-size maps.
- Upgraded pgpro_stats to version 1.4, which provides the following new features and bugfixes:

    - Added `pgpro_stats_vacuum_tables` and `pgpro_stats_vacuum_indexes` views, which show statistics about vacuuming tables and indexes, respectively. Functions with the same names, which define these views for any specified database and table/index, are also added and can return statistics about vacuuming all tables/indexes in the specified database too.
    - Fixed a bug in extra shared memory allocation. The size of this memory was calculated with an error, which could cause memory corruption, incorrect computation of statistics or even a server crash.
    - Fixed an issue that caused a server crash when queries that only differ in constants contained in the query text were sent one after another through the extended query protocol.
- Upgraded pgpro_pwr to version 3.9, which provides the following new features and bugfixes:
    - Added statistics on invalidation messages and on vacuuming tables and indexes to the report.
    - Optimized retention handling for obsolete dictionary entries in the pgpro_pwr historical repository.
    - Fixed the type of value in calculating the wait time while taking a sample. This prevents a yet unlikely integer overflow error.
- Renamed the vops-specific `unnest()` function with conflicting definition to `vops_unnest()`.

E.20.2. Migration to Version 14.4.1

If you are upgrading from a Postgres Pro Enterprise release based on the same PostgreSQL major version, it is enough to install the new version into your current installation directory.

To migrate from PostgreSQL, as well as Postgres Pro Standard or Postgres Pro Enterprise based on a previous PostgreSQL major version, see the migration instructions for version 14.

E.21. Postgres Pro Enterprise 14.2.1

Release Date: 2022-05-13

E.21.1. Overview

This release is based on PostgreSQL 14.2 and includes all the new features introduced in PostgreSQL 14, as well as bug fixes implemented in PostgreSQL 14.1 and 14.2 updates. For the detailed description, see PostgreSQL 14, PostgreSQL 14.1 and PostgreSQL 14.2 Release Notes, respectively.

For the list of extension modules and utilities specific to Postgres Pro Enterprise, as well as the main user-visible core changes over vanilla PostgreSQL, see Section 2. As compared to Postgres Pro Enterprise 13.6.1, the following differences are worth mentioning:

- Implemented event triggers, which fire when an authenticated user logs in. For example, this feature can be used for verifying the connection and assigning roles according to circumstances, or for session data initialization.
- Inherited the vanilla implementation of periodic verification of client-server connection during query execution. The corresponding `client_connection_check_interval` parameter is effectively disabled by default now.
- Fixed a security bug (CVE-2022-1552).
- Removed the infrastructure for minor version upgrades without a server restart as a different approach to this feature is to be considered in the foreseeable future.
- Implemented the evaluation-only version of the multimaster extension for now.
- Implemented collecting statistics about vacuuming tables and indexes. The collected information is displayed in pgpro_stats views.
- Upgraded pgpro_pwr to version 3.8, which particularly adds statistics on invalidation messages and on vacuuming tables and indexes to the report.

E.21.2. Migration to Version 14

You can migrate to Postgres Pro Enterprise 14 from the same or a previous version of PostgreSQL (that is supported by the upgrade method chosen) or Postgres Pro Standard/Postgres Pro Standard Certified and from a previous version of Postgres Pro Enterprise/Postgres Pro Enterprise Certified. The same holds for migration to Postgres Pro Enterprise Certified 14. See Section 18.6 for the methods to upgrade your database cluster. Consult the Postgres Pro Enterprise support team if you experience issues during migration. Backward migration is not supported. Note that migration from Postgres Pro Enterprise to Postgres Pro Enterprise Certified of the same major version (or vice versa) is an update between Postgres Pro compatible versions (see Section 18.6 for more details).

To migrate from PostgreSQL, Postgres Pro Standard, or Postgres Pro Enterprise release based on a previous PostgreSQL major version, make sure to install its latest available minor version and then perform a dump/restore using pg_dumpall or use the pg_upgrade utility:

- If you choose to run pg_upgrade, make sure to initialize the new database cluster with compatible parameters. In particular, pay attention to the provider of the default collation and the checksum settings in the cluster you are migrating from. If pg_upgrade creates any SQL files in its current directory, run these files to complete the upgrade.
- If you are opting for a dump/restore, do not forget to use the `--add-collprovider` option to correctly choose the provider for the default collation of the migrated database.

To find out the default collation and its provider in the original cluster, see the `datcollate` value for the `template0` database in the pg_database catalog. If you are upgrading from a version where provider of the default collation is not specified, use `libc` provider if upgrading from vanilla PostgreSQL, and omit the provider if upgrading from earlier versions of Postgres Pro.

When migrating from PostgreSQL or Postgres Pro Standard, make sure to pay special attention to implementation specifics of 64-bit transaction IDs. If you have used explicit casts to 32-bit integers when handling transaction IDs, you have to replace them with casts to `bigint` since 64-bit transaction IDs are of the `bigint` type.

> **Note**
>
> To avoid conflicts on Linux systems, do not use the `postgrespro-ent-14` package to install the new Postgres Pro binaries. Use the individual packages instead. In this case, server autostart needs to be enabled manually, if required. For details on the available packages and installation instructions, see Chapter 17.

For other upgrade requirements imposed by vanilla PostgreSQL, see Section E.40.

E.22. Release 14.18

Release date: 2025-05-08

This release contains a variety of fixes from 14.17. For information about new features in major release 14, see Section E.40.

E.22.1. Migration to Version 14.18

A dump/restore is not required for those running 14.X.

However, if you have any self-referential foreign key constraints on partitioned tables, it may be necessary to recreate those constraints to ensure that they are being enforced correctly. See the second changelog entry below.

Also, if you have any BRIN bloom indexes, it may be advisable to reindex them after updating. See the third changelog entry below.

Also, if you are upgrading from a version earlier than 14.14, see Section E.26.

E.22.2. Changes

- Avoid one-byte buffer overread when examining invalidly-encoded strings that are claimed to be in GB18030 encoding (Noah Misch, Andres Freund)

  While unlikely, a SIGSEGV crash could occur if an incomplete multibyte character appeared at the end of memory. This was possible both in the server and in libpq-using applications. (CVE-2025-4207)

- Handle self-referential foreign keys on partitioned tables correctly (Álvaro Herrera)

  Creating or attaching partitions failed to make the required catalog entries for a foreign-key constraint, if the table referenced by the constraint was the same partitioned table. This resulted in failure to enforce the constraint fully.

  To fix this, you should drop and recreate any self-referential foreign keys on partitioned tables, if partitions have been created or attached since the constraint was created. Bear in mind that violating rows might already be present, in which case recreating the constraint will fail, and you'll need to fix up those rows before trying again.

- Avoid data loss when merging compressed BRIN summaries in `brin_bloom_union()` (Tomas Vondra)

  The code failed to account for decompression results not being identical to the input objects, which would result in failure to add some of the data to the merged summary, leading to missed rows in index searches.

  This mistake was present back to v14 where BRIN bloom indexes were introduced, but this code path was only rarely reached then. It's substantially more likely to be hit in v17 because parallel index builds now use the code.

- Fix unexpected “attribute has wrong type” errors in `UPDATE`, `DELETE`, and `MERGE` queries that use whole-row table references to views or functions in `FROM` (Tom Lane)

- Prevent failure in `INSERT` commands when the table has a `GENERATED` column of a domain data type and the domain's constraints disallow null values (Jian He)

  Constraint failure was reported even if the generation expression produced a perfectly okay result.

- Correctly process references to outer CTE names that appear within a `WITH` clause attached to an `INSERT`/`UPDATE`/`DELETE`/`MERGE` command that's inside `WITH` (Tom Lane)

  The parser failed to detect disallowed recursion cases, nor did it account for such references when sorting CTEs into a usable order.

- Fix `ARRAY(`*`subquery`*`)` and `ARRAY[`*`expression`*`, ...]` constructs to produce sane results when the input is of type `int2vector` or `oidvector` (Tom Lane)

  This patch restores the behavior that existed before PostgreSQL 9.5: the result is of type `int2vector[]` or `oidvector[]`.

- Fix possible erroneous reports of invalid affixes while parsing Ispell dictionaries (Jacob Brazeal)

- Fix `ALTER TABLE ADD COLUMN` to correctly handle the case of a domain type that has a default (Jian He, Tom Lane, Tender Wang)

  If a domain type has a default, adding a column of that type (without any explicit `DEFAULT` clause) failed to install the domain's default value in existing rows, instead leaving the new column null.

- Improve the error message for disallowed attempts to alter the properties of a foreign key constraint (Álvaro Herrera)

- Avoid error when resetting the `relhassubclass` flag of a temporary table that's marked `ON COMMIT DELETE ROWS` (Noah Misch)

- Fix planner's failure to identify more than one hashable ScalarArrayOpExpr subexpression within a top-level expression (David Geier)

  This resulted in unnecessarily-inefficient execution of any additional subexpressions that could have been processed with a hash table (that is, `IN`, `NOT IN`, or `= ANY` clauses with all-constant right-hand sides).
- Disable “skip fetch” optimization in bitmap heap scan (Matthias van de Meent)

  It turns out that this optimization can result in returning dead tuples when a concurrent vacuum marks a page all-visible.
- Fix performance issues in GIN index search startup when there are many search keys (Tom Lane, Vinod Sridharan)

  An indexable clause with many keys (for example, `jsonbcol ?| array[...]` with tens of thousands of array elements) took $O(N^2)$ time to start up, and was uncancelable for that interval too.
- Detect missing support procedures in a BRIN index operator class, and report an error instead of crashing (Álvaro Herrera)
- Respond to interrupts (such as query cancel) while waiting for asynchronous subplans of an Append plan node (Heikki Linnakangas)

  Previously, nothing would happen until one of the subplans becomes ready.
- Fix race condition in handling of `synchronous_standby_names` immediately after startup (Melnikov Maksim, Michael Paquier)

  For a short period after system startup, backends might fail to wait for synchronous commit even though `synchronous_standby_names` is enabled.
- Fix `pg_strtof()` to not crash with null endptr (Alexander Lakhin, Tom Lane)
- Avoid crash when a Snowball stemmer encounters an out-of-memory condition (Maksim Korotkov)
- Skip WAL recycling and preallocation during archive recovery, to avoid corruption of WAL files that were restored from the archive (Noah Misch, Arun Thirupathi)

  This change back-patches v15-era fixes that were considered largely cosmetic at the time, but turn out to prevent data corruption in the wake of subsequent fixes.
- Prevent over-advancement of catalog xmin in “fast forward” mode of logical decoding (Zhijie Hou)

  This mistake could allow deleted catalog entries to be vacuumed away even though they were still potentially needed by the WAL-reading process.
- Avoid data loss when DDL operations that don't take a strong lock affect tables that are being logically replicated (Shlok Kyal, Hayato Kuroda)

  The catalog changes caused by the DDL command were not reflected into WAL-decoding processes, allowing them to decode subsequent changes using stale catalog data, probably resulting in data corruption.
- Avoid duplicate snapshot creation in logical replication index lookups (Heikki Linnakangas)
- Fix assertion failure in snapshot building (Masahiko Sawada)
- Fix overly-strict assertion in `gistFindCorrectParent()` (Heikki Linnakangas)
- Fix rare assertion failure in standby servers when the primary is restarted (Heikki Linnakangas)
- In PL/pgSQL, avoid “unexpected plan node type” error when a scrollable cursor is defined on a simple `SELECT` *`expression`* query (Andrei Lepikhov)
- Don't try to drop individual index partitions in pg_dump's `--clean` mode (Jian He)

  The server rejects such `DROP` commands. That has no real consequences, since the partitions will go away anyway in the subsequent `DROP`s of either their parent tables or their partitioned index.

However, the error reported for the attempted drop causes problems when restoring in `--single-transaction` mode.

- In pg_dumpall, avoid emitting invalid role `GRANT` commands if `pg_auth_members` contains invalid role OIDs (Tom Lane)

  Instead, print a warning and skip the entry. This copes better with catalog corruption that has been seen to occur in back branches as a result of race conditions between `GRANT` and `DROP ROLE`.

- In pg_amcheck and pg_upgrade, use the correct function to free allocations made by libpq (Michael Paquier, Ranier Vilela)

  These oversights could result in crashes in certain Windows build configurations, such as a debug build of libpq used by a non-debug build of the calling application.

- Allow `contrib/dblink` queries to be interrupted by query cancel (Noah Misch)

  This change back-patches a v17-era fix. It prevents possible hangs in `CREATE DATABASE` and `DROP DATABASE` due to failure to detect deadlocks.

- Avoid crashing with corrupt input data in `contrib/pageinspect`'s `heap_page_items()` (Dmitry Kovalenko)

- Prevent assertion failure in `contrib/pg_freespacemap`'s `pg_freespacemap()` (Tender Wang)

  Applying `pg_freespacemap()` to a relation lacking storage (such as a view) caused an assertion failure, although there was no ill effect in non-assert builds. Add an error check to reject that case.

- Fix build failure on macOS 15.4 (Tom Lane, Peter Eisentraut)

  This macOS update broke our configuration probe for `strchrnul()`.

- Update time zone data files to tzdata release 2025b for DST law changes in Chile, plus historical corrections for Iran (Tom Lane)

  There is a new time zone America/Coyhaique for Chile's Aysén Region, to account for it changing to UTC-03 year-round and thus diverging from America/Santiago.

E.23. Release 14.17

Release date: 2025-02-20

This release contains a few fixes from 14.16. For information about new features in major release 14, see Section E.40.

E.23.1. Migration to Version 14.17

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.14, see Section E.26.

E.23.2. Changes

- Improve behavior of libpq's quoting functions (Andres Freund, Tom Lane)

  The changes made for CVE-2025-1094 had one serious oversight: `PQescapeLiteral()` and `PQescapeIdentifier()` failed to honor their string length parameter, instead always reading to the input string's trailing null. This resulted in including unwanted text in the output, if the caller intended to truncate the string via the length parameter. With very bad luck it could cause a crash due to reading off the end of memory.

  In addition, modify all these quoting functions so that when invalid encoding is detected, an invalid sequence is substituted for just the first byte of the presumed character, not all of it. This reduces the risk of problems if a calling application performs additional processing on the quoted string.

- Fix crash involving triggers on partitioned tables that make use of transition tables (Kyotaro Horiguchi)

  If there are both `AFTER UPDATE` and `AFTER DELETE` triggers, the need for transition tables was determined incorrectly, leading to a crash during cross-partition updates.

E.24. Release 14.16

Release date: 2025-02-13

This release contains a variety of fixes from 14.15. For information about new features in major release 14, see Section E.40.

E.24.1. Migration to Version 14.16

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.14, see Section E.26.

E.24.2. Changes

- Harden `PQescapeString` and allied functions against invalidly-encoded input strings (Andres Freund, Noah Misch)

  Data-quoting functions supplied by libpq now fully check the encoding validity of their input. If invalid characters are detected, they report an error if possible. For the ones that lack an error return convention, the output string is adjusted to ensure that the server will report invalid encoding and no intervening processing will be fooled by bytes that might happen to match single quote, backslash, etc.

  The purpose of this change is to guard against SQL-injection attacks that are possible if one of these functions is used to quote crafted input. There is no hazard when the resulting string is sent directly to a PostgreSQL server (which would check its encoding anyway), but there is a risk when it is passed through psql or other client-side code. Historically such code has not carefully vetted encoding, and in many cases it's not clear what it should do if it did detect such a problem.

  This fix is effective only if the data-quoting function, the server, and any intermediate processing agree on the character encoding that's being used. Applications that insert untrusted input into SQL commands should take special care to ensure that that's true.

  Applications and drivers that quote untrusted input without using these libpq functions may be at risk of similar problems. They should first confirm the data is valid in the encoding expected by the server.

  The PostgreSQL Project thanks Stephen Fewer for reporting this problem. (CVE-2025-1094)

- Exclude parallel workers from connection privilege checks and limits (Tom Lane)

  Do not check `datallowconn`, `rolcanlogin`, and `ACL_CONNECT` privileges when starting a parallel worker, instead assuming that it's enough for the leader process to have passed similar checks originally. This avoids, for example, unexpected failures of parallelized queries when the leader is running as a role that lacks login privilege. In the same vein, enforce `ReservedConnections`, `datconnlimit`, and `rolconnlimit` limits only against regular backends, and count only regular backends while checking if the limits were already reached. Those limits are meant to prevent excessive consumption of process slots for regular backends --- but parallel workers and other special processes have their own pools of process slots with their own limit checks.

- Keep `TransactionXmin` in sync with `MyProc->xmin` (Heikki Linnakangas)

  This oversight could permit a process to try to access data that had already been vacuumed away. One known consequence is transient “could not access status of transaction” errors.

- Fix race condition that could cause failure to add a newly-inserted catalog entry to a catalog cache list (Heikki Linnakangas)

  This could result, for example, in failure to use a newly-created function within an existing session.
- Prevent possible catalog corruption when a system catalog is vacuumed concurrently with an update (Noah Misch)
- Fix data corruption when relation truncation fails (Thomas Munro)

  The filesystem calls needed to perform relation truncation could fail, leaving inconsistent state on disk (for example, effectively reviving deleted data). We can't really prevent that, but we can recover by dint of making such failures into PANICs, so that consistency is restored by replaying from WAL up to just before the attempted truncation. This isn't a hugely desirable behavior, but such failures are rare enough that it seems an acceptable solution.
- Prevent checkpoints from starting during relation truncation (Robert Haas)

  This avoids a race condition wherein the modified file might not get fsync'd before completing the checkpoint, creating a risk of data corruption if the operating system crashes soon after.
- Use `rename()` not `link()`/`unlink()` to rename files (Nathan Bossart)

  The previous coding was intended to assure that the operation could not accidentally overwrite an existing file. However a failure could leave two links to the same file in existence, confusing subsequent operations and creating a risk of data corruption. In practice we do not use this functionality in places where the target filename could already exist, so it seems better to give up the no-overwrite guarantee to remove the multiple-link hazard.
- Avoid possibly losing an update of `pg_database.datfrozenxid` when `VACUUM` runs concurrently with a `REASSIGN OWNED` that changes that database's owner (Kirill Reshke)
- Fix incorrect `tg_updatedcols` values passed to `AFTER UPDATE` triggers (Tom Lane)

  In some cases the `tg_updatedcols` bitmap could describe the set of columns updated by an earlier command in the same transaction, fooling the trigger into doing the wrong thing.

  Also, prevent memory bloat caused by making too many copies of the `tg_updatedcols` bitmap.
- Fix mis-processing of `to_timestamp`'s `FF`*n* format codes (Tom Lane)

  An integer format code immediately preceding `FF`*n* would consume all available digits, leaving none for `FF`*n*.
- When deparsing an `XMLTABLE()` expression, ensure that XML namespace names are double-quoted when necessary (Dean Rasheed)
- Include the `ldapscheme` option in `pg_hba_file_rules()` output (Laurenz Albe)
- Don't merge `UNION` operations if their column collations aren't consistent (Tom Lane)

  Previously we ignored collations when deciding if it's safe to merge `UNION` steps into a single N-way `UNION` operation. This was arguably valid before the introduction of nondeterministic collations, but it's not anymore, since the collation in use can affect the definition of uniqueness.
- Fix missed expression processing for partition pruning steps (Tom Lane)

  This oversight could lead to “unrecognized node type” errors, and perhaps other problems, in queries accessing partitioned tables.
- Allow dshash tables to grow past 1GB (Matthias van de Meent)

  This avoids errors like “invalid DSA memory alloc request size”. The case can occur for example in transactions that process several million tables.
- Avoid possible integer overflow in `bringetbitmap()` (James Hunter, Evgeniy Gorbanyov)

Since the result is only used for statistical purposes, the effects of this error were mostly cosmetic.

- Prevent streaming standby servers from looping infinitely when reading a WAL record that crosses pages (Kyotaro Horiguchi, Alexander Kukushkin)

  This would happen when the record's continuation is on a page that needs to be read from a different WAL source.

- Improve performance of archiver process with many status files (Nathan Bossart)

  This change back-patches a fix originally made in v15, in response to reports of extremely poor archiving performance leading to downtime or loss of replicas.

- Fix unintended promotion of FATAL errors to PANIC during early process startup (Noah Misch)

  This fixes some unlikely cases that would result in “PANIC: proc_exit() called in child process”.

- Fix cases where an operator family member operator or support procedure could become a dangling reference (Tom Lane)

  In some cases a data type could be dropped while references to its OID still remain in `pg_amop` or `pg_amproc`. While that caused no immediate issues, an attempt to drop the owning operator family would fail, and pg_dump would produce bogus output when dumping the operator family. This fix causes creation and modification of operator families/classes to add needed dependency entries so that dropping a data type will also drop any dependent operator family elements. That does not help vulnerable pre-existing operator families, though, so a band-aid has also been added to `DROP OPERATOR FAMILY` to prevent failure when dropping a family that has dangling members.

- Fix multiple memory leaks in logical decoding output (Vignesh C, Masahiko Sawada, Boyu Yang)

- Avoid low-probability crash on out-of-memory, due to missing check for failure return from `malloc()` (Karina Litskevich)

- Avoid integer overflow while testing `wal_skip_threshold` condition (Tom Lane)

  A transaction that created a very large relation could mistakenly decide to ensure durability by copying the relation into WAL instead of fsync'ing it, thereby negating the point of `wal_skip_threshold`. (This only matters when `wal_level` is set to `minimal`, else a WAL copy is required anyway.)

- Fix unsafe order of operations during cache lookups (Noah Misch)

  The only known consequence was a usually-harmless “you don't own a lock of type ExclusiveLock” warning during `GRANT TABLESPACE`.

- Fix possible “failed to resolve name” failures when using JIT on older ARM platforms (Thomas Munro)

  This could occur as a consequence of inconsistency about the default setting of `-moutline-atomics` between gcc and clang. At least Debian and Ubuntu are known to ship gcc and clang compilers that target armv8-a but differ on the use of outline atomics by default.

- Fix handling of Windows junction points that are not of PostgreSQL origin (Thomas Munro)

  Previously, initdb would fail if the path to the data directory included junction points whose expansion isn't in “drive absolute” format, or whose expansion points to another junction point.

- Fix assertion failure in `WITH RECURSIVE ... UNION` queries (David Rowley)

- Avoid assertion failure in rule deparsing if a set operation leaf query contains set operations (Man Zeng, Tom Lane)

- Avoid edge-case assertion failure in parallel query startup (Tom Lane)

- In `NULLIF()`, avoid passing a read-write expanded object pointer to the data type's equality function (Tom Lane)

The equality function could modify or delete the object if it's given a read-write pointer, which would be bad if we decide to return it as the `NULLIF()` result. There is probably no problem with any built-in equality function, but it's easy to demonstrate a failure with one coded in PL/pgSQL.

- Ensure that expression preprocessing is applied to a default null value in `INSERT` (Tom Lane)

  If the target column is of a domain type, the planner must insert a coerce-to-domain step not just a null constant, and this expression missed going through some required processing steps. There is no known consequence with domains based on core data types, but in theory an error could occur with domains based on extension types.

- Repair memory leaks in PL/Python (Mat Arye, Tom Lane)

  Repeated use of `PLyPlan.execute` or `plpy.cursor` resulted in memory leakage for the duration of the calling PL/Python function.

- Fix PL/Tcl to compile with Tcl 9 (Peter Eisentraut)

- In the ecpg preprocessor, fix possible misprocessing of cursors that reference out-of-scope variables (Tom Lane)

- In ecpg, fix compile-time warnings about unsupported use of `COPY ... FROM STDIN` (Ryo Kanbayashi)

  Previously, the intended warning was not issued due to a typo.

- Fix psql to safely handle file path names that are encoded in SJIS (Tom Lane)

  Some two-byte characters in SJIS have a second byte that is equal to ASCII backslash (`\`). These characters were corrupted by path name normalization, preventing access to files whose names include such characters.

- Fix use of wrong version of `pqsignal()` in pgbench and psql (Fujii Masao, Tom Lane)

  This error could lead to misbehavior when using the `-T` option in pgbench or the `\watch` command in psql, due to interrupted system calls not being resumed as expected.

- Fix misexecution of some nested `\if` constructs in pgbench (Michail Nikolaev)

  An `\if` command appearing within a false (not-being-executed) `\if` branch was incorrectly treated the same as `\elif`.

- In pgbench, fix possible misdisplay of progress messages during table initialization (Yushi Ogiwara, Tatsuo Ishii, Fujii Masao)

- Make pg_controldata more robust against corrupted `pg_control` files (Ilyasov Ian, Anton Voloshin)

  Since pg_controldata will attempt to print the contents of `pg_control` even if the CRC check fails, it must take care not to misbehave for invalid field values. This patch fixes some issues triggered by invalid timestamps and apparently-negative WAL segment sizes.

- Fix possible crash in pg_dump with identity sequences attached to tables that are extension members (Tom Lane)

- Fix pg_basebackup to correctly handle `pg_wal.tar` files exceeding 2GB on Windows (Davinder Singh, Thomas Munro)

- Update configuration probes that determine the compiler switches needed to access ARM CRC instructions (Tom Lane)

  On ARM platforms where the baseline CPU target lacks CRC instructions, we need to supply a `-march` switch to persuade the compiler to compile such instructions. Recent versions of gcc reject the value we were trying, leading to silently falling back to software CRC.

- During configure, if a C23 compiler is detected, try asking for C17 (Thomas Munro)

PostgreSQL versions before v16 will not compile under C23 rules. If the chosen compiler defaults to C23 or later, try adding a `-std=gnu17` switch to change that. (If this won't work for your compiler, manually specify `CFLAGS` with a suitable switch.)

- Update time zone data files to tzdata release 2025a for DST law changes in Paraguay, plus historical corrections for the Philippines (Tom Lane)

E.25. Release 14.15

Release date: 2024-11-21

This release contains a few fixes from 14.14. For information about new features in major release 14, see Section E.40.

E.25.1. Migration to Version 14.15

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.14, see Section E.26.

E.25.2. Changes

- Repair ABI break for extensions that work with struct `ResultRelInfo` (Tom Lane)

  Last week's minor releases unintentionally broke binary compatibility with timescaledb and several other extensions. Restore the affected structure to its previous size, so that such extensions need not be rebuilt.

- Restore functionality of `ALTER {ROLE|DATABASE} SET role` (Tom Lane, Noah Misch)

  The fix for CVE-2024-10978 accidentally caused settings for `role` to not be applied if they come from non-interactive sources, including previous `ALTER {ROLE|DATABASE}` commands and the `PGOPTIONS` environment variable.

- Fix cases where a logical replication slot's `restart_lsn` could go backwards (Masahiko Sawada)

  Previously, restarting logical replication could sometimes cause the slot's restart point to be recomputed as an older value than had previously been advertised in `pg_replication_slots`. This is bad, since for example WAL files might have been removed on the basis of the later `restart_lsn` value, in which case replication would fail to restart.

- Avoid deleting still-needed WAL files during pg_rewind (Polina Bungina, Alexander Kukushkin)

  Previously, in unlucky cases, it was possible for pg_rewind to remove important WAL files from the rewound demoted primary. In particular this happens if those files have been marked for archival (i.e., their `.ready` files were created) but not yet archived. Then the newly promoted node no longer has such files because of them having been recycled, but likely they are needed for recovery in the demoted node. If pg_rewind removes them, recovery is not possible anymore.

- Count index scans in `contrib/bloom` indexes in the statistics views, such as the `pg_stat_user_indexes.idx_scan` counter (Masahiro Ikeda)

- Fix crash when checking to see if an index's opclass options have changed (Alexander Korotkov)

  Some forms of `ALTER TABLE` would fail if the table has an index with non-default operator class options.

- Avoid assertion failure caused by disconnected NFA sub-graphs in regular expression parsing (Tom Lane)

  This bug does not appear to have any visible consequences in non-assert builds.

E.26. Release 14.14

Release date: 2024-11-14

This release contains a variety of fixes from 14.13. For information about new features in major release 14, see Section E.40.

E.26.1. Migration to Version 14.14

A dump/restore is not required for those running 14.X.

However, if you have ever detached a partition from a partitioned table that has a foreign-key reference to another partitioned table, and not dropped the former partition, then you may have catalog and/or data corruption to repair, as detailed in the fifth changelog entry below.

Also, if you are upgrading from a version earlier than 14.12, see Section E.28.

E.26.2. Changes

- Ensure cached plans are marked as dependent on the calling role when RLS applies to a non-top-level table reference (Nathan Bossart)

  If a CTE, subquery, sublink, security invoker view, or coercion projection in a query references a table with row-level security policies, we neglected to mark the resulting plan as potentially dependent on which role is executing it. This could lead to later query executions in the same session using the wrong plan, and then returning or hiding rows that should have been hidden or returned instead.

  The PostgreSQL Project thanks Wolfgang Walther for reporting this problem. (CVE-2024-10976)

- Make libpq discard error messages received during SSL or GSS protocol negotiation (Jacob Champion)

  An error message received before encryption negotiation is completed might have been injected by a man-in-the-middle, rather than being real server output. Reporting it opens the door to various security hazards; for example, the message might spoof a query result that a careless user could mistake for correct output. The best answer seems to be to discard such data and rely only on libpq's own report of the connection failure.

  The PostgreSQL Project thanks Jacob Champion for reporting this problem. (CVE-2024-10977)

- Fix unintended interactions between `SET SESSION AUTHORIZATION` and `SET ROLE` (Tom Lane)

  The SQL standard mandates that `SET SESSION AUTHORIZATION` have a side-effect of doing `SET ROLE NONE`. Our implementation of that was flawed, creating more interaction between the two settings than intended. Notably, rolling back a transaction that had done `SET SESSION AUTHORIZATION` would revert `ROLE` to `NONE` even if that had not been the previous state, so that the effective user ID might now be different from what it had been before the transaction. Transiently setting `session_authorization` in a function `SET` clause had a similar effect. A related bug was that if a parallel worker inspected `current_setting('role')`, it saw `none` even when it should see something else.

  The PostgreSQL Project thanks Tom Lane for reporting this problem. (CVE-2024-10978)

- Prevent trusted PL/Perl code from changing environment variables (Andrew Dunstan, Noah Misch)

  The ability to manipulate process environment variables such as `PATH` gives an attacker opportunities to execute arbitrary code. Therefore, "trusted" PLs must not offer the ability to do that. To fix `plperl`, replace `%ENV` with a tied hash that rejects any modification attempt with a warning. Untrusted `plperlu` retains the ability to change the environment.

  The PostgreSQL Project thanks Coby Abrams for reporting this problem. (CVE-2024-10979)

- Fix updates of catalog state for foreign-key constraints when attaching or detaching table partitions (Jehan-Guillaume de Rorthais, Tender Wang, Álvaro Herrera)

  If the referenced table is partitioned, then different catalog entries are needed for a referencing table that is stand-alone versus one that is a partition. `ATTACH/DETACH PARTITION` commands failed to perform this conversion correctly. In particular, after `DETACH` the now stand-alone table would be missing foreign-key enforcement triggers, which could result in the table later containing rows that fail the foreign-key constraint. A subsequent re-`ATTACH` could fail with surprising errors, too.

  The way to fix this is to do `ALTER TABLE DROP CONSTRAINT` on the now stand-alone table for each faulty constraint, and then re-add the constraint. If re-adding the constraint fails, then some erroneous data has crept in. You will need to manually re-establish consistency between the referencing and referenced tables, then re-add the constraint.

  This query can be used to identify broken constraints and construct the commands needed to recreate them:

```
SELECT conrelid::pg_catalog.regclass AS "constrained table",
       conname AS constraint,
       confrelid::pg_catalog.regclass AS "references",
       pg_catalog.format('ALTER TABLE %s DROP CONSTRAINT %I;',
                         conrelid::pg_catalog.regclass, conname) AS "drop",
       pg_catalog.format('ALTER TABLE %s ADD CONSTRAINT %I %s;',
                         conrelid::pg_catalog.regclass, conname,
                         pg_catalog.pg_get_constraintdef(oid)) AS "add"
FROM pg_catalog.pg_constraint c
WHERE contype = 'f' AND conparentid = 0 AND
   (SELECT count(*) FROM pg_catalog.pg_constraint c2
    WHERE c2.conparentid = c.oid) <>
   (SELECT count(*) FROM pg_catalog.pg_inherits i
    WHERE (i.inhparent = c.conrelid OR i.inhparent = c.confrelid) AND
      EXISTS (SELECT 1 FROM pg_catalog.pg_partitioned_table
              WHERE partrelid = i.inhparent));
```

  Since it is possible that one or more of the `ADD CONSTRAINT` steps will fail, you should save the query's output in a file and then attempt to perform each step.

- Avoid possible crashes and “could not open relation” errors in queries on a partitioned table occurring concurrently with a `DETACH CONCURRENTLY` and immediate drop of a partition (Álvaro Herrera, Kuntal Gosh)

- Disallow `ALTER TABLE ATTACH PARTITION` if the table to be attached has a foreign key referencing the partitioned table (Álvaro Herrera)

  This arrangement is not supported, and other ways of creating it already fail.

- Don't use partitionwise joins or grouping if the query's collation for the key column doesn't match the partition key's collation (Jian He, Webbo Han)

  Such plans could produce incorrect results.

- Fix possible “could not find pathkey item to sort” error when the output of a `UNION ALL` member query needs to be sorted, and the sort column is an expression (Andrei Lepikhov, Tom Lane)

- Allow cancellation of the second stage of index build for large hash indexes (Pavel Borisov)

- Fix assertion failure or confusing error message for `COPY (`*`query`*`) TO ...`, when the *`query`* is rewritten by a `DO INSTEAD NOTIFY` rule (Tender Wang, Tom Lane)

- Fix detection of skewed data during parallel hash join (Thomas Munro)

  After repartitioning the inner side of a hash join because one partition has accumulated too many tuples, we check to see if all the partition's tuples went into the same child partition, which suggests that they all have the same hash value and further repartitioning cannot improve matters.

This check malfunctioned in some cases, allowing repeated futile repartitioning which would eventually end in a resource-exhaustion error.

- Fix race condition in committing a serializable transaction (Heikki Linnakangas)

  Mis-processing of a recently committed transaction could lead to an assertion failure or a "could not access status of transaction" error.

- Fix race condition in `COMMIT PREPARED` that resulted in orphaned 2PC files (wuchengwen)

  A concurrent `PREPARE TRANSACTION` could cause `COMMIT PREPARED` to not remove the on-disk two-phase state file for the completed transaction. There was no immediate ill effect, but a subsequent crash-and-recovery could fail with "could not access status of transaction", requiring manual removal of the orphaned file to restore service.

- Avoid invalid memory accesses after skipping an invalid toast index during `VACUUM FULL` (Tender Wang)

  A list tracking yet-to-be-rebuilt indexes was not properly updated in this code path, risking assertion failures or crashes later on.

- Fix ways in which an "in place" catalog update could be lost (Noah Misch)

  Normal row updates write a new version of the row to preserve rollback-ability of the transaction. However, certain system catalog updates are intentionally non-transactional and are done with an in-place update of the row. These patches fix race conditions that could cause the effects of an in-place update to be lost. As an example, it was possible to forget having set `pg_class.relhasindex` to true, preventing updates of the new index and thus causing index corruption.

- Reset catalog caches at end of recovery (Noah Misch)

  This prevents scenarios wherein an in-place catalog update could be lost due to using stale data from a catalog cache.

- Avoid using parallel query while holding off interrupts (Francesco Degrassi, Noah Misch, Tom Lane)

  This situation cannot arise normally, but it can be reached with test scenarios such as using a SQL-language function as B-tree support (which would be far too slow for production usage). If it did occur it would result in an indefinite wait.

- Report the active query ID for statistics purposes at the start of processing of Bind and Execute protocol messages (Sami Imseih)

  This allows more of the work done in extended query protocol to be attributed to the correct query.

- Guard against stack overflow in libxml2 with too-deeply-nested XML input (Tom Lane, with hat tip to Nick Wellnhofer)

  Use `xmlXPathCtxtCompile()` rather than `xmlXPathCompile()`, because the latter fails to protect itself against recursion-to-stack-overflow in libxml2 releases before 2.13.4.

- Do not ignore a concurrent `REINDEX CONCURRENTLY` that is working on an index with predicates or expressions (Michail Nikolaev)

  Normally, `REINDEX CONCURRENTLY` does not need to wait for other `REINDEX CONCURRENTLY` operations on other tables. However, this optimization is not applied if the other `REINDEX CONCURRENTLY` is processing an index with predicates or expressions, on the chance that such expressions contain user-defined code that accesses other tables. Careless coding created a race condition such that that rule was not applied uniformly, possibly allowing inconsistent behavior.

- Fix "failed to find plan for subquery/CTE" errors in `EXPLAIN` (Richard Guo, Tom Lane)

  This case arose while trying to print references to fields of a RECORD-type output of a subquery when the subquery has been optimized out of the plan altogether (which is possible at least in the

case that it has a constant-false WHERE condition). Nothing remains in the plan to identify the original field names, so fall back to printing *fN* for the *N*'th record column. (That's actually the right thing anyway, if the record output arose from a ROW() constructor.)

- Disallow a USING clause when altering the type of a generated column (Peter Eisentraut)

  A generated column already has an expression specifying the column contents, so including USING doesn't make sense.

- Ignore not-yet-defined Portals in the pg_cursors view (Tom Lane)

  It is possible for user-defined code that inspects this view to be called while a new cursor is being set up, and if that happens a null pointer dereference would ensue. Avoid the problem by defining the view to exclude incompletely-set-up cursors.

- Avoid “unexpected table_index_fetch_tuple call during logical decoding” error while decoding a transaction involving insertion of a column default value (Takeshi Ideriha, Hou Zhijie)

- Reduce memory consumption of logical decoding (Masahiko Sawada)

  Use a smaller default block size to store tuple data received during logical replication. This reduces memory wastage, which has been reported to be severe while processing long-running transactions, even leading to out-of-memory failures.

- Re-disable sending of stateless (TLSv1.2) session tickets (Daniel Gustafsson)

  A previous change to prevent sending of stateful (TLSv1.3) session tickets accidentally re-enabled sending of stateless ones. Thus, while we intended to prevent clients from thinking that TLS session resumption is supported, some still did.

- Avoid “wrong tuple length” failure when dropping a database with many ACL (permission) entries (Ayush Tiwari)

- Allow adjusting the session_authorization and role settings in parallel workers (Tom Lane)

  Our code intends to allow modifiable server settings to be set by function SET clauses, but not otherwise within a parallel worker. SET clauses failed for these two settings, though.

- Fix behavior of stable functions called from a CALL statement's argument list, when the CALL is within a PL/pgSQL EXCEPTION block (Tom Lane)

  As with a similar fix in our previous quarterly releases, this case allowed such functions to be passed the wrong snapshot, causing them to see stale values of rows modified since the start of the outer transaction.

- Fix “cache lookup failed for function” errors in edge cases in PL/pgSQL's CALL (Tom Lane)

- Fix thread safety of our fallback (non-OpenSSL) MD5 implementation on big-endian hardware (Heikki Linnakangas)

  Thread safety is not currently a concern in the server, but it is for libpq.

- Parse libpq's keepalives connection option in the same way as other integer-valued options (Yuto Sasaki)

  The coding used here rejected trailing whitespace in the option value, unlike other cases. This turns out to be problematic in ecpg's usage, for example.

- Avoid use of pnstrdup() in ecpglib (Jacob Champion)

  That function will call exit() on out-of-memory, which is undesirable in a library. The calling code already handles allocation failures properly.

- In ecpglib, fix out-of-bounds read when parsing incorrect datetime input (Bruce Momjian, Pavel Nekrasov)

It was possible to try to read the location just before the start of a constant array. Real-world consequences seem minimal, though.

- Include the source timeline history in pg_rewind's debug output (Heikki Linnakangas)

  This was the intention to begin with, but a coding error caused the source history to always print as empty.

- Fix misbehavior with junction points on Windows, particularly in pg_rewind (Alexandra Wang)

  This entailed back-patching previous fixes by Thomas Munro, Peter Eisentraut, Alexander Lakhin, and Juan José Santamaría Flecha. Those changes were originally not back-patched out of caution, but they have been in use in later branches for long enough to deem them safe.

- Avoid trying to reindex temporary tables and indexes in vacuumdb and in parallel reindexdb (VaibhaveS, Michael Paquier, Fujii Masao, Nathan Bossart)

  Reindexing other sessions' temporary tables cannot work, but the check to skip them was missing in some code paths, leading to unwanted failures.

- Allow inspection of sequence relations in relevant functions of `contrib/pageinspect` and `contrib/pgstattuple` (Nathan Bossart, Ayush Vatsa)

  This had been allowed in the past, but it got broken during the introduction of non-default access methods for tables.

- Fix incorrect LLVM-generated code on ARM64 platforms (Thomas Munro, Anthonin Bonnefoy)

  When using JIT compilation on ARM platforms, the generated code could not support relocation distances exceeding 32 bits, allowing unlucky placement of generated code to cause server crashes on large-memory systems.

- Fix a few places that assumed that process start time (represented as a `time_t`) will fit into a `long` value (Max Johnson, Nathan Bossart)

  On platforms where `long` is 32 bits (notably Windows), this coding would fail after Y2038. Most of the failures appear only cosmetic, but notably `pg_ctl start` would hang.

- Prevent “nothing provides perl(PostgreSQL::Test::Utils)” failures while building RPM packages of PostgreSQL (Noah Misch)

- Fix building with Strawberry Perl on Windows (Andrew Dunstan)

- Update time zone data files to tzdata release 2024b (Tom Lane)

  This tzdata release changes the old System-V-compatibility zone names to duplicate the corresponding geographic zones; for example `PST8PDT` is now an alias for `America/Los_Angeles`. The main visible consequence is that for timestamps before the introduction of standardized time zones, the zone is considered to represent local mean solar time for the named location. For example, in `PST8PDT`, `timestamptz` input such as `1801-01-01 00:00` would previously have been rendered as `1801-01-01 00:00:00-08`, but now it is rendered as `1801-01-01 00:00:00-07:52:58`.

  Also, historical corrections for Mexico, Mongolia, and Portugal. Notably, `Asia/Choibalsan` is now an alias for `Asia/Ulaanbaatar` rather than being a separate zone, mainly because the differences between those zones were found to be based on untrustworthy data.

E.27. Release 14.13

Release date: 2024-08-08

This release contains a variety of fixes from 14.12. For information about new features in major release 14, see Section E.40.

E.27.1. Migration to Version 14.13

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.12, see Section E.28.

E.27.2. Changes

- Prevent unauthorized code execution during pg_dump (Masahiko Sawada)

  An attacker able to create and drop non-temporary objects could inject SQL code that would be executed by a concurrent pg_dump session with the privileges of the role running pg_dump (which is often a superuser). The attack involves replacing a sequence or similar object with a view or foreign table that will execute malicious code. To prevent this, introduce a new server parameter `restrict_nonsystem_relation_kind` that can disable expansion of non-builtin views as well as access to foreign tables, and teach pg_dump to set it when available. Note that the attack is prevented only if both pg_dump and the server it is dumping from are new enough to have this fix.

  The PostgreSQL Project thanks Noah Misch for reporting this problem. (CVE-2024-7348)

- Prevent infinite loop in `VACUUM` (Melanie Plageman)

  After a disconnected standby server with an old running transaction reconnected to the primary, it was possible for `VACUUM` on the primary to get confused about which tuples are removable, resulting in an infinite loop.

- Fix failure after attaching a table as a partition, if the table had previously had inheritance children (Álvaro Herrera)

- Fix `ALTER TABLE DETACH PARTITION` for cases involving inconsistent index-based constraints (Álvaro Herrera, Tender Wang)

  When a partitioned table has an index that is not associated with a constraint, but a partition has an equivalent index that is, then detaching the partition would misbehave, leaving the ex-partition's constraint with an incorrect `coninhcount` value. This would cause trouble during any further manipulations of that constraint.

- Fix partition pruning setup during `ALTER TABLE DETACH PARTITION CONCURRENTLY` (Álvaro Herrera)

  The executor assumed that no partition could be detached between planning and execution of a query on a partitioned table. This is no longer true since the introduction of `DETACH PARTITION`'s `CONCURRENTLY` option, making it possible for query execution to fail transiently when that is used.

- Correctly update a partitioned table's `pg_class.reltuples` field to zero after its last child partition is dropped (Noah Misch)

  The first `ANALYZE` on such a partitioned table must update `relhassubclass` as well, and that caused the `reltuples` update to be lost.

- Fix handling of polymorphic output arguments for procedures (Tom Lane)

  The SQL `CALL` statement did not resolve the correct data types for such arguments, leading to errors such as “cannot display a value of type anyelement”, or even outright crashes. (But `CALL` in PL/pgSQL worked correctly.)

- Fix behavior of stable functions called from a `CALL` statement's argument list (Tom Lane)

  If the `CALL` is within an atomic context (e.g. there's an outer transaction block), such functions were passed the wrong snapshot, causing them to see stale values of rows modified since the start of the outer transaction.

- Detect integer overflow in `money` calculations (Joseph Koshakow)

None of the arithmetic functions for the `money` type checked for overflow before, so they would silently give wrong answers for overflowing cases.

- Fix over-aggressive clamping of the scale argument in `round(numeric)` and `trunc(numeric)` (Dean Rasheed)

  These functions clamped their scale argument to +/-2000, but there are valid use-cases for it to be larger; the functions returned incorrect results in such cases. Instead clamp to the actual allowed range of type `numeric`.

- Prevent `pg_sequence_last_value()` from failing on unlogged sequences on standby servers and on temporary sequences of other sessions (Nathan Bossart)

  Make it return NULL in these cases instead of throwing an error.

- Fix parsing of ignored operators in `websearch_to_tsquery()` (Tom Lane)

  Per the manual, punctuation in the input of `websearch_to_tsquery()` is ignored except for the special cases of dashes and quotes. However, parentheses and a few other characters appearing immediately before an `or` could cause `or` to be treated as a data word, rather than as an `OR` operator as expected.

- Detect another integer overflow case while computing new array dimensions (Joseph Koshakow)

  Reject applying array dimensions `[-2147483648:2147483647]` to an empty array. This is closely related to CVE-2023-5869, but appears harmless since the array still ends up empty.

- Detect another case of a new catalog cache entry becoming stale while detoasting its fields (Noah Misch)

  An in-place update occurring while we expand out-of-line fields in a catalog tuple could be missed, leading to a catalog cache entry that lacks the in-place change but is not known to be stale. This is only possible in the `pg_database` catalog, so the effects are narrow, but misbehavior is possible.

- Correctly check updatability of view columns targeted by `INSERT ... DEFAULT` (Tom Lane)

  If such a column is non-updatable, we should give an error reporting that. But the check was missed and then later code would report an unhelpful error such as “attribute number *N* not found in view targetlist”.

- Avoid reporting an unhelpful internal error for incorrect recursive queries (Tom Lane)

  Rearrange the order of error checks so that we throw an on-point error when a `WITH RECURSIVE` query does not have a self-reference within the second arm of the `UNION`, but does have one self-reference in some other place such as `ORDER BY`.

- Don't throw an error if a queued `AFTER` trigger no longer exists (Tom Lane)

  It's possible for a transaction to execute an operation that queues a deferred `AFTER` trigger for later execution, and then to drop the trigger before that happens. Formerly this led to weird errors such as “could not find trigger *NNNN*”. It seems better to silently do nothing if the trigger no longer exists at the time when it would have been executed.

- Fix failure to remove `pg_init_privs` entries for column-level privileges when their table is dropped (Tom Lane)

  If an extension grants some column-level privileges on a table it creates, relevant catalog entries would remain behind after the extension is dropped. This was harmless until/unless the table's OID was re-used for another relation, when it could interfere with what pg_dump dumps for that relation.

- Fix selection of an arbiter index for `ON CONFLICT` when the desired index has expressions or predicates (Tom Lane)

If a query using `ON CONFLICT` accesses the target table through an updatable view, it could fail with "there is no unique or exclusion constraint matching the ON CONFLICT specification", even though a matching index does exist.

- Refuse to modify a temporary table of another session with `ALTER TABLE` (Tom Lane)

  Permissions checks normally would prevent this case from arising, but it is possible to reach it by altering a parent table whose child is another session's temporary table. Throw an error if we discover that such a child table belongs to another session.

- Fix handling of extended statistics on expressions in `CREATE TABLE LIKE STATISTICS` (Tom Lane)

  The `CREATE` command failed to adjust column references in statistics expressions to the possibly-different column numbering of the new table. This resulted in invalid statistics objects that would cause problems later. A typical scenario where renumbering columns is needed is when the source table contains some dropped columns.

- Fix failure to recalculate sub-queries generated from `MIN()` or `MAX()` aggregates (Tom Lane)

  In some cases the aggregate result computed at one row of the outer query could be re-used for later rows when it should not be. This has only been seen to happen when the outer query uses `DISTINCT` that is implemented with hash aggregation, but other cases may exist.

- Avoid crashing when a JIT-inlined backend function throws an error (Tom Lane)

  The error state can include pointers into the dynamically loaded module holding the JIT-compiled code (for error location strings). In some code paths the module could get unloaded before the error report is processed, leading to SIGSEGV when the location strings are accessed.

- Cope with behavioral changes in libxml2 version 2.13.x (Erik Wienhold, Tom Lane)

  Notably, we now suppress "chunk is not well balanced" errors from libxml2, unless that is the only reported error. This is to make error reports consistent between 2.13.x and earlier libxml2 versions. In earlier versions, that message was almost always redundant or outright incorrect, so 2.13.x substantially reduced the number of cases in which it's reported.

- Fix handling of subtransactions of prepared transactions when starting a hot standby server (Heikki Linnakangas)

  When starting a standby's replay at a shutdown checkpoint WAL record, transactions that had been prepared but not yet committed on the primary are correctly understood as being still in progress. But subtransactions of a prepared transaction (created by savepoints or PL/pgSQL exception blocks) were not accounted for and would be treated as aborted. That led to inconsistency if the prepared transaction was later committed.

- Prevent incorrect initialization of logical replication slots (Masahiko Sawada)

  In some cases a replication slot's start point within the WAL stream could be set to a point within a transaction, leading to assertion failures or incorrect decoding results.

- Avoid memory leakage after servicing a notify or sinval interrupt (Tom Lane)

  The processing functions for these events could switch the current memory context to TopMemoryContext, resulting in session-lifespan leakage of any data allocated before the incorrect setting gets replaced. There were observable leaks associated with (at least) encoding conversion of incoming queries and parameters attached to Bind messages.

- Prevent deadlocks and assertion failures during truncation of the multixact SLRU log (Heikki Linnakangas)

  A process trying to delete SLRU segments could deadlock with the checkpointer process.

- Avoid possibly missing end-of-input events on Windows sockets (Thomas Munro)

Windows reports an FD_CLOSE event only once after the remote end of the connection disconnects. With unlucky timing, we could miss that report and wait indefinitely, or at least until a timeout elapsed, expecting more input.

- Fix buffer overread in JSON parse error reports for incomplete byte sequences (Jacob Champion)

  It was possible to walk off the end of the input buffer by a few bytes when the last bytes comprise an incomplete multi-byte character. While usually harmless, in principle this could cause a crash.

- Disable creation of stateful TLS session tickets by OpenSSL (Daniel Gustafsson)

  This avoids possible failures with clients that think receipt of a session ticket means that TLS session resumption is supported.

- When replanning a PL/pgSQL “simple expression”, check it's still simple (Tom Lane)

  Certain fairly-artificial cases, such as dropping a referenced function and recreating it as an aggregate, could lead to surprising failures such as “unexpected plan node type”.

- Fix incompatibility between PL/Perl and Perl 5.40 (Andrew Dunstan)

- Fix recursive `RECORD`-returning PL/Python functions (Tom Lane)

  If we recurse to a new call of the same function that passes a different column definition list (`AS` clause), it would fail because the inner call would overwrite the outer call's idea of what rowtype to return.

- Don't corrupt PL/Python's `TD` dictionary during a recursive trigger call (Tom Lane)

  If a PL/Python-language trigger caused another one to be invoked, the `TD` dictionary created for the inner one would overwrite the outer one's `TD` dictionary.

- Fix PL/Tcl's reporting of invalid list syntax in the result of a function returning tuple (Erik Wienhold, Tom Lane)

  Such a case could result in a crash, or in emission of misleading context information that actually refers to the previous Tcl error.

- Avoid non-thread-safe usage of `strerror()` in libpq (Peter Eisentraut)

  Certain error messages returned by OpenSSL could become garbled in multi-threaded applications.

- Ensure that `pg_restore -l` reports dependent TOC entries correctly (Tom Lane)

  If `-l` was specified together with selective-restore options such as `-n` or `-N`, dependent TOC entries such as comments would be omitted from the listing, even when an actual restore would have selected them.

- In `contrib/postgres_fdw`, do not send `FETCH FIRST WITH TIES` clauses to the remote server (Japin Li)

  The remote server might not implement this clause, or might interpret it differently than we would locally, so don't risk attempting remote execution.

- Avoid clashing with system-provided `<regex.h>` headers (Thomas Munro)

  This fixes a compilation failure on macOS version 15 and up.

- Fix otherwise-harmless assertion failure in Memoize cost estimation (David Rowley)

- Fix otherwise-harmless assertion failures in `REINDEX CONCURRENTLY` applied to an SP-GiST index (Tom Lane)

E.28. Release 14.12

Release date: 2024-05-09

This release contains a variety of fixes from 14.11. For information about new features in major release 14, see Section E.40.

E.28.1. Migration to Version 14.12

A dump/restore is not required for those running 14.X.

However, a security vulnerability was found in the system views `pg_stats_ext` and `pg_stats_ext_exprs`, potentially allowing authenticated database users to see data they shouldn't. If this is of concern in your installation, follow the steps in the first changelog entry below to rectify it.

Also, if you are upgrading from a version earlier than 14.11, see Section E.29.

E.28.2. Changes

- Restrict visibility of `pg_stats_ext` and `pg_stats_ext_exprs` entries to the table owner (Nathan Bossart)

  These views failed to hide statistics for expressions that involve columns the accessing user does not have permission to read. View columns such as `most_common_vals` might expose security-relevant data. The potential interactions here are not fully clear, so in the interest of erring on the side of safety, make rows in these views visible only to the owner of the associated table.

  The PostgreSQL Project thanks Lukas Fittl for reporting this problem. (CVE-2024-4317)

  By itself, this fix will only fix the behavior in newly initdb'd database clusters. If you wish to apply this change in an existing cluster, you will need to do the following:

  1. Find the SQL script `fix-CVE-2024-4317.sql` in the *share* directory of the PostgreSQL installation (typically located someplace like `/usr/share/postgresql/`). Be sure to use the script appropriate to your PostgreSQL major version. If you do not see this file, either your version is not vulnerable (only v14–v16 are affected) or your minor version is too old to have the fix.
  2. In *each* database of the cluster, run the `fix-CVE-2024-4317.sql` script as superuser. In psql this would look like

     ```
     \i /usr/share/postgresql/fix-CVE-2024-4317.sql
     ```

     (adjust the file path as appropriate). Any error probably indicates that you've used the wrong script version. It will not hurt to run the script more than once.
  3. Do not forget to include the `template0` and `template1` databases, or the vulnerability will still exist in databases you create later. To fix `template0`, you'll need to temporarily make it accept connections. Do that with

     ```
     ALTER DATABASE template0 WITH ALLOW_CONNECTIONS true;
     ```

     and then after fixing `template0`, undo it with

     ```
     ALTER DATABASE template0 WITH ALLOW_CONNECTIONS false;
     ```

- Fix `INSERT` from multiple `VALUES` rows into a target column that is a domain over an array or composite type (Tom Lane)

  Such cases would either fail with surprising complaints about mismatched datatypes, or insert unexpected coercions that could lead to odd results.

- Fix incorrect pruning of NULL partition when a table is partitioned on a boolean column and the query has a boolean `IS NOT` clause (David Rowley)

  A NULL value satisfies a clause such as *`boolcol` `IS NOT FALSE`*, so pruning away a partition containing NULLs yielded incorrect answers.

- Make `ALTER FOREIGN TABLE SET SCHEMA` move any owned sequences into the new schema (Tom Lane)

Moving a regular table to a new schema causes any sequences owned by the table to be moved to that schema too (along with indexes and constraints). This was overlooked for foreign tables, however.

- Improve `ALTER TABLE ... ALTER COLUMN TYPE`'s error message when there is a dependent function or publication (Tom Lane)
- Fix `EXPLAIN`'s counting of heap pages accessed by a bitmap heap scan (Melanie Plageman)

  Previously, heap pages that contain no visible tuples were not counted; but it seems more consistent to count all pages returned by the bitmap index scan.
- Avoid deadlock during removal of orphaned temporary tables (Mikhail Zhilin)

  If the session that creates a temporary table crashes without removing the table, autovacuum will eventually try to remove the orphaned table. However, an incoming session that's been assigned the same temporary namespace will do that too. If a temporary table has a dependency (such as an owned sequence) then a deadlock could result between these two cleanup attempts.
- Avoid race condition while examining per-relation frozen-XID values (Noah Misch)

  `VACUUM`'s computation of per-database frozen-XID values from per-relation values could get confused by a concurrent update of those values by another `VACUUM`.
- Disallow converting a table to a view within an outer SQL command that is using that table (Tom Lane)

  This avoids possible crashes.
- Ensure that join conditions generated from equivalence classes are applied at the correct plan level (Tom Lane)

  In versions before PostgreSQL 16, it was possible for generated conditions to be evaluated below outer joins when they should be evaluated above (after) the outer join, leading to incorrect query results. All versions have a similar hazard when considering joins to `UNION ALL` trees that have constant outputs for the join column in some `SELECT` arms.
- Avoid unnecessary use of moving-aggregate mode with a non-moving window frame (Vallimaharajan G)

  When a plain aggregate is used as a window function, and the window frame start is specified as `UNBOUNDED PRECEDING`, the frame's head cannot move so we do not need to use the special (and more expensive) moving-aggregate mode. This optimization was intended all along, but due to a coding error it never triggered.
- Avoid use of already-freed data while planning partition-wise joins under GEQO (Tom Lane)

  This would typically end in a crash or unexpected error message.
- Avoid freeing still-in-use data in Memoize (Tender Wang, Andrei Lepikhov)

  In production builds this error frequently didn't cause any problems, as the freed data would most likely not get overwritten before it was used.
- Fix incorrectly-reported statistics kind codes in “requested statistics kind *`X`* is not yet built” error messages (David Rowley)
- Be more careful with `RECORD`-returning functions in `FROM` (Tom Lane)

  The output columns of such a function call must be defined by an `AS` clause that specifies the column names and data types. If the actual function output value doesn't match that, an error is supposed to be thrown at runtime. However, some code paths would examine the actual value prematurely, and potentially issue strange errors or suffer assertion failures if it doesn't match expectations.

- Fix confusion about the return rowtype of SQL-language procedures (Tom Lane)

  A procedure implemented in SQL language that returns a single composite-type column would cause an assertion failure or core dump.

- Add protective stack depth checks to some recursive functions (Egor Chindyaskin)

- Fix mis-rounding and overflow hazards in `date_bin()` (Moaaz Assali)

  In the case where the source timestamp is before the origin timestamp and their difference is already an exact multiple of the stride, the code incorrectly subtracted the stride anyway. Also, detect some integer-overflow cases that would have produced incorrect results.

- Detect integer overflow when adding or subtracting an `interval` to/from a `timestamp` (Joseph Koshakow)

  Some cases that should cause an out-of-range error produced an incorrect result instead.

- Avoid race condition in `pg_get_expr()` (Tom Lane)

  If the relation referenced by the argument is dropped concurrently, the function's intention is to return NULL, but sometimes it failed instead.

- Fix detection of old transaction IDs in XID status functions (Karina Litskevich)

  Transaction IDs more than 2^{31} transactions in the past could be misidentified as recent, leading to misbehavior of `pg_xact_status()` or `txid_status()`.

- Ensure that a table's freespace map won't return a page that's past the end of the table (Ronan Dunklau)

  Because the freespace map isn't WAL-logged, this was possible in edge cases involving an OS crash, a replica promote, or a PITR restore. The result would be a “could not read block” error.

- Fix file descriptor leakage when an error is thrown while waiting in `WaitEventSetWait` (Etsuro Fujita)

- Avoid corrupting exception stack if an FDW implements async append but doesn't configure any wait conditions for the Append plan node to wait for (Alexander Pyhalov)

- Throw an error if an index is accessed while it is being reindexed (Tom Lane)

  Previously this was just an assertion check, but promote it into a regular runtime error. This will provide a more on-point error message when reindexing a user-defined index expression that attempts to access its own table.

- Ensure that index-only scans on `name` columns return a fully-padded value (David Rowley)

  The value physically stored in the index is truncated, and previously a pointer to that value was returned to callers. This provoked complaints when testing under valgrind. In theory it could result in crashes, though none have been reported.

- Fix crash with DSM allocations larger than 4GB (Heikki Linnakangas)

- Disconnect if a new server session's client socket cannot be put into non-blocking mode (Heikki Linnakangas)

  It was once theoretically possible for us to operate with a socket that's in blocking mode; but that hasn't worked fully in a long time, so fail at connection start rather than misbehave later.

- Fix inadequate error reporting with OpenSSL 3.0.0 and later (Heikki Linnakangas, Tom Lane)

  System-reported errors passed through by OpenSSL were reported with a numeric error code rather than anything readable.

- Avoid concurrent calls to `bindtextdomain()` in libpq and ecpglib (Tom Lane)

Although GNU gettext's implementation seems to be fine with concurrent calls, the version available on Windows is not.

- Fix crash in ecpg's preprocessor if the program tries to redefine a macro that was defined on the preprocessor command line (Tom Lane)
- In ecpg, avoid issuing false “unsupported feature will be passed to server” warnings (Tom Lane)
- Ensure that the string result of ecpg's `intoasc()` function is correctly zero-terminated (Oleg Tselebrovskiy)
- Fix pg_dumpall so that role comments, if present, will be dumped regardless of the setting of `--no-role-passwords` (Daniel Gustafsson, Álvaro Herrera)
- Fix PL/pgSQL's parsing of single-line comments (`---`-style comments) following expressions (Erik Wienhold, Tom Lane)

  This mistake caused parse errors if such a comment followed a `WHEN` expression in a PL/pgSQL `CASE` statement.
- In `contrib/amcheck`, don't report false match failures due to short- versus long-header values (Andrey Borodin, Michael Zhilin)

  A variable-length datum in a heap tuple or index tuple could have either a short or a long header, depending on compression parameters that applied when it was made. Treat these cases as equivalent rather than complaining if there's a difference.
- Fix bugs in BRIN output functions (Tomas Vondra)

  These output functions are only used for displaying index entries in `contrib/pageinspect`, so the errors are of limited practical concern.
- In `contrib/postgres_fdw`, avoid emitting requests to sort by a constant (David Rowley)

  This could occur in cases involving `UNION ALL` with constant-emitting subqueries. Sorting by a constant is useless of course, but it also risks being misinterpreted by the remote server, leading to “ORDER BY position *N* is not in select list” errors.
- Make `contrib/postgres_fdw` set the remote session's time zone to `GMT` not `UTC` (Tom Lane)

  This should have the same results for practical purposes. However, `GMT` is recognized by hard-wired code in the server, while `UTC` is looked up in the timezone database. So the old code could fail in the unlikely event that the remote server's timezone database is missing entries.
- In `contrib/xml2`, avoid use of library functions that have been deprecated in recent versions of libxml2 (Dmitry Koval)
- Fix incompatibility with LLVM 18 (Thomas Munro, Dmitry Dolgov)
- Allow `make check` to work with the musl C library (Thomas Munro, Bruce Momjian, Tom Lane)

E.29. Release 14.11

Release date: 2024-02-08

This release contains a variety of fixes from 14.10. For information about new features in major release 14, see Section E.40.

E.29.1. Migration to Version 14.11

A dump/restore is not required for those running 14.X.

However, one bug was fixed that could have resulted in corruption of GIN indexes during concurrent updates. If you suspect such corruption, reindex affected indexes after installing this update.

Also, if you are upgrading from a version earlier than 14.10, see Section E.30.

E.29.2. Changes

- Tighten security restrictions within `REFRESH MATERIALIZED VIEW CONCURRENTLY` (Heikki Linnakangas)

  One step of a concurrent refresh command was run under weak security restrictions. If a materialized view's owner could persuade a superuser or other high-privileged user to perform a concurrent refresh on that view, the view's owner could control code executed with the privileges of the user running `REFRESH`. Fix things so that all user-determined code is run as the view's owner, as expected.

  The only known exploit for this error does not work in PostgreSQL 16.0 and later, so it may be that v16 is not vulnerable in practice.

  The PostgreSQL Project thanks Pedro Gallegos for reporting this problem. (CVE-2024-0985)

- Fix memory leak when performing JIT inlining (Andres Freund, Daniel Gustafsson)

  There have been multiple reports of backend processes suffering out-of-memory conditions after sufficiently many JIT compilations. This fix should resolve that.

- When dequeueing from an LWLock, avoid needing to search the list of waiting processes (Andres Freund)

  This fixes O(N^2) behavior when the list of waiters is long. In some use-cases this results in substantial throughput improvements.

- Avoid generating incorrect partitioned-join plans (Richard Guo)

  Some uncommon situations involving lateral references could create incorrect plans. Affected queries could produce wrong answers, or odd failures such as “variable not found in subplan target list”, or executor crashes.

- Fix incorrect wrapping of subquery output expressions in PlaceHolderVars (Tom Lane)

  This fixes incorrect results when a subquery is underneath an outer join and has an output column that laterally references something outside the outer join's scope. The output column might not appear as NULL when it should do so due to the action of the outer join.

- Prevent access to a no-longer-pinned buffer in `BEFORE ROW UPDATE` triggers (Alexander Lakhin, Tom Lane)

  If the tuple being updated had just been updated and moved to another page by another session, there was a narrow window where we would attempt to fetch data from the new tuple version without any pin on its buffer. In principle this could result in garbage data appearing in non-updated columns of the proposed new tuple. The odds of problems in practice seem rather low, however.

- Avoid requesting an oversize shared-memory area in parallel hash join (Thomas Munro, Andrei Lepikhov, Alexander Korotkov)

  The limiting value was too large, allowing “invalid DSA memory alloc request size” errors to occur with sufficiently large expected hash table sizes.

- Avoid assertion failures in `heap_update()` and `heap_delete()` when a tuple to be updated by a foreign-key enforcement trigger fails the extra visibility crosscheck (Alexander Lakhin)

  This error had no impact in non-assert builds.

- Fix overly tight assertion about `false_positive_rate` parameter of BRIN bloom operator classes (Alexander Lakhin)

  This error had no impact in non-assert builds, either.

- Fix possible failure during `ALTER TABLE ADD COLUMN` on a complex inheritance tree (Tender Wang)

  If a grandchild table would inherit the new column via multiple intermediate parents, the command failed with “tuple already updated by self”.

- Fix problems with duplicate token names in `ALTER TEXT SEARCH CONFIGURATION ... MAPPING` commands (Tender Wang, Michael Paquier)

- Properly lock the associated table during `DROP STATISTICS` (Tomas Vondra)

  Failure to acquire the lock could result in “tuple concurrently deleted” errors if the `DROP` executes concurrently with `ANALYZE`.

- Fix function volatility checking for `GENERATED` and `DEFAULT` expressions (Tom Lane)

  These places could fail to detect insertion of a volatile function default-argument expression, or decide that a polymorphic function is volatile although it is actually immutable on the datatype of interest. This could lead to improperly rejecting or accepting a `GENERATED` clause, or to mistakenly applying the constant-default-value optimization in `ALTER TABLE ADD COLUMN`.

- Detect that a new catalog cache entry became stale while detoasting its fields (Tom Lane)

  We expand any out-of-line fields in a catalog tuple before inserting it into the catalog caches. That involves database access which might cause invalidation of catalog cache entries — but the new entry isn't in the cache yet, so we would miss noticing that it should get invalidated. The result is a race condition in which an already-stale cache entry could get made, and then persist indefinitely. This would lead to hard-to-predict misbehavior. Fix by rechecking the tuple's visibility after detoasting.

- Fix edge-case integer overflow detection bug on some platforms (Dean Rasheed)

  Computing `0 - INT64_MIN` should result in an overflow error, and did on most platforms. However, platforms with neither integer overflow builtins nor 128-bit integers would fail to spot the overflow, instead returning `INT64_MIN`.

- Detect Julian-date overflow when adding or subtracting an `interval` to/from a `timestamp` (Tom Lane)

  Some cases that should cause an out-of-range error produced an incorrect result instead.

- Add more checks for overflow in `interval_mul()` and `interval_div()` (Dean Rasheed)

  Some cases that should cause an out-of-range error produced an incorrect result instead.

- Make the `pg_file_settings` view check validity of unapplied values for settings with `backend` or `superuser-backend` context (Tom Lane)

  Invalid values were not noted in the view as intended. This escaped detection because there are very few settings in these groups.

- Match collation too when matching an existing index to a new partitioned index (Peter Eisentraut)

  Previously we could accept an index that has a different collation from the corresponding element of the partition key, possibly leading to misbehavior.

- Avoid failure if a child index is dropped concurrently with `REINDEX INDEX` on a partitioned index (Fei Changhong)

- Fix insufficient locking when cleaning up an incomplete split of a GIN index's internal page (Fei Changhong, Heikki Linnakangas)

  The code tried to do this with shared rather than exclusive lock on the buffer. This could lead to index corruption if two processes attempted the cleanup concurrently.

- Avoid premature release of buffer pin in GIN index insertion (Tom Lane)

If an index root page split occurs concurrently with our own insertion, the code could fail with “buffer NNNN is not owned by resource owner”.

- Avoid failure with partitioned SP-GiST indexes (Tom Lane)

  Trying to use an index of this kind could lead to “No such file or directory” errors.

- Fix ownership change reporting for large objects (Tom Lane)

  A no-op `ALTER LARGE OBJECT OWNER` command (that is, one selecting the existing owner) passed the wrong class ID to the `PostAlterHook`, probably confusing any extension using that hook.

- Prevent standby servers from incorrectly processing dead index tuples during subtransactions (Fei Changhong)

  The `startedInRecovery` flag was not correctly set for a subtransaction. This affects only processing of dead index tuples. It could allow a query in a subtransaction to ignore index entries that it should return (if they are already dead on the primary server, but not dead to the standby transaction), or to prematurely mark index entries as dead that are not yet dead on the primary. It is not clear that the latter case has any serious consequences, but it's not the intended behavior.

- Fix deadlock between a logical replication apply worker, its tablesync worker, and a session process trying to alter the subscription (Shlok Kyal)

  One edge of the deadlock loop did not involve a lock wait, so the deadlock went undetected and would persist until manual intervention.

- Prevent examining system catalogs with the wrong snapshot during logical decoding (Fei Changhong)

  If decoding begins partway through a transaction that modifies system catalogs, the decoder may not recognize that, causing it to fail to treat that transaction as in-progress for catalog lookups. This fix deals with the case that a top-level transaction is already marked as containing catalog changes, but its subtransaction(s) are not.

- Return the correct status code when a new client disconnects without responding to the server's password challenge (Liu Lang, Tom Lane)

  In some cases we'd treat this as a loggable error, which was not the intention and tends to create log spam, since common clients like psql frequently do this. It may also confuse extensions that use `ClientAuthentication_hook`.

- Fix incompatibility with OpenSSL 3.2 (Tristan Partin, Bo Andreson)

  Use the BIO “app_data” field for our private storage, instead of assuming it's okay to use the “data” field. This mistake didn't cause problems before, but with 3.2 it leads to crashes and complaints about double frees.

- Be more wary about OpenSSL not setting `errno` on error (Tom Lane)

  If `errno` isn't set, assume the cause of the reported failure is read EOF. This fixes rare cases of strange error reports like “could not accept SSL connection: Success”.

- Fix file descriptor leakage when a foreign data wrapper's `ForeignAsyncRequest` function fails (Heikki Linnakangas)

- Report ENOMEM errors from file-related system calls as `ERRCODE_OUT_OF_MEMORY`, not `ERRCODE_INTERNAL_ERROR` (Alexander Kuzmenkov)

- In PL/pgSQL, support SQL commands that are `CREATE FUNCTION`/`CREATE PROCEDURE` with SQL-standard bodies (Tom Lane)

  Previously, such cases failed with parsing errors due to the semicolon(s) appearing in the function body.

- Fix libpq's handling of errors in pipelines (Álvaro Herrera)

  The pipeline state could get out of sync if an error is returned for reasons other than a query problem (for example, if the connection is lost). Potentially this would lead to a busy-loop in the calling application.

- Make libpq's `PQsendFlushRequest()` function flush the client output buffer under the same rules as other `PQsend` functions (Jelte Fennema-Nio)

  In pipeline mode, it may still be necessary to call `PQflush()` as well; but this change removes some inconsistency.

- Avoid race condition when libpq initializes OpenSSL support concurrently in two different threads (Willi Mann, Michael Paquier)

- Fix timing-dependent failure in GSSAPI data transmission (Tom Lane)

  When using GSSAPI encryption in non-blocking mode, libpq sometimes failed with “GSSAPI caller failed to retransmit all data needing to be retried”.

- In pg_dump, don't dump RLS policies or security labels for extension member objects (Tom Lane, Jacob Champion)

  Previously, commands would be included in the dump to set these properties, which is really incorrect since they should be considered as internal affairs of the extension. Moreover, the restoring user might not have adequate privilege to set them, and indeed the dumping user might not have enough privilege to dump them (since dumping RLS policies requires acquiring lock on their table).

- In pg_dump, don't dump an extended statistics object if its underlying table isn't being dumped (Rian McGuire, Tom Lane)

  This conforms to the behavior for other dependent objects such as indexes.

- Make it an error for a pgbench script to end with an open pipeline (Anthonin Bonnefoy)

  Previously, pgbench would behave oddly if a `\startpipeline` command lacked a matching `\endpipeline`. This seems like a scripting mistake rather than a case that pgbench needs to handle nicely, so throw an error.

- Fix crash in `contrib/intarray` if an array with an element equal to `INT_MAX` is inserted into a `gist__int_ops` index (Alexander Lakhin, Tom Lane)

- Report a better error when `contrib/pageinspect`'s `hash_bitmap_info()` function is applied to a partitioned hash index (Alexander Lakhin, Michael Paquier)

- Report a better error when `contrib/pgstattuple`'s `pgstathashindex()` function is applied to a partitioned hash index (Alexander Lakhin)

- On Windows, suppress autorun options when launching subprocesses in pg_ctl and pg_regress (Kyotaro Horiguchi)

  When launching a child process via `cmd.exe`, pass the `/D` flag to prevent executing any autorun commands specified in the registry. This avoids possibly-surprising side effects.

- Fix compilation failures with libxml2 version 2.12.0 and later (Tom Lane)

- Fix compilation failure of `WAL_DEBUG` code on Windows (Bharath Rupireddy)

- Suppress compiler warnings from Python's header files (Peter Eisentraut, Tom Lane)

  Our preferred compiler options provoke warnings about constructs appearing in recent versions of Python's header files. When using gcc, we can suppress these warnings with a pragma.

- Avoid deprecation warning when compiling with LLVM 18 (Thomas Munro)

- Update time zone data files to tzdata release 2024a for DST law changes in Greenland, Kazakhstan, and Palestine, plus corrections for the Antarctic stations Casey and Vostok. Also historical corrections for Vietnam, Toronto, and Miquelon. (Tom Lane)

E.30. Release 14.10

Release date: 2023-11-09

This release contains a variety of fixes from 14.9. For information about new features in major release 14, see Section E.40.

E.30.1. Migration to Version 14.10

A dump/restore is not required for those running 14.X.

However, several mistakes have been discovered that could lead to certain types of indexes yielding wrong search results or being unnecessarily inefficient. It is advisable to `REINDEX` potentially-affected indexes after installing this update. See the fourth through seventh changelog entries below.

Also, if you are upgrading from a version earlier than 14.9, see Section E.31.

E.30.2. Changes

- Fix handling of unknown-type arguments in `DISTINCT "any"` aggregate functions (Tom Lane)

  This error led to a `text`-type value being interpreted as an `unknown`-type value (that is, a zero-terminated string) at runtime. This could result in disclosure of server memory following the `text` value.

  The PostgreSQL Project thanks Jingzhou Fu for reporting this problem. (CVE-2023-5868)

- Detect integer overflow while computing new array dimensions (Tom Lane)

  When assigning new elements to array subscripts that are outside the current array bounds, an undetected integer overflow could occur in edge cases. Memory stomps that are potentially exploitable for arbitrary code execution are possible, and so is disclosure of server memory.

  The PostgreSQL Project thanks Pedro Gallegos for reporting this problem. (CVE-2023-5869)

- Prevent the `pg_signal_backend` role from signalling background workers and autovacuum processes (Noah Misch, Jelte Fennema-Nio)

  The documentation says that `pg_signal_backend` cannot issue signals to superuser-owned processes. It was able to signal these background processes, though, because they advertise a role OID of zero. Treat that as indicating superuser ownership. The security implications of cancelling one of these process types are fairly small so far as the core code goes (we'll just start another one), but extensions might add background workers that are more vulnerable.

  Also ensure that the `is_superuser` parameter is set correctly in such processes. No specific security consequences are known for that oversight, but it might be significant for some extensions.

  The PostgreSQL Project thanks Hemanth Sandrana and Mahendrakar Srinivasarao for reporting this problem. (CVE-2023-5870)

- Fix misbehavior during recursive page split in GiST index build (Heikki Linnakangas)

  Fix a case where the location of a page downlink was incorrectly tracked, and introduce some logic to allow recovering from such situations rather than silently doing the wrong thing. This error could result in incorrect answers from subsequent index searches. It may be advisable to reindex all GiST indexes after installing this update.

- Prevent de-duplication of btree index entries for `interval` columns (Noah Misch)

  There are `interval` values that are distinguishable but compare equal, for example `24:00:00` and `1 day`. This breaks assumptions made by btree de-duplication, so `interval` columns need to be excluded from de-duplication. This oversight can cause incorrect results from index-only scans. Moreover, after updating amcheck will report an error for almost all such indexes. Users should reindex any btree indexes on `interval` columns.

- Process `date` values more sanely in BRIN `datetime_minmax_multi_ops` indexes (Tomas Vondra)

  The distance calculation for dates was backward, causing poor decisions about which entries to merge. The index still produces correct results, but is much less efficient than it should be. Reindexing BRIN `minmax_multi` indexes on `date` columns is advisable.

- Process large `timestamp` and `timestamptz` values more sanely in BRIN `datetime_minmax_multi_ops` indexes (Tomas Vondra)

  Infinities were mistakenly treated as having distance zero rather than a large distance from other values, causing poor decisions about which entries to merge. Also, finite-but-very-large values (near the endpoints of the representable timestamp range) could result in internal overflows, again causing poor decisions. The index still produces correct results, but is much less efficient than it should be. Reindexing BRIN `minmax_multi` indexes on `timestamp` and `timestamptz` columns is advisable if the column contains, or has contained, infinities or large finite values.

- Avoid calculation overflows in BRIN `interval_minmax_multi_ops` indexes with extreme interval values (Tomas Vondra)

  This bug might have caused unexpected failures while trying to insert large interval values into such an index.

- Fix partition step generation and runtime partition pruning for hash-partitioned tables with multiple partition keys (David Rowley)

  Some cases involving an `IS NULL` condition on one of the partition keys could result in a crash.

- Correctly identify the target table in an inherited `UPDATE`/`DELETE`/`MERGE` even when the parent table is excluded by constraints (Amit Langote, Tom Lane)

  If the initially-named table is excluded by constraints, but not all its inheritance descendants are, the first non-excluded descendant was identified as the primary target table. This would lead to firing statement-level triggers associated with that table, rather than the initially-named table as should happen. In v16, the same oversight could also lead to “invalid perminfoindex 0 in RTE with relid NNNN” errors.

- Fix edge case in btree mark/restore processing of ScalarArrayOpExpr clauses (Peter Geoghegan)

  When restoring an indexscan to a previously marked position, the code could miss required setup steps if the scan had advanced exactly to the end of the matches for a ScalarArrayOpExpr (that is, an `indexcol = ANY(ARRAY[])`) clause. This could result in missing some rows that should have been fetched.

- Fix intra-query memory leak in Memoize execution (Orlov Aleksej, David Rowley)

- Fix intra-query memory leak when a set-returning function repeatedly returns zero rows (Tom Lane)

- Don't crash if `cursor_to_xmlschema()` is applied to a non-data-returning Portal (Boyu Yang)

- Throw the intended error if `pgrowlocks()` is applied to a partitioned table (David Rowley)

  Previously, a not-on-point complaint “only heap AM is supported” would be raised.

- Handle invalid indexes more cleanly in assorted SQL functions (Noah Misch)

  Report an error if `pgstatindex()`, `pgstatginindex()`, `pgstathashindex()`, or `pgstattuple()` is applied to an invalid index. If `brin_desummarize_range()`, `brin_summarize_new_values()`, `brin_summarize_range()`, or `gin_clean_pending_list()` is applied to an invalid index, do nothing except to report a debug-level message. Formerly these functions attempted to process the index, and might fail in strange ways depending on what the failed `CREATE INDEX` had left behind.

- Avoid premature memory allocation failure with long inputs to `to_tsvector()` (Tom Lane)

- Fix over-allocation of the constructed `tsvector` in `tsvectorrecv()` (Denis Erokhin)

If the incoming vector includes position data, the binary receive function left wasted space (roughly equal to the size of the position data) in the finished `tsvector`. In extreme cases this could lead to "maximum total lexeme length exceeded" failures for vectors that were under the length limit when emitted. In any case it could lead to wasted space on-disk.

- Fix incorrect coding in `gtsvector_picksplit()` (Alexander Lakhin)

  This could lead to poor page-split decisions in GiST indexes on `tsvector` columns.

- Improve checks for corrupt PGLZ compressed data (Flavien Guedez)

- Fix `COMMIT AND CHAIN`/`ROLLBACK AND CHAIN` to work properly when there is an unreleased savepoint (Liu Xiang, Tom Lane)

  Instead of propagating the current transaction's properties to the new transaction, they propagated some previous transaction's properties.

- In `COPY FROM`, fail cleanly when an unsupported encoding conversion is needed (Tom Lane)

  Recent refactoring accidentally removed the intended error check for this, such that it ended in "cache lookup failed for function 0" instead of a useful error message.

- Avoid crash in `EXPLAIN` if a parameter marked to be displayed by `EXPLAIN` has a NULL boot-time value (Xing Guo, Aleksander Alekseev, Tom Lane)

  No built-in parameter fits this description, but an extension could define such a parameter.

- Ensure we have a snapshot while dropping `ON COMMIT DROP` temp tables (Tom Lane)

  This prevents possible misbehavior if any catalog entries for the temp tables have fields wide enough to require toasting (such as a very complex `CHECK` condition).

- Avoid improper response to shutdown signals in child processes just forked by `system()` (Nathan Bossart)

  This fix avoids a race condition in which a child process that has been forked off by `system()`, but hasn't yet exec'd the intended child program, might receive and act on a signal intended for the parent server process. That would lead to duplicate cleanup actions being performed, which will not end well.

- Cope with torn reads of `pg_control` in frontend programs (Thomas Munro)

  On some file systems, reading `pg_control` may not be an atomic action when the server concurrently writes that file. This is detectable via a bad CRC. Retry a few times to see if the file becomes valid before we report error.

- Avoid torn reads of `pg_control` in relevant SQL functions (Thomas Munro)

  Acquire the appropriate lock before reading `pg_control`, to ensure we get a consistent view of that file.

- Avoid integer overflow when computing size of backend activity string array (Jakub Wartak)

  On 64-bit machines we will allow values of `track_activity_query_size` large enough to cause 32-bit overflow when multiplied by the allowed number of connections. The code actually allocating the per-backend local array was careless about this though, and allocated the array incorrectly.

- Fix briefly showing inconsistent progress statistics for `ANALYZE` on inherited tables (Heikki Linnakangas)

  The block-level counters should be reset to zero at the same time we update the current-relation field.

- Fix the background writer to report any WAL writes it makes to the statistics counters (Nazir Bilal Yavuz)

- Track the dependencies of cached `CALL` statements, and re-plan them when needed (Tom Lane)

  DDL commands, such as replacement of a function that has been inlined into a `CALL` argument, can create the need to re-plan a `CALL` that has been cached by PL/pgSQL. That was not happening, leading to misbehavior or strange errors such as “cache lookup failed”.

- Track nesting depth correctly when inspecting `RECORD`-type Vars from outer query levels (Richard Guo)

  This oversight could lead to assertion failures, core dumps, or “bogus varno” errors.

- Track hash function and negator function dependencies of ScalarArrayOpExpr plan nodes (David Rowley)

  In most cases this oversight was harmless, since these functions would be unlikely to disappear while the node's original operator remains present.

- Fix error-handling bug in `RECORD` type cache management (Thomas Munro)

  An out-of-memory error occurring at just the wrong point could leave behind inconsistent state that would lead to an infinite loop.

- Fix assertion failure when logical decoding is retried in the same session after an error (Hou Zhijie)

- Treat out-of-memory failures as fatal while reading WAL (Michael Paquier)

  Previously this would be treated as a bogus-data condition, leading to the conclusion that we'd reached the end of WAL, which is incorrect and could lead to inconsistent WAL replay.

- Fix possible recovery failure due to trying to allocate memory based on a bogus WAL record length field (Thomas Munro, Michael Paquier)

- Ensure that standby-mode WAL recovery reports an error when an invalid page header is found (Yugo Nagata, Kyotaro Horiguchi)

- Fix datatype size confusion in logical tape management (Ranier Vilela)

  Integer overflow was possible on platforms where long is wider than int, although it would take a multiple-terabyte temporary file to cause a problem.

- Avoid unintended close of syslogger process's stdin (Heikki Linnakangas)

- Avoid doing plan cache revalidation of utility statements that do not receive interesting processing during parse analysis (Tom Lane)

  Aside from saving a few cycles, this prevents failure after a cache invalidation for statements that must not set a snapshot, such as `SET TRANSACTION ISOLATION LEVEL`.

- Keep by-reference `attmissingval` values in a long-lived context while they are being used (Andrew Dunstan)

  This avoids possible use of dangling pointers when a tuple slot outlives the tuple descriptor with which its value was constructed.

- Recalculate the effective value of `search_path` after `ALTER ROLE` (Jeff Davis)

  This ensures that after renaming a role, the meaning of the special string `$user` is re-determined.

- Fix “could not duplicate handle” error occurring on Windows when `min_dynamic_shared_memory` is set above zero (Thomas Munro)

- Fix order of operations in `GenericXLogFinish` (Jeff Davis)

  This code violated the conditions required for crash safety by writing WAL before marking changed buffers dirty. No core code uses this function, but extensions do (`contrib/bloom` does, for example).

- Remove incorrect assertion in PL/Python exception handling (Alexander Lakhin)
- Fix pg_restore so that selective restores will include both table-level and column-level ACLs for selected tables (Euler Taveira, Tom Lane)

  Formerly, only the table-level ACL would get restored if both types were present.
- Add logic to pg_upgrade to check for use of `abstime`, `reltime`, and `tinterval` data types (Álvaro Herrera)

  These obsolete data types were removed in PostgreSQL version 12, so check to make sure they aren't present in an older database before claiming it can be upgraded.
- Avoid generating invalid temporary slot names in pg_basebackup (Jelte Fennema)

  This has only been seen to occur when the server connection runs through pgbouncer.
- Avoid false “too many client connections” errors in pgbench on Windows (Noah Misch)
- In `contrib/amcheck`, do not report interrupted page deletion as corruption (Noah Misch)

  This fix prevents false-positive reports of “the first child of leftmost target page is not leftmost of its level”, “block NNNN is not leftmost” or “left link/right link pair in index XXXX not in agreement”. They appeared if amcheck ran after an unfinished btree index page deletion and before `VACUUM` had cleaned things up.
- Fix failure of `contrib/btree_gin` indexes on `interval` columns, when an indexscan using the `<` or `<=` operator is performed (Dean Rasheed)

  Such an indexscan failed to return all the entries it should.
- Add support for LLVM 16 and 17 (Thomas Munro, Dmitry Dolgov)
- Suppress assorted build-time warnings on recent macOS (Tom Lane)

  Xcode 15 (released with macOS Sonoma) changed the linker's behavior in a way that causes many duplicate-library warnings while building PostgreSQL. These were harmless, but they're annoying so avoid citing the same libraries twice. Also remove use of the `-multiply_defined suppress` linker switch, which apparently has been a no-op for a long time, and is now actively complained of.
- When building `contrib/unaccent`'s rules file, fall back to using `python` if `--with-python` was not given and make variable `PYTHON` was not set (Japin Li)
- Remove `PHOT` (Phoenix Islands Time) from the default timezone abbreviations list (Tom Lane)

  Presence of this abbreviation in the default list can cause failures on recent Debian and Ubuntu releases, as they no longer install the underlying tzdb entry by default. Since this is a made-up abbreviation for a zone with a total human population of about two dozen, it seems unlikely that anyone will miss it. If someone does, they can put it back via a custom abbreviations file.

E.31. Release 14.9

Release date: 2023-08-10

This release contains a variety of fixes from 14.8. For information about new features in major release 14, see Section E.40.

E.31.1. Migration to Version 14.9

A dump/restore is not required for those running 14.X.

However, if you use BRIN indexes, it may be advisable to reindex them; see the second changelog entry below.

Also, if you are upgrading from a version earlier than 14.4, see Section E.36.

E.31.2. Changes

- Disallow substituting a schema or owner name into an extension script if the name contains a quote, backslash, or dollar sign (Noah Misch)

  This restriction guards against SQL-injection hazards for trusted extensions.

  The PostgreSQL Project thanks Micah Gates, Valerie Woolard, Tim Carey-Smith, and Christoph Berg for reporting this problem. (CVE-2023-39417)

- Fix confusion between empty (no rows) ranges and all-NULL ranges in BRIN indexes, as well as incorrect merging of all-NULL summaries (Tomas Vondra)

  Each of these oversights could result in forgetting that a BRIN index range contains any NULL values, potentially allowing subsequent queries that should return NULL values to miss doing so.

  This fix will not in itself correct faulty BRIN entries. It's recommended to `REINDEX` any BRIN indexes that may be used to search for nulls.

- Avoid leaving a corrupted database behind when `DROP DATABASE` is interrupted (Andres Freund)

  If `DROP DATABASE` was interrupted after it had already begun taking irreversible steps, the target database remained accessible (because the removal of its `pg_database` row would roll back), but it would have corrupt contents. Fix by marking the database as inaccessible before we begin to perform irreversible operations. A failure after that will leave the database still partially present, but nothing can be done with it except to issue another `DROP DATABASE`.

- Ensure that partitioned indexes are correctly marked as valid or not at creation (Michael Paquier)

  If a new partitioned index matches an existing but invalid index on one of the partitions, the partitioned index could end up being marked valid prematurely. This could lead to misbehavior or assertion failures in subsequent queries on the partitioned table.

- Ignore invalid child indexes when matching partitioned indexes to child indexes during `ALTER TABLE ATTACH PARTITION` (Michael Paquier)

  Such an index will now be ignored, and a new child index created instead.

- Fix possible failure when marking a partitioned index valid after all of its partitions have been attached (Michael Paquier)

  The update of the index's `pg_index` entry could use stale data for other columns. One reported symptom is an “attempted to update invisible tuple” error.

- Fix `ALTER EXTENSION SET SCHEMA` to complain if the extension contains any objects outside the extension's schema (Michael Paquier, Heikki Linnakangas)

  Erroring out if the extension contains objects in multiple schemas was always intended; but the check was mis-coded so that it would fail to detect some cases, leading to surprising behavior.

- Don't use partial unique indexes for uniqueness proofs in the planner (David Rowley)

  This could give rise to incorrect plans, since the presumed uniqueness of rows read from a table might not hold if the index in question isn't used to scan the table.

- Don't Memoize lateral joins with volatile join conditions (Richard Guo)

  Applying Memoize to a sub-plan that contains volatile filter conditions is likely to lead to wrong answers. The check to avoid doing this missed some cases that can arise when using `LATERAL`.

- Avoid producing incorrect plans for foreign joins with pseudoconstant join clauses (Etsuro Fujita)

  The planner currently lacks support for attaching pseudoconstant join clauses to a pushed-down remote join, so disable generation of remote joins in such cases. (A better solution will require ABI-breaking changes of planner data structures, so it will have to wait for a future major release.)

- Correctly handle sub-SELECTs in RLS policy expressions and security-barrier views when expanding rule actions (Tom Lane)
- Fix race conditions in conflict detection for `SERIALIZABLE` isolation mode (Thomas Munro)

  Conflicts could be missed when using bitmap heap scans, when using GIN indexes, and when examining an initially-empty btree index. All these cases could lead to serializability failures due to improperly allowing conflicting transactions to commit.
- Fix misbehavior of EvalPlanQual checks with inherited or partitioned target tables (Tom Lane)

  This oversight could lead to update or delete actions in `READ COMMITTED` isolation mode getting performed when they should have been skipped because of a conflicting concurrent update.
- Fix hash join with an inner-side hash key that contains Params coming from an outer nested loop (Tom Lane)

  When rescanning the join after the values of such Params have changed, we must rebuild the hash table, but neglected to do so. This could result in missing join output rows.
- Fix intermittent failures when trying to update a field of a composite column (Tom Lane)

  If the overall value of the composite column is wide enough to require out-of-line toasting, then an unluckily-timed cache flush could cause errors or server crashes.
- Prevent query-lifespan memory leaks in some `UPDATE` queries with triggers (Tomas Vondra)
- Prevent query-lifespan memory leaks when an Incremental Sort plan node is rescanned (James Coleman, Laurenz Albe, Tom Lane)
- Accept fractional seconds in the input to `jsonpath`'s `datetime()` method (Tom Lane)
- Prevent stack-overflow crashes with very complex text search patterns (Tom Lane)
- Allow tokens up to 10240 bytes long in `pg_hba.conf` and `pg_ident.conf` (Tom Lane)

  The previous limit of 256 bytes has been found insufficient for some use-cases.
- Fix mishandling of C++ out-of-memory conditions (Heikki Linnakangas)

  If JIT is in use, running out of memory in a C++ `new` call would lead to a PostgreSQL FATAL error, instead of the expected C++ exception.
- Fix rare null-pointer crash in `plancache.c` (Tom Lane)
- Avoid losing track of possibly-useful shared memory segments when a page free results in coalescing ranges of free space (Dongming Liu)

  Ensure that the segment is moved into the appropriate “bin” for its new amount of free space, so that it will be found by subsequent searches.
- Allow `VACUUM` to continue after detecting certain types of b-tree index corruption (Peter Geoghegan)

  If an invalid sibling-page link is detected, log the issue and press on, rather than throwing an error as before. Nothing short of `REINDEX` will fix the broken index, but preventing `VACUUM` from completing until that is done risks making matters far worse.
- Ensure that `WrapLimitsVacuumLock` is released after `VACUUM` detects invalid data in `pg_database.datfrozenxid` or `pg_database.datminmxid` (Andres Freund)

  Failure to release this lock could lead to a deadlock later, although the lock would be cleaned up if the session exits or encounters some other error.
- Avoid double replay of prepared transactions during crash recovery (suyu.cmj, Michael Paquier)

  After a crash partway through a checkpoint with some two-phase transaction state data already flushed to disk by this checkpoint, crash recovery could attempt to replay the prepared transaction(s) twice, leading to a fatal error such as “lock is already held” in the startup process.

- Fix possible failure while promoting a standby server, if archiving is enabled and two-phase transactions need to be recovered (Julian Markwort)

  If any required two-phase transactions were logged in the most recent (partial) log segment, promotion would fail with an incorrect complaint about “requested WAL segment has already been removed”.

- Ensure that a newly created, but still empty table is `fsync`'ed at the next checkpoint (Heikki Linnakangas)

  Without this, if there is an operating system crash causing the empty file to disappear, subsequent operations on the table might fail with “could not open file” errors.

- Ensure that creation of the init fork of an unlogged index is WAL-logged (Heikki Linnakangas)

  While an unlogged index's main data fork is not WAL-logged, its init fork should be, to ensure that we have a consistent state to restore the index to after a crash. This step was missed if the init fork contains no data, which is a case not used by any standard index AM; but perhaps some extension behaves that way.

- Fix missing reinitializations of delay-checkpoint-end flags (suyu.cmj)

  This could result in unnecessary delays of checkpoints, or in assertion failures in assert-enabled builds.

- Fix overly strict assertion in `jsonpath` code (David Rowley)

  This assertion failed if a query applied the `.type()` operator to a `like_regex` result. There was no bug in non-assert builds.

- Avoid assertion failure when processing an empty statement via the extended query protocol in an already-aborted transaction (Tom Lane)

- Fix `contrib/fuzzystrmatch`'s Soundex `difference()` function to handle empty input sanely (Alexander Lakhin, Tom Lane)

  An input string containing no alphabetic characters resulted in unpredictable output.

- Tighten whitespace checks in `contrib/hstore` input (Evan Jones)

  In some cases, characters would be falsely recognized as whitespace and hence discarded.

- Disallow oversize input arrays with `contrib/intarray`'s `gist__int_ops` index opclass (Ankit Kumar Pandey, Alexander Lakhin)

  Previously this code would report a `NOTICE` but press on anyway, creating an invalid index entry that presents a risk of crashes when the index is read.

- Avoid useless double decompression of GiST index entries in `contrib/intarray` (Konstantin Knizhnik, Matthias van de Meent, Tom Lane)

- Fix `contrib/pageinspect`'s `gist_page_items()` function to work when there are included index columns (Alexander Lakhin, Michael Paquier)

  Previously, if the index has included columns, `gist_page_items()` would fail to display those values on index leaf pages, or crash outright on non-leaf pages.

- Fix pg_dump to correctly handle new-style SQL-language functions whose bodies require parse-time dependencies on unique indexes (Tom Lane)

  Such cases can arise from `GROUP BY` and `ON CONFLICT` clauses, for example. The function must then be postponed until after the unique index in the dump output, but pg_dump did not do that and instead printed a warning about “could not resolve dependency loop”.

- Ensure that `pg_index.indisreplident` is kept up-to-date in relation cache entries (Shruthi Gowda)

This value could be stale in some cases. There is no core code that relies on the relation cache's copy, so this is only a latent bug as far as Postgres itself is concerned; but there may be extensions for which it is a live bug.

E.32. Release 14.8

Release date: 2023-05-11

This release contains a variety of fixes from 14.7. For information about new features in major release 14, see Section E.40.

E.32.1. Migration to Version 14.8

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.4, see Section E.36.

E.32.2. Changes

- Prevent `CREATE SCHEMA` from defeating changes in `search_path` (Alexander Lakhin)

  Within a `CREATE SCHEMA` command, objects in the prevailing `search_path`, as well as those in the newly-created schema, would be visible even within a called function or script that attempted to set a secure `search_path`. This could allow any user having permission to create a schema to hijack the privileges of a security definer function or extension script.

  The PostgreSQL Project thanks Alexander Lakhin for reporting this problem. (CVE-2023-2454)

- Enforce row-level security policies correctly after inlining a set-returning function (Stephen Frost, Tom Lane)

  If a set-returning SQL-language function refers to a table having row-level security policies, and it can be inlined into a calling query, those RLS policies would not get enforced properly in some cases involving re-using a cached plan under a different role. This could allow a user to see or modify rows that should have been invisible.

  The PostgreSQL Project thanks Wolfgang Walther for reporting this problem. (CVE-2023-2455)

- Avoid crash when the new schema name is omitted in `CREATE SCHEMA` (Michael Paquier)

  The SQL standard allows writing `CREATE SCHEMA AUTHORIZATION` *`owner_name`*, with the schema name defaulting to *`owner_name`*. However some code paths expected the schema name to be present and would fail.

- Fix enabling/disabling of cloned triggers in partitioned tables (Tom Lane)

  `ALTER TABLE ... ENABLE/DISABLE TRIGGER USER` skipped cloned triggers, mistaking them for system triggers. Other variants of `ENABLE/DISABLE TRIGGER` would process them, but only after improperly enforcing a superuserness check.

- Disallow altering composite types that are stored in indexes (Tom Lane)

  `ALTER TYPE` disallows non-binary-compatible modifications of composite types if they are stored in any table columns. (Perhaps that will be allowed someday, but it hasn't happened yet; the locking implications of rewriting many tables are daunting.) We overlooked the possibility that an index might contain a composite type that doesn't also appear in its table.

- Disallow system columns as elements of foreign keys (Tom Lane)

  Since the removal of OID as a system column, there is no plausible use-case for this, and various bits of code no longer support it. Disallow it rather than trying to fix all the cases.

- Ensure that `COPY TO` from an RLS-enabled parent table does not copy any rows from child tables (Antonin Houska)

  The documentation is quite clear that `COPY TO` copies rows from only the named table, not any inheritance children it may have. However, if row-level security was enabled on the table then this stopped being true.

- Avoid possible crash when `array_position()` or `array_positions()` is passed an empty array (Tom Lane)

- Fix possible out-of-bounds fetch in `to_char()` (Tom Lane)

  With bad luck this could have resulted in a server crash.

- Avoid buffer overread in `translate()` function (Daniil Anisimov)

  When using the deletion feature, the function might fetch the byte just after the input string, creating a small risk of crash.

- Fix error cursor setting for parse errors in JSON string literals (Tom Lane)

  Most cases in which a syntax error is detected in a string literal within a JSON value failed to set the error cursor appropriately. This led at least to an unhelpful error message (pointing to the token before the string, rather than the actual trouble spot), and could even result in a crash in v14 and later.

- Fix data corruption due to `vacuum_defer_cleanup_age` being larger than the current 64-bit xid (Andres Freund)

  In v14 and later with non-default settings of `vacuum_defer_cleanup_age`, it was possible to compute a very large vacuum cleanup horizon xid, leading to vacuum removing rows that are still live. v12 and v13 have a lesser form of the same problem affecting only GiST indexes, which could lead to index pages getting recycled too early.

- Fix parser's failure to detect some cases of improperly-nested aggregates (Tom Lane)

  This oversight could lead to executor failures for queries that should have been rejected as invalid.

- Fix data structure corruption during parsing of serial `SEQUENCE NAME` options (David Rowley)

  This can lead to trouble if an event trigger captures the corrupted parse tree.

- Correctly update plan nodes' parallel-safety markings when moving initplans from one node to another (Tom Lane)

  This planner oversight could lead to “subplan was not initialized” errors at runtime.

- Avoid failure with PlaceHolderVars in extended-statistics code (Tom Lane)

  Use of dependency-type extended statistics could fail with “PlaceHolderVar found where not expected”.

- Disable the inverse-transition optimization for window aggregates when the call contains sub-SELECTs (David Rowley)

  This optimization requires that the aggregate's argument expressions have repeatable results, which might not hold for a sub-SELECT.

- Fix oversights in execution of nested `ARRAY[]` constructs (Alexander Lakhin, Tom Lane)

  Correctly detect overflow of the total space needed for the result array, avoiding a possible crash due to undersized output allocation. Also ensure that any trailing padding space in the result array is zeroed; while leaving garbage there is harmless for most purposes, it can result in odd behavior later.

- Prevent crash when updating a field within an array-of-domain-over-composite-type column (Dmitry Dolgov)
- Fix partition pruning logic for partitioning on boolean columns (David Rowley)

  Pruning with a condition like `boolcol IS NOT TRUE` was done incorrectly, leading to possibly not returning rows in which `boolcol` is NULL. Also, the rather unlikely case of partitioning on `NOT boolcol` was handled incorrectly.
- Fix race condition in per-batch cleanup during parallel hash join (Thomas Munro, Melanie Plageman)

  A crash was possible given unlucky timing and `parallel_leader_participation` = `off` (which is not the default).
- Recalculate `GENERATED` columns after an EvalPlanQual check (Tom Lane)

  In `READ COMMITTED` isolation mode, the effects of a row update might need to get reapplied to a newer version of the row than the query found originally. If so, we need to recompute any `GENERATED` columns, in case they depend on columns that were changed by the concurrent update.
- Fix memory leak in Memoize plan execution (David Rowley)
- Fix buffer refcount leak when using batched inserts for a foreign table included in a partitioned tree (Alexander Pyhalov)
- Restore support for sub-millisecond `vacuum_cost_delay` settings (Thomas Munro)
- Don't balance vacuum cost delay when a table has a per-relation `vacuum_cost_delay` setting of zero (Masahiko Sawada)

  Delay balancing is supposed to be disabled whenever autovacuum is processing a table with a per-relation `vacuum_cost_delay` setting, but this was done only for positive settings, not zero.
- Fix corner-case crashes when columns have been added to the end of a view (Tom Lane)
- Repair rare failure of MULTIEXPR_SUBLINK subplans in partitioned updates (Andres Freund, Tom Lane)

  Use of the syntax `INSERT ... ON CONFLICT DO UPDATE SET (c1, ...) = (SELECT ...)` with a partitioned target table could result in failure if any child table is dissimilar from the parent (for example, different physical column order). This typically manifested as failure of consistency checks in the executor; but a crash or incorrect data updates are also possible.
- Fix handling of `DEFAULT` markers within a multi-row `INSERT ... VALUES` query on a view that has a `DO ALSO INSERT ... SELECT` rule (Dean Rasheed)

  Such cases typically failed with “unrecognized node type” errors or assertion failures.
- Support references to `OLD` and `NEW` within subqueries in rule actions (Dean Rasheed, Tom Lane)

  Such references are really lateral references, but the server could crash if the subquery wasn't explicitly marked with `LATERAL`. Arrange to do that implicitly when necessary.
- When decompiling a rule or SQL function body containing `INSERT`/`UPDATE`/`DELETE` within `WITH`, take care to print the correct alias for the target table (Tom Lane)
- Fix glitches in `SERIALIZABLE READ ONLY` optimization (Thomas Munro)

  Transactions already marked as “doomed” confused the safe-snapshot optimization for `SERIALIZABLE READ ONLY` transactions. The optimization was unnecessarily skipped in some cases. In other cases an assertion failure occurred (but there was no problem in non-assert builds).
- Avoid leaking cache callback slots in the `pgoutput` logical decoding plugin (Shi Yu)

  Multiple cycles of starting up and shutting down the plugin within a single session would eventually lead to an “out of relcache_callback_list slots” error.

- Avoid unnecessary calls to custom validators for index operator class options (Alexander Korotkov)

  This change fixes some cases where an unexpected error was thrown.

- Avoid useless work while scanning a multi-column BRIN index with multiple scan keys (Tomas Vondra)

  The existing code effectively considered only the last scan key while deciding whether a range matched, thus usually scanning more of the index than it needed to.

- Fix netmask handling in BRIN inet_minmax_multi_ops opclass (Tomas Vondra)

  This error triggered an assertion failure in assert-enabled builds, but is mostly harmless in production builds.

- Fix dereference of dangling pointer during buffering build of a GiST index (Alexander Lakhin)

  This error seems to usually be harmless in production builds, as the fetched value is noncritical; but in principle it could cause a server crash.

- Ignore dropped columns and generated columns during logical replication of an update or delete action (Onder Kalaci, Shi Yu)

  Replication with the `REPLICA IDENTITY FULL` option failed if the table contained such columns.

- Correct the name of the wait event for SLRU buffer I/O for commit timestamps (Alexander Lakhin)

  This wait event is named `CommitTsBuffer` according to the documentation, but the code had it as `CommitTSBuffer`. Change the code to match the documentation, as that way is more consistent with the naming of related wait events.

- Re-activate reporting of wait event `SLRUFlushSync` (Thomas Munro)

  Reporting of this type of wait was accidentally removed in code refactoring.

- Avoid possible underflow when calculating how many WAL segments to keep (Kyotaro Horiguchi)

  This could result in not honoring `wal_keep_size` accurately.

- Support RSA-PSS certificates with SCRAM-SHA-256 channel binding (Jacob Champion, Heikki Linnakangas)

  This feature requires building with OpenSSL 1.1.1 or newer. Both the server and libpq are affected.

- Avoid race condition with process ID tracking on Windows (Thomas Munro)

  The operating system could recycle a PID before the postmaster observed that that child process was gone. This could lead to tracking more than one child with the same PID, resulting in confusion.

- Add missing cases to `SPI_result_code_string()` (Dean Rasheed)

- Fix erroneous Valgrind markings in `AllocSetRealloc()` (Karina Litskevich)

  In the unusual case where the size of a large (>8kB) palloc chunk is decreased, a Valgrind-aware build would mismark the defined-ness state of the memory released from the chunk, possibly causing incorrect results during Valgrind testing.

- Avoid assertion failure when decoding a transactional logical replication message (Tomas Vondra)

- Avoid locale sensitivity when processing regular expression escapes (Jeff Davis)

  A backslash followed by a non-ASCII character could sometimes cause an assertion failure, depending on the prevailing locale.

- Avoid trying to write an empty WAL record in `log_newpage_range()` when the last few pages in the specified range are empty (Matthias van de Meent)

It is not entirely clear whether this case is reachable in released branches, but if it is then an assertion failure could occur.

- Fix session-lifespan memory leakage in plpgsql `DO` blocks that use cast expressions (Ajit Awekar, Tom Lane)
- Tighten array dimensionality checks when converting Perl list structures to multi-dimensional SQL arrays (Tom Lane)

  plperl could misbehave when the nesting of sub-lists is inconsistent so that the data does not represent a rectangular array of values. Such cases now produce errors, but previously they could result in a crash or garbage output.
- Tighten array dimensionality checks when converting Python list structures to multi-dimensional SQL arrays (Tom Lane)

  plpython could misbehave when dealing with empty sub-lists, or when the nesting of sub-lists is inconsistent so that the data does not represent a rectangular array of values. The former should result in an empty output array, and the latter in an error. But some cases resulted in a crash, and others in unexpected output.
- Fix unwinding of exception stack in plpython (Xing Guo)

  Some rare failure cases could return without cleaning up the PG_TRY exception stack, risking a crash if another error was raised before the next stack level was unwound.
- Fix inconsistent GSS-encryption error handling in libpq's `PQconnectPoll()` (Michael Paquier)

  With `gssencmode` set to `require`, the connection was not marked dead after a GSS initialization failure. Make it fail immediately, as the equivalent case for TLS encryption has long done.
- Fix possible data corruption in ecpg programs built with the `-C ORACLE` option (Kyotaro Horiguchi)

  When `ecpg_get_data()` is called with `varcharsize` set to zero, it could write a terminating zero character into the last byte of the preceding field, truncating the data in that field.
- Fix pg_dump so that partitioned tables that are hash-partitioned on an enum-type column can be restored successfully (Tom Lane)

  Since the hash codes for enum values depend on the OIDs assigned to the enum, they are typically different after a dump and restore, meaning that rows often need to go into a different partition than they were in originally. Users can work around that by specifying the `--load-via-partition-root` option; but since there is very little chance of success without that, teach pg_dump to apply it automatically to such tables.

  Also, fix pg_restore to not try to `TRUNCATE` target tables before restoring into them when `--load-via-partition-root` mode is used. This avoids a hazard of deadlocks and lost data.
- Correctly detect non-seekable files on Windows (Juan José Santamaría Flecha, Michael Paquier, Daniel Watzinger)

  This bug led to misbehavior when pg_dump writes to a pipe or pg_restore reads from one.
- In pgbench's “prepared” mode, prepare all the commands in a pipeline before starting the pipeline (Álvaro Herrera)

  This avoids a failure when a pgbench script tries to start a serializable transaction inside a pipeline.
- In `contrib/amcheck`'s heap checking code, deal correctly with tuples having zero xmin or xmax (Robert Haas)
- In `contrib/amcheck`, deal sanely with xids that appear to be before epoch zero (Andres Freund)

  In cases of corruption we might see a wrapped-around 32-bit xid that appears to be before the first xid epoch. Promoting such a value to 64-bit form produced a value far in the future, resulting in

wrong reports. Return FirstNormalFullTransactionId in such cases so that things work reasonably sanely.

- In `contrib/hstore_plpython`, avoid crashing if the Python value to be transformed isn't a mapping (Dmitry Dolgov, Tom Lane)

  This should give an error, but Python 3 changed some APIs in a way that caused the check to misbehave, allowing a crash to ensue.

- Require the `siglen` option of a GiST index on an `ltree` column, if specified, to be a multiple of 4 (Alexander Korotkov)

  Other values result in misaligned accesses to index content, which is harmless on Intel-compatible hardware but can cause a crash on some other architectures.

- In `contrib/pageinspect`, add defenses against incorrect input for the `gist_page_items()` function (Dmitry Koval)

- Fix misbehavior in `contrib/pg_trgm` with an unsatisfiable regular expression (Tom Lane)

  A regex such as `$foo` is legal but unsatisfiable; the regex compiler recognizes that and produces an empty NFA graph. Attempting to optimize such a graph into a pg_trgm GIN or GiST index qualification resulted in accessing off the end of a work array, possibly leading to crashes.

- Use the `--strip-unneeded` option when stripping static libraries with GNU-compatible strip (Tom Lane)

  Previously, `make install-strip` used the `-x` option in this case. This change avoids misbehavior of llvm-strip, and gives slightly smaller output as well.

- Stop recommending auto-download of DTD files for building the documentation, and indeed disable it (Aleksander Alekseev, Peter Eisentraut, Tom Lane)

  It appears no longer possible to build the SGML documentation without a local installation of the DocBook DTD files. Formerly xsltproc could download those files on-the-fly from sourceforge.net; but sourceforge.net now permits only HTTPS access, and no common version of xsltproc supports that. Hence, remove the bits of our documentation suggesting that that's possible or useful, and instead add xsltproc's `--nonet` option to the build recipes.

- When running TAP tests in PGXS builds, use a saner location for the temporary `portlock` directory (Peter Eisentraut)

  Place it under `tmp_check` in the build directory. With the previous coding, a PGXS build would try to place it in the installation directory, which is not necessarily writable.

- Update time zone data files to tzdata release 2023c for DST law changes in Egypt, Greenland, Morocco, and Palestine. (Tom Lane)

  When observing Moscow time, Europe/Kirov and Europe/Volgograd now use the abbreviations MSK/MSD instead of numeric abbreviations, for consistency with other timezones observing Moscow time. Also, America/Yellowknife is no longer distinct from America/Edmonton; this affects some pre-1948 timestamps in that area.

E.33. Release 14.7

Release date: 2023-02-09

This release contains a variety of fixes from 14.6. For information about new features in major release 14, see Section E.40.

E.33.1. Migration to Version 14.7

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.4, see Section E.36.

E.33.2. Changes

- libpq can leak memory contents after GSSAPI transport encryption initiation fails (Jacob Champion)

  A modified server, or an unauthenticated man-in-the-middle, can send a not-zero-terminated error message during setup of GSSAPI (Kerberos) transport encryption. libpq will then copy that string, as well as following bytes in application memory up to the next zero byte, to its error report. Depending on what the calling application does with the error report, this could result in disclosure of application memory contents. There is also a small probability of a crash due to reading beyond the end of memory. Fix by properly zero-terminating the server message. (CVE-2022-41862)

- Fix calculation of which `GENERATED` columns need to be updated in child tables during an `UPDATE` on a partitioned table or inheritance tree (Amit Langote, Tom Lane)

  This fixes failure to update `GENERATED` columns that do not exist in the parent table, or that have different dependencies than are in the parent column's generation expression.

- Allow a `WITH RECURSIVE ... CYCLE` CTE to access its output column (Tom Lane)

  A reference to the `SET` column from within the CTE would fail with “cache lookup failed for type 0”.

- Fix handling of pending inserts when doing a bulk insertion to a foreign table (Etsuro Fujita)

  In some cases pending insertions were not flushed to the FDW soon enough, leading to logical inconsistencies, for example `BEFORE ROW` triggers not seeing rows they should be able to see.

- Allow `REPLICA IDENTITY` to be set on an index that's not (yet) valid (Tom Lane)

  When pg_dump dumps a partitioned index that's marked `REPLICA IDENTITY`, it generates a command sequence that applies `REPLICA IDENTITY` before the partitioned index has been marked valid, causing restore to fail. There seems no very good reason to prohibit doing it in that order, so allow it. The marking will have no effect anyway until the index becomes valid.

- Fix handling of `DEFAULT` markers in rules that perform an `INSERT` from a multi-row `VALUES` list (Dean Rasheed)

  In some cases a `DEFAULT` marker would not get replaced with the proper default-value expression, leading to an “unrecognized node type” error.

- Reject uses of undefined variables in `jsonpath` existence checks (Alexander Korotkov, David G. Johnston)

  While `jsonpath` match operators threw an error for an undefined variable in the path pattern, the existence operators silently treated it as a match.

- Fix `jsonb` subscripting to cope with toasted subscript values (Tom Lane, David G. Johnston)

  Using a text value fetched directly from a table as a `jsonb` subscript was likely to fail. Fetches would usually not find any matching element. Assignments could store the value with a garbage key, although keys long enough to cause that problem are probably rare in the field.

- Fix edge-case data corruption in parallel hash joins (Dmitry Astapov)

  If the final chunk of a large tuple being written out to a temporary file was exactly 32760 bytes, it would be corrupted due to a fencepost bug. The query would typically fail later with corrupted-data symptoms.

- Honor non-default settings of `checkpoint_completion_target` (Bharath Rupireddy)

  Internal state was not updated after a change in `checkpoint_completion_target`, possibly resulting in performing checkpoint I/O faster or slower than desired, especially if that setting was changed on-the-fly.

- Log the correct ending timestamp in `recovery_target_xid` mode (Tom Lane)

  When ending recovery based on the `recovery_target_xid` setting with `recovery_target_inclusive` = `off`, we printed an incorrect timestamp (always 2000-01-01) in the “recovery stopping before ... transaction” log message.

- Improve error reporting for some buffered file read failures (Peter Eisentraut)

  Correctly report a short read, giving the numbers of bytes desired and actually read, instead of reporting an irrelevant error code. Most places got this right already, but some recently-written replication logic did not.

- In extended query protocol, avoid an immediate commit after `ANALYZE` if we're running a pipeline (Tom Lane)

  If there's not been an explicit `BEGIN TRANSACTION`, `ANALYZE` would take it on itself to commit, which should not happen within a pipelined series of commands.

- Reject cancel request packets having the wrong length (Andrey Borodin)

  The server would process a cancel request even if its length word was too small. This led to reading beyond the end of the allocated buffer. In theory that could cause a segfault, but it seems quite unlikely to happen in practice, since the buffer would have to be very close to the end of memory. The more likely outcome was a bogus log message about wrong backend PID or cancel code. Complain about the wrong length, instead.

- Add recursion and looping defenses in subquery pullup (Tom Lane)

  A contrived query can result in deep recursion and unreasonable amounts of time spent trying to flatten subqueries. A proper fix for that seems unduly invasive for a back-patch, but we can at least add stack depth checks and an interrupt check to allow the query to be cancelled.

- Fix planner issues when combining Memoize nodes with partitionwise joins or parameterized nestloops (Richard Guo)

  These errors could lead to not using Memoize in contexts where it would be useful, or possibly to wrong query plans.

- Fix partitionwise-join code to tolerate failure to produce a plan for each partition (Tom Lane)

  This could result in “could not devise a query plan for the given query” errors.

- Limit the amount of cleanup work done by `get_actual_variable_range` (Simon Riggs)

  Planner runs occurring just after deletion of a large number of tuples appearing at the end of an index could expend significant amounts of work setting the “killed” bits for those index entries. Limit the amount of work done in any one query by giving up on this process after examining 100 heap pages. All the cleanup will still happen eventually, but without so large a performance hiccup.

- Fix under-parenthesized display of `AT TIME ZONE` constructs (Tom Lane)

  This could result in dump/restore failures for rules or views in which an argument of `AT TIME ZONE` is itself an expression.

- Prevent clobbering of cached parsetrees for utility statements in SQL functions (Tom Lane, Daniel Gustafsson)

  If a SQL-language function executes the same utility command more than once within a single calling query, it could crash or report strange errors such as “unrecognized node type”.

- Ensure that execution of full-text-search queries can be cancelled while they are performing phrase matches (Tom Lane)

- Fix memory leak in hashing strings with nondeterministic collations (Jeff Davis)

- Fix deadlock between `DROP DATABASE` and logical replication worker process (Hou Zhijie)

This was caused by an ill-advised choice to block interrupts while creating a logical replication slot in the worker. In version 15 that could lead to an undetected deadlock. In version 14, no deadlock has been observed, but it's still a bad idea to block interrupts while waiting for network I/O.

- Clean up the libpq connection object after a failed replication connection attempt (Andres Freund)

  The previous coding leaked the connection object. In background code paths that's pretty harmless because the calling process will give up and exit. But in commands such as `CREATE SUBSCRIPTION`, such a failure resulted in a small session-lifespan memory leak.

- In hot-standby servers, reduce processing effort for tracking XIDs known to be active on the primary (Simon Riggs, Michail Nikolaev)

  Insufficiently-aggressive cleanup of the KnownAssignedXids array could lead to poor performance, particularly when `max_connections` is set to a large value on the standby.

- Ignore invalidated logical-replication slots while determining oldest catalog xmin (Sirisha Chamarthi)

  A replication slot could prevent cleanup of dead tuples in the system catalogs even after it becomes invalidated due to exceeding `max_slot_wal_keep_size`. Thus, failure of a replication consumer could lead to indefinitely-large catalog bloat.

- In logical decoding, notify the remote node when a transaction is detected to have crashed (Hou Zhijie)

  After a server restart, we'll re-stream the changes for transactions occurring shortly before the restart. Some of these transactions probably never completed; when we realize that one didn't we throw away the relevant decoding state locally, but we neglected to tell the subscriber about it. That led to the subscriber keeping useless streaming files until it's next restarted.

- Fix uninitialized-memory usage in logical decoding (Masahiko Sawada)

  In certain cases, resumption of logical decoding could try to re-use XID data that had already been freed, leading to unpredictable behavior.

- Avoid rare “failed to acquire cleanup lock” panic during WAL replay of hash-index page split operations (Robert Haas)

- Advance a heap page's LSN when setting its all-visible bit during WAL replay (Jeff Davis)

  Failure to do this left the page possibly different on standby servers than the primary, and violated some other expectations about when the LSN changes. This seems only a theoretical hazard so far as PostgreSQL itself is concerned, but it could upset third-party tools.

- Prevent unsafe usage of a relation cache entry's `rd_smgr` pointer (Amul Sul)

  Remove various assumptions that `rd_smgr` would stay valid over a series of operations, by wrapping all uses of it in a function that will recompute it if needed. This prevents bugs occurring when an unexpected cache flush occurs partway through such a series.

- Fix `int64_div_fast_to_numeric()` to work for a wider range of inputs (Dean Rasheed)

  This function misbehaved with some values of its second argument. No such usages exist in core PostgreSQL, but it's clearly a hazard for external modules, so repair.

- Fix latent buffer-overrun problem in `WaitEventSet` logic (Thomas Munro)

  The `epoll`-based and `kqueue`-based implementations could ask the kernel for too many events if the size of their internal buffer was different from the size of the caller's output buffer. That case is not known to occur in released PostgreSQL versions, but this error is a hazard for external modules and future bug fixes.

- Avoid nominally-undefined behavior when accessing shared memory in 32-bit builds (Andres Freund)

clang's undefined-behavior sanitizer complained about use of a pointer that was less aligned than it should be. It's very unlikely that this would cause a problem in non-debug builds, but it's worth fixing for testing purposes.

- Fix assertion failure in BRIN minmax-multi opclasses (Tomas Vondra)

  The assertion was overly strict, so this mistake was harmless in non-assert builds.

- Remove faulty assertion in useless-RESULT-RTE optimization logic (Tom Lane)
- Fix copy-and-paste errors in cache-lookup-failure messages for ACL checks (Justin Pryzby)

  In principle these errors should never be reached. But if they are, some of them reported the wrong type of object.

- In pg_dump, avoid calling unsafe server functions before we have locks on the tables to be examined (Tom Lane, Gilles Darold)

  pg_dump uses certain server functions that can fail if examining a table that gets dropped concurrently. Avoid this type of failure by ensuring that we obtain access share lock before inquiring too deeply into a table's properties, and that we don't apply such functions to tables we don't intend to dump at all.

- Fix psql's `\sf` and `\ef` commands to handle SQL-language functions that have SQL-standard function bodies (Tom Lane)

  These commands misidentified the start of the function body when it used new-style syntax.

- Fix tab completion of `ALTER FUNCTION/PROCEDURE/ROUTINE ... SET SCHEMA` (Dean Rasheed)
- Fix `contrib/seg` to not crash or print garbage if an input number has more than 127 digits (Tom Lane)
- Fix build on Microsoft Visual Studio 2013 (Tom Lane)

  A previous patch supposed that all platforms of interest have `snprintf()`, but MSVC 2013 isn't quite there yet. Revert to using `sprintf()` on that platform.

- Fix compile failure in building PL/Perl with MSVC when using Strawberry Perl (Andrew Dunstan)
- Fix mismatch of PL/Perl built with MSVC versus a Perl library built with gcc (Andrew Dunstan)

  Such combinations could previously fail with “loadable library and perl binaries are mismatched” errors.

- Suppress compiler warnings from Perl's header files (Andres Freund)

  Our preferred compiler options provoke warnings about constructs appearing in recent versions of Perl's header files. When using gcc, we can suppress these warnings with a pragma.

- Fix pg_waldump to build on compilers that don't discard unused static-inline functions (Tom Lane)
- Update time zone data files to tzdata release 2022g for DST law changes in Greenland and Mexico, plus historical corrections for northern Canada, Colombia, and Singapore. (Tom Lane)

  Notably, a new timezone America/Ciudad_Juarez has been split off from America/Ojinaga.

E.34. Release 14.6

Release date: 2022-11-10

This release contains a variety of fixes from 14.5. For information about new features in major release 14, see Section E.40.

E.34.1. Migration to Version 14.6

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.4, see Section E.36.

E.34.2. Changes

- Avoid rare PANIC during updates occurring concurrently with VACUUM (Tom Lane, Jeff Davis)

  If a concurrent VACUUM sets the all-visible flag bit in a page that UPDATE or DELETE is in process of modifying, the updating command needs to clear that bit again; but some code paths failed to do so, ending in a PANIC exit and database restart.

  This is known to be possible in versions 14 and 15. It may be only latent in previous branches.

- Fix handling of DEFAULT tokens that appear in a multi-row VALUES clause of an INSERT on an updatable view (Tom Lane)

  This oversight could lead to “cache lookup failed for type” errors, or in older branches even to crashes.

- Disallow rules named _RETURN that are not ON SELECT (Tom Lane)

  This avoids confusion between a view's ON SELECT rule and any other rules it may have.

- Fix resource management bug in saving tuples for AFTER triggers (Tom Lane)

  Given the right circumstances, this manifested as a “tupdesc reference *NNNN* is not owned by resource owner” error followed by a PANIC exit.

- Avoid failure in EXPLAIN VERBOSE for a query using SEARCH BREADTH FIRST with constant initial values (Tom Lane)

- Fix construction of per-partition foreign key constraints while doing ALTER TABLE ATTACH PARTITION (Jehan-Guillaume de Rorthais, Álvaro Herrera)

  Previously, incorrect or duplicate constraints could be constructed for the newly-added partition.

- Fix generation of constraint names for per-partition foreign key constraints (Jehan-Guillaume de Rorthais)

  If the initially-given name is already in use for some constraint of the partition, a new one is selected; but it wasn't being spelled as intended.

- Fix incorrect matching of index expressions and predicates when creating a partitioned index (Richard Guo, Tom Lane)

  While creating a partitioned index, we try to identify any existing indexes on the partitions that match the partitioned index, so that we can absorb those as child indexes instead of building new ones. Matching of expressions was not done right, so that a usable child index might be ignored, leading to creation of a duplicative index.

- Prevent WAL corruption after a standby promotion (Dilip Kumar, Robert Haas)

  When a PostgreSQL instance performing archive recovery (but not using standby mode) is promoted, and the last WAL segment that it attempted to read ended in a partial record, the instance would write an invalid WAL segment on the new timeline.

- Fix mis-ordering of WAL operations in fast insert path for GIN indexes (Matthias van de Meent, Zhang Mingli)

  This mistake is not known to have any negative consequences within core PostgreSQL, but it did cause issues for some extensions.

- Fix bugs in logical decoding when replay starts from a point between the beginning of a transaction and the beginning of its subtransaction (Masahiko Sawada, Kuroda Hayato)

  These errors could lead to assertion failures in debug builds, and otherwise to memory leaks.

- Prevent examining system catalogs with the wrong snapshot during logical decoding (Masahiko Sawada)

  If decoding begins partway through a transaction that modifies system catalogs, the decoder may not recognize that, causing it to fail to treat that transaction as in-progress for catalog lookups.

- Accept interrupts in more places during logical decoding (Amit Kapila, Masahiko Sawada)

  This ameliorates problems with slow shutdown of replication workers.

- Prevent attempts to replicate into a foreign-table partition in replication workers (Shi Yu, Tom Lane)

  Although partitioned tables can have foreign tables as partitions, replicating into such a partition isn't currently supported. The logical replication worker process would crash if it was attempted. Now, an error is thrown.

- Remove pointless check on replica identity setting of partitioned tables (Hou Zhijie)

  What matters is the replica identity setting of the leaf partitions, so there's no need to throw error if it's not set on the parent.

- Avoid crash after function syntax error in replication workers (Maxim Orlov, Anton Melnikov, Masahiko Sawada, Tom Lane)

  If a syntax error occurred in a SQL-language or PL/pgSQL-language `CREATE FUNCTION` or `DO` command executed in a logical replication worker, the worker process would crash with a null pointer dereference or assertion failure.

- Fix handling of read-write expanded datums that are passed to SQL functions (Tom Lane)

  If a non-inlined SQL function uses a parameter in more than one place, and one of those functions expects to be able to modify read-write datums in place, then later uses of the parameter would observe the wrong value. (Within core PostgreSQL, the expanded-datum mechanism is only used for array and composite-type values; but extensions might use it for other structured types.)

- Fix type `circle`'s equality comparator to handle NaNs properly (Ranier Vilela)

  If the left-hand circle had a floating-point NaN for its radius, it would be considered equal to a circle with the same center and any radius.

- In Snowball dictionaries, don't try to stem excessively-long words (Olly Betts, Tom Lane)

  If the input word exceeds 1000 bytes, return it as-is after case folding, rather than trying to run it through the Snowball code. This restriction protects against a known recursion-to-stack-overflow problem in the Turkish stemmer, and it seems like good insurance against any other safety or performance issues that may exist in the Snowball stemmers. Such a long string is surely not a word in any human language, so it's doubtful that the stemmer would have done anything desirable with it anyway.

- Fix use-after-free hazard in string comparisons (Tom Lane)

  Improper memory management in the string comparison functions could result in scribbling on no-longer-allocated buffers, potentially breaking things for whatever is using that memory now. This would only happen with fairly long strings (more than 1kB), and only if an ICU collation is in use.

- Add plan-time check for attempted access to a table that has no table access method (Tom Lane)

  This prevents a crash in some catalog-corruption scenarios, for example use of a view whose `ON SELECT` rule is missing.

- Prevent postmaster crash when shared-memory state is corrupted (Tom Lane)

  The postmaster process is supposed to survive and initiate a database restart if shared memory becomes corrupted, but one bit of code was being insufficiently cautious about that.

- Add some more defenses against recursion till stack overrun (Richard Guo, Tom Lane)
- Avoid misbehavior when choosing hash table size with very small `work_mem` and large tuples (Zhang Mingli)
- Avoid long-term memory leakage in the autovacuum launcher process (Reid Thompson)

  The lack of field reports suggests that this problem is only latent in pre-v15 branches; but it's not very clear why, so back-patch the fix anyway.
- Improve PL/pgSQL's ability to handle parameters declared as `RECORD` (Tom Lane)

  Build a separate function cache entry for each concrete type passed to the `RECORD` parameter during a session, much as we do for polymorphic parameters. This allows some usages to work that previously failed with errors such as “type of parameter does not match that when preparing the plan”.
- In libpq, handle single-row mode correctly when pipelining (Denis Laxalde)

  The single-row flag was not reset at the correct time if pipeline mode was also active.
- Add missing guards for `NULL` connection pointer in libpq (Daniele Varrazzo, Tom Lane)

  There's a convention that libpq functions should check for a NULL PGconn argument, and fail gracefully instead of crashing. `PQflush()` and `PQisnonblocking()` didn't get that memo, so fix them.
- In ecpg, fix omission of variable storage classes when multiple `varchar` or `bytea` variables are declared in the same declaration (Andrey Sokolov)

  For example, ecpg translated `static varchar str1[10], str2[20], str3[30];` in such a way that only `str1` was marked `static`.
- Allow cross-platform tablespace relocation in pg_basebackup (Robert Haas)

  Allow the remote path in `--tablespace-mapping` to be either a Unix-style or Windows-style absolute path, since the source server could be on a different OS than the local system.
- In pg_stat_statements, fix access to already-freed memory (zhaoqigui)

  This occurred if pg_stat_statements tracked a `ROLLBACK` command issued via extended query protocol. In debug builds it consistently led to an assertion failure. In production builds there would often be no visible ill effect; but if the freed memory had already been reused, the likely result would be to store garbage for the query string.
- In postgres_fdw, ensure that target lists constructed for EvalPlanQual plans will have all required columns (Richard Guo, Etsuro Fujita)

  This avoids “variable not found in subplan target list” errors in rare cases.
- Reject unwanted output from the platform's `uuid_create()` function (Nazir Bilal Yavuz)

  The uuid-ossp module expects libc's `uuid_create()` to produce a version-1 UUID, but recent NetBSD releases produce a version-4 (random) UUID instead. Check for that, and complain if so. Drop the documentation's claim that the NetBSD implementation is usable for uuid-ossp. (If a version-4 UUID is okay for your purposes, you don't need uuid-ossp at all; just use `gen_random_uuid()`.)
- Include new Perl test modules in standard installations (Álvaro Herrera)

  Add `PostgreSQL/Test/Cluster.pm` and `PostgreSQL/Test/Utils.pm` to the standard installation file set in pre-version-15 branches. This is for the benefit of extensions that want to use newly-written test code in older branches.
- On NetBSD, force dynamic symbol resolution at postmaster start (Andres Freund, Tom Lane)

  This avoids a risk of deadlock in the dynamic linker on NetBSD 10.

- Fix incompatibilities with LLVM 15 (Thomas Munro, Andres Freund)
- Allow use of `__sync_lock_test_and_set()` for spinlocks on any machine (Tom Lane)

  This eases porting to new machine architectures, at least if you're using a compiler that supports this GCC builtin function.
- Rename symbol `REF` to `REF_P` to avoid compile failure on recent macOS (Tom Lane)
- Avoid using `sprintf`, to avoid compile-time deprecation warnings (Tom Lane)
- Silence assorted compiler warnings from clang 15 and later (Tom Lane)
- Update time zone data files to tzdata release 2022f for DST law changes in Chile, Fiji, Iran, Jordan, Mexico, Palestine, and Syria, plus historical corrections for Chile, Crimea, Iran, and Mexico. (Tom Lane)

  Also, the Europe/Kiev zone has been renamed to Europe/Kyiv. Also, the following zones have been merged into nearby, more-populous zones whose clocks have agreed with them since 1970: Antarctica/Vostok, Asia/Brunei, Asia/Kuala_Lumpur, Atlantic/Reykjavik, Europe/Amsterdam, Europe/Copenhagen, Europe/Luxembourg, Europe/Monaco, Europe/Oslo, Europe/Stockholm, Indian/Christmas, Indian/Cocos, Indian/Kerguelen, Indian/Mahe, Indian/Reunion, Pacific/Chuuk, Pacific/Funafuti, Pacific/Majuro, Pacific/Pohnpei, Pacific/Wake and Pacific/Wallis. (This indirectly affects zones that were already links to one of these: Arctic/Longyearbyen, Atlantic/Jan_Mayen, Iceland, Pacific/Ponape, Pacific/Truk, and Pacific/Yap.) America/Nipigon, America/Rainy_River, America/Thunder_Bay, Europe/Uzhgorod, and Europe/Zaporozhye were also merged into nearby zones after discovering that their claimed post-1970 differences from those zones seem to have been errors. In all these cases, the previous zone name remains as an alias; but the actual data is that of the zone that was merged into.

  These zone mergers result in loss of pre-1970 timezone history for the merged zones, which may be troublesome for applications expecting consistency of `timestamptz` display. As an example, the stored value `1944-06-01 12:00 UTC` would previously display as `1944-06-01 13:00:00+01` if the Europe/Stockholm zone is selected, but now it will read out as `1944-06-01 14:00:00+02`.

  It is possible to build the time zone data files with options that will restore the older zone data, but that choice also inserts a lot of other old (and typically poorly-attested) zone data, resulting in more total changes from the previous release than accepting these upstream changes does. PostgreSQL has chosen to ship the tzdb data as-recommended, and so far as we are aware most major operating system distributions are doing likewise. However, if these changes cause significant problems for your application, a possible solution is to install a local build of the time zone data files using tzdb's backwards-compatibility options (see their `PACKRATDATA` and `PACKRATLIST` options).

E.35. Release 14.5

Release date: 2022-08-11

This release contains a variety of fixes from 14.4. For information about new features in major release 14, see Section E.40.

E.35.1. Migration to Version 14.5

A dump/restore is not required for those running 14.X.

However, if you are upgrading from a version earlier than 14.4, see Section E.36.

E.35.2. Changes

- Do not let extension scripts replace objects not already belonging to the extension (Tom Lane)

  This change prevents extension scripts from doing `CREATE OR REPLACE` if there is an existing object that does not belong to the extension. It also prevents `CREATE IF NOT EXISTS` in the same situation. This prevents a form of trojan-horse attack in which a hostile database user could become the

owner of an extension object and then modify it to compromise future uses of the object by other users. As a side benefit, it also reduces the risk of accidentally replacing objects one did not mean to.

The PostgreSQL Project thanks Sven Klemm for reporting this problem. (CVE-2022-2625)

- Fix replay of `CREATE DATABASE` WAL records on standby servers (Kyotaro Horiguchi, Asim R Praveen, Paul Guo)

  Standby servers may encounter missing tablespace directories when replaying database-creation WAL records. Prior to this patch, a standby would fail to recover in such a case; however, such directories could be legitimately missing. Create the tablespace (as a plain directory), then check that it has been dropped again once replay reaches a consistent state.

- Support “in place” tablespaces (Thomas Munro, Michael Paquier, Álvaro Herrera)

  Normally a Postgres tablespace is a symbolic link to a directory on some other filesystem. This change allows it to just be a plain directory. While this has no use for separating tables onto different filesystems, it is a convenient setup for testing. Moreover, it is necessary to support the `CREATE DATABASE` replay fix, which transiently creates a missing tablespace as an “in place” tablespace.

- Fix permissions checks in `CREATE INDEX` (Nathan Bossart, Noah Misch)

  The fix for CVE-2022-1552 caused `CREATE INDEX` to apply the table owner's permissions while performing lookups of operator classes and other objects, where formerly the calling user's permissions were used. This broke dump/restore scenarios, because pg_dump issues `CREATE INDEX` before re-granting permissions.

- In extended query protocol, force an immediate commit after `CREATE DATABASE` and other commands that can't run in a transaction block (Tom Lane)

  If the client does not send a Sync message immediately after such a command, but instead sends another command, any failure in that command would lead to rolling back the preceding command, typically leaving inconsistent state on-disk (such as a missing or extra database directory). The mechanisms intended to prevent that situation turn out to work for multiple commands in a simple-Query message, but not for a series of extended-protocol messages. To prevent inconsistency without breaking use-cases that work today, force an implicit commit after such commands.

- Fix race condition when checking transaction visibility (Simon Riggs)

  `TransactionIdIsInProgress` could report `false` before the subject transaction is considered visible, leading to various misbehaviors. The race condition window is normally very narrow, but use of synchronous replication makes it much wider, because the wait for a synchronous replica happens in that window.

- Fix incorrect plans when sorting by an expression that contains a non-top-level set-returning function (Richard Guo, Tom Lane)

- Fix incorrect permissions-checking code for extended statistics (Richard Guo)

  If there are extended statistics on a table that the user has only partial `SELECT` permissions on, some queries would fail with “unrecognized node type” errors.

- Fix extended statistics machinery to handle MCV-type statistics on boolean-valued expressions (Tom Lane)

  Statistics collection worked fine, but a query containing such an expression in `WHERE` would fail with “unknown clause type”.

- Avoid planner core dump with *`constant`* `= ANY(`*`array`*`)` clauses when there are MCV-type extended statistics on the *`array`* variable (Tom Lane)

- Fix `ALTER TABLE ... ENABLE/DISABLE TRIGGER` to handle recursion correctly for triggers on partitioned tables (Álvaro Herrera, Amit Langote)

In certain cases, a “trigger does not exist” failure would occur because the command would try to adjust the trigger on a child partition that doesn't have it.

- Allow cancellation of `ANALYZE` while it is computing extended statistics (Tom Lane, Justin Pryzby)

  In some scenarios with high statistics targets, it was possible to spend many seconds in an un-cancellable sort operation.

- Improve syntax error messages for type `jsonpath` (Andrew Dunstan)
- Ensure that `pg_stop_backup()` cleans up session state properly (Fujii Masao)

  This omission could lead to assertion failures or crashes later in the session.

- Fix `trim_array()` to handle a zero-dimensional array argument sanely (Martin Kalcher)
- Fix join alias matching in `FOR [KEY] UPDATE/SHARE` clauses (Dean Rasheed)

  In corner cases, a misleading error could be reported.

- Reject `ROW()` expressions and functions in `FROM` that have too many columns (Tom Lane)

  Cases with more than about 1600 columns are unsupported, and have always failed at execution. However, it emerges that some earlier code could be driven to assertion failures or crashes by queries with more than 32K columns. Add a parse-time check to prevent that.

- Fix dumping of a view using a function in `FROM` that returns a composite type, when column(s) of the composite type have been dropped since the view was made (Tom Lane)

  This oversight could lead to dump/reload or pg_upgrade failures, as the dumped view would have too many column aliases for the function.

- Disallow nested backup operations in logical replication walsenders (Fujii Masao)
- Fix memory leak in logical replication subscribers (Hou Zhijie)
- Fix logical replication's checking of replica identity when the target table is partitioned (Shi Yu, Hou Zhijie)

  The replica identity columns have to be re-identified for the child partition.

- Fix failures to update cached schema data in a logical replication subscriber after a schema change on the publisher (Shi Yu, Hou Zhijie)
- Fix WAL consistency checking logic to correctly handle `BRIN_EVACUATE_PAGE` flags (Haiyang Wang)
- Fix erroneous assertion checks in shared hashtable management (Thomas Munro)
- Avoid assertion failure when `min_dynamic_shared_memory` is set to a non-default value (Thomas Munro)
- Arrange to clean up after commit-time errors within `SPI_commit()`, rather than expecting callers to do that (Peter Eisentraut, Tom Lane)

  Proper cleanup is complicated and requires use of low-level facilities, so it's not surprising that no known caller got it right. This led to misbehaviors when a PL procedure issued `COMMIT` but a failure occurred (such as a deferred constraint check). To improve matters, redefine `SPI_commit()` as starting a new transaction, so that it becomes equivalent to `SPI_commit_and_chain()` except that you get default transaction characteristics instead of preserving the prior transaction's characteristics. To make this somewhat transparent API-wise, redefine `SPI_start_transaction()` as a no-op. All known callers of `SPI_commit()` immediately call `SPI_start_transaction()`, so they will not notice any change. Similar remarks apply to `SPI_rollback()`.

  Also fix PL/Python, which omitted any handling of such errors at all, resulting in jumping out of the Python interpreter. This is reported to crash Python 3.11. Older Python releases leak some memory but seem okay with it otherwise.

- Improve libpq's handling of idle states in pipeline mode (Álvaro Herrera, Kyotaro Horiguchi)

  This fixes “message type 0x33 arrived from server while idle” warnings, as well as possible loss of end-of-query NULL results from `PQgetResult()`.

- Avoid core dump in ecpglib with unexpected orders of operations (Tom Lane)

  Certain operations such as `EXEC SQL PREPARE` would crash (rather than reporting an error as expected) if called before establishing any database connection.

- In ecpglib, avoid redundant `newlocale()` calls (Noah Misch)

  Allocate a C locale object once per process when first connecting, rather than creating and freeing locale objects once per query. This mitigates a libc memory leak on AIX, and may offer some performance benefit everywhere.

- In psql's `\watch` command, echo a newline after cancellation with control-C (Pavel Stehule)

  This prevents libedit (and possibly also libreadline) from becoming confused about which column the cursor is in.

- Fix pg_upgrade to detect non-upgradable usages of functions taking `anyarray` (Justin Pryzby)

  Version 14 changed some built-in functions to take type `anycompatiblearray` instead of `anyarray`. While this is mostly transparent, user-defined aggregates and operators built atop these functions have to be declared with exactly matching types. The presence of an object referencing the old signature will cause pg_upgrade to fail, so change it to detect and report such cases before beginning the upgrade.

- Fix possible report of wrong error condition after `clone()` failure in pg_upgrade with `--clone` option (Justin Pryzby)

- Fix `contrib/pg_stat_statements` to avoid problems with very large query-text files on 32-bit platforms (Tom Lane)

- In `contrib/postgres_fdw`, prevent batch insertion when there are `WITH CHECK OPTION` constraints (Etsuro Fujita)

  Such constraints cannot be checked properly if more than one row is inserted at a time.

- Fix `contrib/postgres_fdw` to detect failure to send an asynchronous data fetch query (Fujii Masao)

- Ensure that `contrib/postgres_fdw` sends constants of `regconfig` and other `reg*` types with proper schema qualification (Tom Lane)

- Block signals while allocating dynamic shared memory on Linux (Thomas Munro)

  This avoids problems when a signal interrupts `posix_fallocate()`.

- Detect unexpected `EEXIST` error from `shm_open()` (Thomas Munro)

  This avoids a possible crash on Solaris.

- Avoid using `signalfd()` on illumos systems (Thomas Munro)

  This appears to trigger hangs and kernel panics, so avoid the function until a fix is available.

E.36. Release 14.4

Release date: 2022-06-16

This release contains a variety of fixes from 14.3. For information about new features in major release 14, see Section E.40.

E.36.1. Migration to Version 14.4

A dump/restore is not required for those running 14.X.

However, if you have any indexes that were created using the CONCURRENTLY option under 14.X, you should re-index them after updating. See the first changelog entry below.

Also, if you are upgrading from a version earlier than 14.3, see Section E.37.

E.36.2. Changes

- Prevent possible corruption of indexes created or rebuilt with the CONCURRENTLY option (Álvaro Herrera)

  An optimization added in v14 caused CREATE INDEX ... CONCURRENTLY and REINDEX ... CONCURRENTLY to sometimes miss indexing rows that were updated during the index build. Revert that optimization. It is recommended that any indexes made with the CONCURRENTLY option be rebuilt after installing this update. (Alternatively, rebuild them without CONCURRENTLY.)

- Harden Memoize plan node against non-deterministic equality functions (David Rowley)

  Memoize could crash if a data type's equality or hash functions gave inconsistent results across different calls. Throw a runtime error instead.

- Fix incorrect cost estimates for Memoize plans (David Rowley)

  This mistake could lead to Memoize being used when it isn't really the best plan, or to very long executor startup times due to initializing an overly-large hash table for a Memoize node.

- Fix queries in which a “whole-row variable” references the result of a function that returns a domain over composite type (Tom Lane)

- Fix “variable not found in subplan target list” planner error when pulling up a sub-SELECT that's referenced in a GROUPING function (Richard Guo)

- Prevent pg_stat_get_subscription() from possibly returning an extra row containing garbage values (Kuntal Ghosh)

- Fix COPY FROM's error checking in the case where the database encoding is SQL_ASCII while the client's encoding is a multi-byte encoding (Heikki Linnakangas)

  This mistake could lead to false complaints of invalidly-encoded input data.

- Avoid crashing if too many column aliases are attached to an XMLTABLE or JSON_TABLE construct (Álvaro Herrera)

- When decompiling a view or rule, show a SELECT output column's AS "?column?" alias clause if it could be referenced elsewhere (Tom Lane)

  Previously, this auto-generated alias was always hidden; but there are corner cases where doing so results in a non-restorable view or rule definition.

- Report implicitly-created operator families to event triggers (Masahiko Sawada)

  If CREATE OPERATOR CLASS results in the implicit creation of an operator family, that object was not reported to event triggers that should capture such events.

- Fix control file updates made when a restartpoint is running during promotion of a standby server (Kyotaro Horiguchi)

  Previously, when the restartpoint completed it could incorrectly update the last-checkpoint fields of the control file, potentially leading to PANIC and failure to restart if the server crashes before the next normal checkpoint completes.

- Prevent triggering of standby's wal_receiver_timeout during logical replication of large transactions (Wang Wei, Amit Kapila)

If a large transaction on the primary server sends no data to the standby (perhaps because no table it changes is published), it was possible for the standby to timeout. Fix that by ensuring we send keepalive messages periodically in such situations.

- Prevent open-file leak when reading an invalid timezone abbreviation file (Kyotaro Horiguchi)

  Such cases could result in harmless warning messages.

- Allow custom server parameters to have short descriptions that are NULL (Steve Chavez)

  Previously, although extensions could choose to create such settings, some code paths would crash while processing them.

- Remove misguided SSL key file ownership check in libpq (Tom Lane)

  In the previous minor releases, we copied the server's permission checking rules for SSL private key files into libpq. But we should not have also copied the server's file-ownership check. While that works in normal use-cases, it can result in an unexpected failure for clients running as root, and perhaps in other cases.

- Ensure ecpg reports server connection loss sanely (Tom Lane)

  Misprocessing of a libpq-generated error result, such as a report of lost connection, would lead to printing “(null)” instead of a useful error message; or in older releases it would lead to a crash.

- Prevent crash after server connection loss in pg_amcheck (Tom Lane)

  Misprocessing of a libpq-generated error result, such as a report of lost connection, would lead to a crash.

- Adjust PL/Perl test case so it will work under Perl 5.36 (Dagfinn Ilmari Mannsåker)
- Avoid incorrectly using an out-of-date libldap_r library when multiple OpenLDAP installations are present while building PostgreSQL (Tom Lane)

E.37. Release 14.3

Release date: 2022-05-12

This release contains a variety of fixes from 14.2. For information about new features in major release 14, see Section E.40.

E.37.1. Migration to Version 14.3

A dump/restore is not required for those running 14.X.

However, if you have any GiST indexes on columns of type `ltree` (supplied by the `contrib/ltree` extension), you should re-index them after updating. See the second changelog entry below.

Also, if you are upgrading from a version earlier than 14.2, see Section E.38.

E.37.2. Changes

- Confine additional operations within “security restricted operation” sandboxes (Sergey Shinderuk, Noah Misch)

  Autovacuum, `CLUSTER`, `CREATE INDEX`, `REINDEX`, `REFRESH MATERIALIZED VIEW`, and pg_amcheck activated the “security restricted operation” protection mechanism too late, or even not at all in some code paths. A user having permission to create non-temporary objects within a database could define an object that would execute arbitrary SQL code with superuser permissions the next time that autovacuum processed the object, or that some superuser ran one of the affected commands against it.

  The PostgreSQL Project thanks Alexander Lakhin for reporting this problem. (CVE-2022-1552)

- Fix default signature length for `gist_ltree_ops` indexes (Tomas Vondra, Alexander Korotkov)

  The default signature length (hash size) for GiST indexes on `ltree` columns was accidentally changed while upgrading that operator class to support operator class parameters. If any operations had been done on such an index without first upgrading the `ltree` extension to version 1.2, they were done assuming that the signature length was 28 bytes rather than the intended 8. This means it is very likely that such indexes are now corrupt. For safety we recommend re-indexing all GiST indexes on `ltree` columns after installing this update. (Note that GiST indexes on `ltree[]` columns, that is arrays of `ltree`, are not affected.)

- Stop using query-provided column aliases for the columns of whole-row variables that refer to plain tables (Tom Lane)

  The column names in tuples produced by a whole-row variable (such as `tbl.*` in contexts other than the top level of a `SELECT` list) are now always those of the associated named composite type, if there is one. We'd previously attempted to make them track any column aliases that had been applied to the `FROM` entry the variable refers to. But that's semantically dubious, because really then the output of the variable is not at all of the composite type it claims to be. Previous attempts to deal with that inconsistency had bad results up to and including storing unreadable data on disk, so just give up on the whole idea.

  In cases where it's important to be able to relabel such columns, a workaround is to introduce an extra level of sub-`SELECT`, so that the whole-row variable is referring to the sub-`SELECT`'s output and not to a plain table. Then the variable is of type `record` to begin with and there's no issue.

- Fix incorrect roundoff when extracting epoch values from intervals (Peter Eisentraut)

  The new `numeric`-based code for `EXTRACT()` failed to yield results equivalent to the old `float`-based code, as a result of accidentally truncating the `DAYS_PER_YEAR` value to an integer.

- Defend against `pg_stat_get_replication_slot(NULL)` (Andres Freund)

  This function should be marked strict in the catalog data, but it was not in v14, so add a run-time check instead.

- Fix incorrect output for types `timestamptz` and `timetz` in `table_to_xmlschema()` and allied functions (Renan Soares Lopes)

  The xmlschema output for these types included a malformed regular expression.

- Avoid core dump in parser for a `VALUES` clause with zero columns (Tom Lane)

- Fix planner failure when a Result plan node appears immediately underneath an Append node (Etsuro Fujita)

  Recently-added code to support asynchronous remote queries failed to handle this case, leading to crashes or errors about unrecognized node types.

- Fix planner failure if a query using `SEARCH` or `CYCLE` features contains a duplicate CTE name (Tom Lane, Kyotaro Horiguchi)

  When the name of the recursive `WITH` query is re-used within itself, the planner could crash or report odd errors such as “could not find attribute 2 in subquery targetlist”.

- Fix planner errors for `GROUPING()` constructs that reference outer query levels (Richard Guo, Tom Lane)

- Fix plan generation for index-only scans on indexes with both returnable and non-returnable columns (Tom Lane)

  The previous coding could try to read non-returnable columns in addition to the returnable ones. This was fairly harmless because it didn't actually do anything with the bogus values, but it fell foul of a recently-added error check that rejected such a plan.

- Avoid accessing a no-longer-pinned shared buffer while attempting to lock an outdated tuple during EvalPlanQual (Tom Lane)

  The code would touch the buffer a couple more times after releasing its pin. In theory another process could recycle the buffer (or more likely, try to defragment its free space) as soon as the pin is gone, probably leading to failure to find the newer version of the tuple.

- Fix query-lifespan memory leak in an IndexScan node that is performing reordering (Aliaksandr Kalenik)

- Fix `ALTER FUNCTION` to support changing a function's parallelism property and its `SET`-variable list in the same command (Tom Lane)

  The parallelism property change was lost if the same command also updated the function's `SET` clause.

- Tighten lookup of the index “owned by” a constraint (Tom Lane, Japin Li)

  Some code paths mistook the index depended on by a foreign key constraint for one owned by a unique or primary key constraint, resulting in odd errors during certain `ALTER TABLE` operations on tables having foreign key constraints.

- Fix bogus errors from attempts to alter system columns of tables (Tom Lane)

  The system should just tell you that you can't do it, but sometimes it would report “no owned sequence found” instead.

- Fix mis-sorting of table rows when `CLUSTER`ing using an index whose leading key is an expression (Peter Geoghegan, Thomas Munro)

  The table would be rebuilt with the correct data, but in an order having little to do with the index order.

- Prevent data loss if a system crash occurs shortly after a sorted GiST index build (Heikki Linnakangas)

  The code path for building GiST indexes using sorting neglected to `fsync` the file upon completion. This could result in a corrupted index if the operating system crashed shortly later.

- Fix risk of deadlock failures while dropping a partitioned index (Jimmy Yih, Gaurab Dey, Tom Lane)

  Ensure that the required table and index locks are taken in the standard order (parents before children, tables before indexes). The previous coding for `DROP INDEX` did it differently, and so could deadlock against concurrent queries taking these locks in the standard order.

- Fix race condition between `DROP TABLESPACE` and checkpointing (Nathan Bossart)

  The checkpoint forced by `DROP TABLESPACE` could sometimes fail to remove all dead files from the tablespace's directory, leading to a bogus “tablespace is not empty” error.

- Fix possible trouble in crash recovery after a `TRUNCATE` command that overlaps a checkpoint (Kyotaro Horiguchi, Heikki Linnakangas, Robert Haas)

  `TRUNCATE` must ensure that the table's disk file is truncated before the checkpoint is allowed to complete. Otherwise, replay starting from that checkpoint might find unexpected data in the supposedly-removed pages, possibly causing replay failure.

- Fix unsafe toast-data accesses during temporary object cleanup (Andres Freund)

  Temporary-object deletion during server process exit could fail with “FATAL: cannot fetch toast data without an active snapshot”. This was usually harmless since the next use of that temporary schema would clean up successfully.

- Re-allow underscore as the first character in a custom parameter name (Japin Li)

Such names were unintentionally disallowed in v14.

- Add `regress` option for the `compute_query_id` parameter (Michael Paquier)

  This is intended to facilitate testing, by allowing query IDs to be computed but not shown in `EXPLAIN` output.

- Improve wait logic in RegisterSyncRequest (Thomas Munro)

  If we run out of space in the checkpointer sync request queue (which is hopefully rare on real systems, but is common when testing with a very small buffer pool), we wait for it to drain. While waiting, we should report that as a wait event so that users know what is going on, and also watch for postmaster death, since otherwise the loop might never terminate if the checkpointer has already exited.

- Wake up for latch events when the checkpointer is waiting between writes (Thomas Munro)

  This improves responsiveness to backends sending sync requests. The change also creates a proper wait event class for these waits.

- Fix “PANIC: xlog flush request is not satisfied” failure during standby promotion when there is a missing WAL continuation record (Sami Imseih)

- Fix possibility of self-deadlock in hot standby conflict handling (Andres Freund)

  With unlucky timing, the WAL-applying process could get stuck while waiting for some other process to release a buffer lock.

- Fix possible mis-identification of the correct ancestor relation to publish logical replication changes through (Tomas Vondra, Hou zj, Amit Kapila)

  If `publish_via_partition_root` is enabled, and there are multiple publications naming different ancestors of the currently-modified relation, the wrong ancestor might be chosen for reporting the change.

- Ensure that logical replication apply workers can be restarted even when we're up against the `max_sync_workers_per_subscription` limit (Amit Kapila)

  Faulty coding of the limit check caused a restarted worker to exit immediately, leaving fewer workers than there should be.

- Include unchanged replica identity key columns in the WAL log for an update, if they are stored out-of-line (Dilip Kumar, Amit Kapila)

  Otherwise subscribers cannot see the values and will fail to replicate the update.

- Cope correctly with platforms that have no support for altering the server process's display in ps(1) (Andrew Dunstan)

  Few platforms are like this (the only supported one is Cygwin), so we'd managed not to notice that refactoring introduced a potential memory clobber.

- Make the server more robust against missed timer interrupts (Michael Harris, Tom Lane)

  An optimization added in v14 meant that if a server process somehow missed a timer interrupt, it would never again ask the kernel for another one, thus breaking timeout detection for the remainder of the session. This seems unduly fragile, so add a recovery path.

- Disallow execution of SPI functions during PL/Perl function compilation (Tom Lane)

  Perl can be convinced to execute user-defined code during compilation of a PL/Perl function. However, it's not okay for such code to try to invoke SQL operations via SPI. That results in a crash, and if it didn't crash it would be a security hazard, because we really don't want code execution during function validation. Put in a check to give a friendlier error message instead.

- Make libpq accept root-owned SSL private key files (David Steele)

This change synchronizes libpq's rules for safe ownership and permissions of SSL key files with the rules the server has used since release 9.6. Namely, in addition to the current rules, allow the case where the key file is owned by root and has permissions `rw-r-----` or less. This is helpful for system-wide management of key files.

- Fix behavior of libpq's `PQisBusy()` function after a connection failure (Tom Lane)

  If we'd detected a write failure, `PQisBusy()` would always return true, which is the wrong thing: we want input processing to carry on normally until we've read whatever is available from the server. The practical effect of this error is that applications using libpq's async-query API would typically detect connection loss only when `PQconsumeInput()` returns a hard failure. With this fix, a connection loss will normally be reported via an error `PGresult` object, which is a much cleaner behavior for most applications.

- Re-allow *`database`*.*`schema`*.*`table`* patterns in psql, pg_dump, and pg_amcheck (Mark Dilger)

  Versions before v14 silently ignored all but the *`schema`* and *`table`* fragments of a pattern containing more than one dot. Refactoring in v14 accidentally broke that use-case. Reinstate it, but now complain if the first fragment is not the name of the current database.

- Make pg_ctl recheck postmaster aliveness while waiting for stop/restart/promote actions (Tom Lane)

  pg_ctl would verify that the postmaster is alive as a side-effect of sending the stop or promote signal, but then it just naively waited to see the on-disk state change. If the postmaster died uncleanly without having removed its PID file or updated the control file, pg_ctl would wait until timeout. Instead make it recheck every so often that the postmaster process is still there.

- Fix error handling in pg_waldump (Kyotaro Horiguchi, Andres Freund)

  While trying to read a WAL file to determine the WAL segment size, pg_waldump would report an incorrect error for the case of a too-short file. In addition, the file name reported in this and related error messages could be garbage.

- Ensure that `contrib/pageinspect` functions cope with all-zero pages (Michael Paquier)

  This is a legitimate edge case, but the module was mostly unprepared for it. Arrange to return nulls, or no rows, as appropriate; that seems more useful than raising an error.

- In `contrib/pageinspect`, add defenses against incorrect page “special space” contents, tighten checks for correct page size, and add some missing checks that an index is of the expected type (Michael Paquier, Justin Pryzby, Julien Rouhaud)

  These changes make it less likely that the module will crash on bad data.

- In `contrib/postgres_fdw`, disable batch insertion when `BEFORE INSERT ... FOR EACH ROW` triggers exist on the foreign table (Etsuro Fujita)

  Such a trigger might query the table it's on and expect to see previously-inserted rows. With batch insertion, those rows might not be visible yet, so disable the feature to avoid unexpected behavior.

- In `contrib/postgres_fdw`, verify that `ORDER BY` clauses are safe to ship before requesting a remotely-ordered query, and include a `USING` clause if necessary (Ronan Dunklau)

  This fix prevents situations where the remote server might sort in a different order than we intend. While sometimes that would be only cosmetic, it could produce thoroughly wrong results if the remote data is used as input for a locally-performed merge join.

- Fix configure to handle platforms that have `sys/epoll.h` but not `sys/signalfd.h` (Tom Lane)
- Update JIT code to work with LLVM 14 (Thomas Munro)
- Clean up assorted failures under clang's `-fsanitize=undefined` checks (Tom Lane, Andres Freund, Zhihong Yu)

Most of these changes are just for pro-forma compliance with the letter of the C and POSIX standards, and are unlikely to have any effect on production builds.

- Do not add OpenSSL dependencies to libpq's `pkg-config` file when building without OpenSSL (Fabrice Fontaine)
- Fix PL/Perl so it builds on C compilers that don't support statements nested within expressions (Tom Lane)
- Fix possible build failure of pg_dumpall on Windows, when not using MSVC to build (Andres Freund)
- In Windows builds, use gendef instead of pexports to build DEF files (Andrew Dunstan)

  This adapts the build process to work on recent MSys tool chains.
- Prevent extra expansion of shell wildcard patterns in programs built under MinGW (Andrew Dunstan)

  For some reason the C library provided by MinGW will expand shell wildcard characters in a program's command-line arguments by default. This is confusing, not least because it doesn't happen under MSVC, so turn it off.
- Update time zone data files to tzdata release 2022a for DST law changes in Palestine, plus historical corrections for Chile and Ukraine. (Tom Lane)

E.38. Release 14.2

Release date: 2022-02-10

This release contains a variety of fixes from 14.1. For information about new features in major release 14, see Section E.40.

E.38.1. Migration to Version 14.2

A dump/restore is not required for those running 14.X.

However, some bugs have been found that may have resulted in corrupted indexes, as explained in the first two changelog entries. If any of those cases apply to you, it's recommended to reindex possibly-affected indexes after updating.

Also, if you are upgrading from a version earlier than 14.1, see Section E.39.

E.38.2. Changes

- Enforce standard locking protocol for TOAST table updates, to prevent problems with `REINDEX CONCURRENTLY` (Michael Paquier)

  If applied to a TOAST table or TOAST table's index, `REINDEX CONCURRENTLY` tended to produce a corrupted index. This happened because sessions updating TOAST entries released their `ROW EXCLUSIVE` locks immediately, rather than holding them until transaction commit as all other updates do. The fix is to make TOAST updates hold the table lock according to the normal rule. Any existing corrupted indexes can be repaired by reindexing again.
- Fix corruption of HOT chains when a RECENTLY_DEAD tuple changes state to fully DEAD during page pruning (Andres Freund)

  It was possible for `VACUUM` to remove a recently-dead tuple while leaving behind a redirect item that pointed to it. When the tuple's item slot is later re-used by some new tuple, that tuple would be seen as part of the pre-existing HOT chain, creating a form of index corruption. If this has hap-

pened, reindexing the table should repair the damage. However, this is an extremely low-probability scenario, so we do not recommend reindexing just on the chance that it might have happened.

- Fix crash in EvalPlanQual rechecks for tables with a mix of local and foreign partitions (Etsuro Fujita)
- Fix dangling pointer in `COPY TO` (Bharath Rupireddy)

  This oversight could cause an incorrect error message or a crash after an error in `COPY`.
- Avoid null-pointer crash in `ALTER STATISTICS` when the statistics object is dropped concurrently (Tomas Vondra)
- Correctly handle alignment padding when extracting a range from a multirange (Alexander Korotkov)

  This error could cause crashes when handling multiranges over variable-length data types.
- Fix over-optimistic use of hashing for anonymous `RECORD` data types (Tom Lane)

  This prevents some cases of “could not identify a hash function for type record” errors.
- Fix incorrect plan creation for parallel single-child Append nodes (David Rowley)

  In some cases the Append would be simplified away when it should not be, leading to wrong query results (duplicated rows).
- Fix index-only scan plans for cases where not all index columns can be returned (Tom Lane)

  If an index has both returnable and non-returnable columns, and one of the non-returnable columns is an expression using a table column that appears in a returnable index column, then a query using that expression could result in an index-only scan plan that attempts to read the non-returnable column, instead of recomputing the expression from the returnable column as intended. The non-returnable column would read as NULL, resulting in wrong query results.
- Fix Memoize plan nodes to handle subplans that use parameters coming from above the Memoize (David Rowley)
- Fix Memoize plan nodes to work correctly with non-hashable join operators (David Rowley)
- Ensure that casting to an unspecified typmod generates a RelabelType node rather than a length-coercion function call (Tom Lane)

  While the coercion function should do the right thing (nothing), this translation is undesirably inefficient.
- Fix checking of `anycompatible`-family data type matches (Tom Lane)

  In some cases the parser would think that a function or operator with `anycompatible`-family polymorphic parameters matches a set of arguments that it really shouldn't match. In reported cases, that led to matching more than one operator to a call, leading to ambiguous-operator errors; but a failure later on is also possible.
- Fix WAL replay failure when database consistency is reached exactly at a WAL page boundary (Álvaro Herrera)
- Fix startup of a physical replica to tolerate transaction ID wraparound (Abhijit Menon-Sen, Tomas Vondra)

  If a replica server is started while the set of active transactions on the primary crosses a wraparound boundary (so that there are some newer transactions with smaller XIDs than older ones), the replica would fail with “out-of-order XID insertion in KnownAssignedXids”. The replica would retry, but could never get past that error.
- In logical replication, avoid double transmission of a child table's data (Hou Zhijie)

If a publication includes both child and parent tables, and has the `publish_via_partition_root` option set, subscribers uselessly initiated synchronization on both child and parent tables. Ensure that only the parent table is synchronized in such cases.

- Remove lexical limitations for SQL commands issued on a logical replication connection (Tom Lane)

  The walsender process would fail for a SQL command containing an unquoted semicolon, or with dollar-quoted literals containing odd numbers of single or double quote marks, or when the SQL command starts with a comment. Moreover, faulty error recovery could lead to unexpected errors in later commands too.

- Ensure that replication origin timestamp is set while replicating a `ROLLBACK PREPARED` operation (Masahiko Sawada)

- Fix possible loss of the commit timestamp for the last subtransaction of a transaction (Alex Kingsborough, Kyotaro Horiguchi)

- Be sure to `fsync` the `pg_logical/mappings` subdirectory during checkpoints (Nathan Bossart)

  On some filesystems this oversight could lead to losing logical rewrite status files after a system crash.

- Build extended statistics for partitioned tables (Justin Pryzby)

  A previous bug fix disabled building of extended statistics for old-style inheritance trees, but it also prevented building them for partitioned tables, which was an unnecessary restriction. This change allows `ANALYZE` to compute values for statistics objects for partitioned tables. (But note that autovacuum does not process partitioned tables as such, so you must periodically issue manual `ANALYZE` on the partitioned table if you want to maintain such statistics.)

- Ignore extended statistics for inheritance trees (Justin Pryzby)

  Currently, extended statistics values are only computed locally for each table, not for entire inheritance trees. However the values were mistakenly consulted when planning queries across inheritance trees, possibly resulting in worse-than-default estimates.

- Disallow altering data type of a partitioned table's columns when the partitioned table's row type is used as a composite type elsewhere (Tom Lane)

  This restriction has long existed for regular tables, but through an oversight it was not checked for partitioned tables.

- Disallow `ALTER TABLE ... DROP NOT NULL` for a column that is part of a replica identity index (Haiying Tang, Hou Zhijie)

  The same prohibition already existed for primary key indexes.

- Correctly update cached table state during `ALTER TABLE ADD PRIMARY KEY USING INDEX` (Hou Zhijie)

  Concurrent sessions failed to update their opinion of whether the table has a primary key, possibly causing incorrect logical replication behavior.

- Correctly update cached table state when switching `REPLICA IDENTITY` index (Tang Haiying, Hou Zhijie)

  Concurrent sessions failed to update their opinion of which index is the replica identity one, possibly causing incorrect logical replication behavior.

- Fix failure of SP-GiST indexes when the indexed column's data type is binary-compatible with the declared input type of the operator class (Tom Lane)

  Such cases should work, but failed with “compress method must be defined when leaf type is different from input type”.

- Allow parallel vacuuming and concurrent index building to be ignored while computing oldest xmin (Masahiko Sawada)

  Non-parallelized instances of these operations were already ignored, but the logic did not work for parallelized cases. Holding back the xmin horizon has undesirable effects such as delaying vacuum cleanup.

- Fix memory leak when updating expression indexes (Peter Geoghegan)

  An `UPDATE` affecting many rows could consume significant amounts of memory.

- Avoid leaking memory during `REASSIGN OWNED BY` operations that reassign ownership of many objects (Justin Pryzby)

- Improve performance of walsenders sending logical changes by avoiding unnecessary cache accesses (Hou Zhijie)

- Fix display of `cert` authentication method's options in `pg_hba_file_rules` view (Magnus Hagander)

  The `cert` authentication method implies `clientcert=verify-full`, but the `pg_hba_file_rules` view incorrectly reported `clientcert=verify-ca`.

- Ensure that the session targeted by `pg_log_backend_memory_contexts()` sends its results only to the server's log (Fujii Masao)

  Previously, a sufficiently high setting of `client_min_messages` could result in the log message also being sent to the connected client. Since that client hadn't requested it, that would be surprising (and possibly a wire protocol violation).

- Fix display of whole-row variables appearing in `INSERT ... VALUES` rules (Tom Lane)

  A whole-row variable would be printed as “var.*”, but that allows it to be expanded to individual columns when the rule is reloaded, resulting in different semantics. Attach an explicit cast to prevent that, as we do elsewhere.

- When reverse-listing a SQL-standard function body, display function parameters appropriately within `INSERT ... SELECT` (Tom Lane)

  Previously, they'd come out as `$N` even when the parameter had a name.

- Fix one-byte buffer overrun when applying Unicode string normalization to an empty string (Michael Paquier)

  The practical impact of this is limited thanks to alignment considerations; but in debug builds, a warning was raised.

- Fix or remove some incorrect assertions (Simon Riggs, Michael Paquier, Alexander Lakhin)

  These errors should affect only debug builds, not production.

- Fix race condition that could lead to failure to localize error messages that are reported early in multi-threaded use of libpq or ecpglib (Tom Lane)

- Avoid calling `strerror` from libpq's `PQcancel` function (Tom Lane)

  `PQcancel` is supposed to be safe to call from a signal handler, but `strerror` is not safe. The faulty usage only occurred in the unlikely event of failure to send the cancel message to the server, perhaps explaining the lack of reports.

- Make psql's `\password` command default to setting the password for `CURRENT_USER`, not the connection's original user name (Tom Lane)

  This agrees with the documented behavior, and avoids probable permissions failure if `SET ROLE` or `SET SESSION AUTHORIZATION` has been done since the session began. To prevent confusion, the role name to be acted on is now included in the password prompt.

- Fix psql `\d` command's query for identifying parent triggers (Justin Pryzby)

  The previous coding failed with “more than one row returned by a subquery used as an expression” if a partition had triggers and there were unrelated statement-level triggers of the same name on some parent partitioned table.
- Make psql's `\d` command sort a table's extended statistics objects by name not OID (Justin Pryzby)
- Fix psql's tab-completion of label values for enum types (Tom Lane)
- Fix failures on Windows when using the terminal as data source or destination (Dmitry Koval, Juan José Santamaría Flecha, Michael Paquier)

  This affects psql's `\copy` command, as well as pg_recvlogical with `-f -`.
- In psql and some other client programs, avoid trying to invoke `gettext()` from a control-C signal handler (Tom Lane)

  While no reported failures have been traced to this mistake, it seems highly unlikely to be a safe thing to do.
- Allow canceling the initial password prompt in pg_receivewal and pg_recvlogical (Tom Lane, Nathan Bossart)

  Previously it was impossible to terminate these programs via control-C while they were prompting for a password.
- Fix pg_dump's dump ordering for user-defined casts (Tom Lane)

  In rare cases, the output script might refer to a user-defined cast before it had been created.
- Fix pg_dump's `--inserts` and `--column-inserts` modes to handle tables containing both generated columns and dropped columns (Tom Lane)
- Fix possible mis-reporting of errors in pg_dump and pg_basebackup (Tom Lane)

  The previous code failed to check for errors from some kernel calls, and could report the wrong errno values in other cases.
- Fix results of index-only scans on `contrib/btree_gist` indexes on `char(N)` columns (Tom Lane)

  Index-only scans returned column values with trailing spaces removed, which is not the expected behavior. That happened because that's how the data was stored in the index. This fix changes the code to store `char(N)` values with the expected amount of space padding. The behavior of such an index will not change immediately unless you `REINDEX` it; otherwise space-stripped values will be gradually replaced over time during updates. Queries that do not use index-only scan plans will be unaffected in any case.
- Fix edge cases in `postgres_fdw`'s handling of asynchronous queries (Etsuro Fujita)

  These errors could lead to crashes or incorrect results when attempting to parallelize scans of foreign tables.
- Change configure to use Python's sysconfig module, rather than the deprecated distutils module, to determine how to build PL/Python (Peter Eisentraut, Tom Lane, Andres Freund)

  With Python 3.10, this avoids configure-time warnings about distutils being deprecated and scheduled for removal in Python 3.12. Presumably, once 3.12 is out, `configure --with-python` would fail altogether. This future-proofing does come at a cost: sysconfig did not exist before Python 2.7, nor before 3.2 in the Python 3 branch, so it is no longer possible to build PL/Python against long-dead Python versions.
- Re-allow cross-compilation without OpenSSL (Tom Lane)

  configure should assume that `/dev/urandom` will be available on the target system, but it failed instead.

- Fix PL/Perl compile failure on Windows with Perl 5.28 and later (Victor Wagner)
- Fix PL/Python compile failure with Python 3.11 and later (Peter Eisentraut)
- Add support for building with Visual Studio 2022 (Hans Buschmann)
- Allow the `.bat` wrapper scripts in our MSVC build system to be called without first changing into their directory (Anton Voloshin, Andrew Dunstan)

E.39. Release 14.1

Release date: 2021-11-11

This release contains a variety of fixes from 14.0. For information about new features in major release 14, see Section E.40.

E.39.1. Migration to Version 14.1

A dump/restore is not required for those running 14.X.

However, note that installations using physical replication should update standby servers before the primary server, as explained in the third changelog entry below.

Also, several bugs have been found that may have resulted in corrupted indexes, as explained in the next several changelog entries. If any of those cases apply to you, it's recommended to reindex possibly-affected indexes after updating.

E.39.2. Changes

- Make the server reject extraneous data after an SSL or GSS encryption handshake (Tom Lane)

  A man-in-the-middle with the ability to inject data into the TCP connection could stuff some cleartext data into the start of a supposedly encryption-protected database session. This could be abused to send faked SQL commands to the server, although that would only work if the server did not demand any authentication data. (However, a server relying on SSL certificate authentication might well not do so.)

  The PostgreSQL Project thanks Jacob Champion for reporting this problem. (CVE-2021-23214)

- Make libpq reject extraneous data after an SSL or GSS encryption handshake (Tom Lane)

  A man-in-the-middle with the ability to inject data into the TCP connection could stuff some cleartext data into the start of a supposedly encryption-protected database session. This could probably be abused to inject faked responses to the client's first few queries, although other details of libpq's behavior make that harder than it sounds. A different line of attack is to exfiltrate the client's password, or other sensitive data that might be sent early in the session. That has been shown to be possible with a server vulnerable to CVE-2021-23214.

  The PostgreSQL Project thanks Jacob Champion for reporting this problem. (CVE-2021-23222)

- Fix physical replication for cases where the primary crashes after shipping a WAL segment that ends with a partial WAL record (Álvaro Herrera)

  If the primary did not survive long enough to finish writing the rest of the incomplete WAL record, then the previous crash-recovery logic had it back up and overwrite WAL starting from the beginning of the incomplete WAL record. This is problematic since standby servers may already have copies of that WAL segment. They will then see an inconsistent next segment, and will not be able to recover without manual intervention. To fix, do not back up over a WAL segment boundary when restarting after a crash. Instead write a new type of WAL record at the start of the next WAL segment, informing readers that the incomplete WAL record will never be finished and must be disregarded.

When applying this update, it's best to update standby servers before the primary, so that they will be ready to handle this new WAL record type if the primary happens to crash.

- Ensure that parallel `VACUUM` doesn't miss any indexes (Peter Geoghegan, Masahiko Sawada)

  A parallel `VACUUM` would fail to process indexes that are below the `min_parallel_index_scan_size` cutoff, if the table also has at least two indexes that are above that size. This could result in those indexes becoming corrupt, since they'd still contain references to any heap entries removed by the `VACUUM`; subsequent queries using such indexes would be likely to return rows they shouldn't. This problem does not affect autovacuum, since it doesn't use parallel vacuuming. However, it is advisable to reindex any manually-vacuumed tables that have the right mix of index sizes.

- Fix `CREATE INDEX CONCURRENTLY` to wait for the latest prepared transactions (Andrey Borodin)

  Rows inserted by just-prepared transactions might be omitted from the new index, causing queries relying on the index to miss such rows. The previous fix for this type of problem failed to account for `PREPARE TRANSACTION` commands that were still in progress when `CREATE INDEX CONCURRENTLY` checked for them. As before, in installations that have enabled prepared transactions (`max_prepared_transactions` > 0), it's recommended to reindex any concurrently-built indexes in case this problem occurred when they were built.

- Avoid race condition that can cause backends to fail to add entries for new rows to an index being built concurrently (Noah Misch, Andrey Borodin)

  While it's apparently rare in the field, this case could potentially affect any index built or reindexed with the `CONCURRENTLY` option. It is recommended to reindex any such indexes to make sure they are correct.

- Fix `REINDEX CONCURRENTLY` to preserve operator class parameters that were attached to the target index (Michael Paquier)

- Fix incorrect creation of shared dependencies when cloning a database that contains non-builtin objects (Aleksander Alekseev)

  The effects of this error are probably limited in practice. In principle, it could allow a role to be dropped while it still owns objects; but most installations would never want to drop a role that had been used for objects they'd added to `template1`.

- Ensure that the relation cache is invalidated for a table being attached to or detached from a partitioned table (Amit Langote, Álvaro Herrera)

  This oversight could allow misbehavior of subsequent inserts/updates addressed directly to the partition, but only in currently-existing sessions.

- Fix corruption of parse tree while creating a range type (Alex Kozhemyakin, Sergey Shinderuk)

  `CREATE TYPE` incorrectly freed an element of the parse tree, which could cause problems for a later event trigger, or if the `CREATE TYPE` command was stored in the plan cache and used again later.

- Fix updates of element fields in arrays of domain over composite (Tom Lane)

  A command such as `UPDATE tab SET fld[1].subfld = val` failed if the array's elements were domains rather than plain composites.

- Disallow the combination of `FETCH FIRST WITH TIES` and `FOR UPDATE SKIP LOCKED` (David Christensen)

  `FETCH FIRST WITH TIES` necessarily fetches one more row than requested, since it cannot stop until it finds a row that is not a tie. In our current implementation, if `FOR UPDATE` is used then that row will also get locked even though it is not returned. That results in undesirable behavior if the `SKIP LOCKED` option is specified. It's difficult to change this without introducing a different set of undesirable behaviors, so for now, forbid the combination.

- Disallow `ALTER INDEX index ALTER COLUMN col SET (options)` (Nathan Bossart, Michael Paquier)

  While the parser accepted this, it's undocumented and doesn't actually work.

- Fix corner-case loss of precision in numeric `power()` (Dean Rasheed)

  The result could be inaccurate when the first argument is very close to 1.

- Avoid choosing the wrong hash equality operator for Memoize plans (David Rowley)

  This error could result in crashes or incorrect query results.

- Fix planner error with pulling up subquery expressions into function rangetable entries (Tom Lane)

  If a function in `FROM` laterally references the output of some sub-`SELECT` earlier in the `FROM` clause, and we are able to flatten that sub-`SELECT` into the outer query, the expression(s) copied into the function expression were not fully processed. This could lead to crashes at execution.

- Avoid using MCV-only statistics to estimate the range of a column (Tom Lane)

  There are corner cases in which `ANALYZE` will build a most-common-values (MCV) list but not a histogram, even though the MCV list does not account for all the observed values. In such cases, keep the planner from using the MCV list alone to estimate the range of column values.

- Fix restoration of a Portal's snapshot inside a subtransaction (Bertrand Drouvot)

  If a procedure commits or rolls back a transaction, and then its next significant action is inside a new subtransaction, snapshot management went wrong, leading to a dangling pointer and probable crash. A typical example in PL/pgSQL is a `COMMIT` immediately followed by a `BEGIN ... EXCEPTION` block that performs a query.

- Clean up correctly if a transaction fails after exporting its snapshot (Dilip Kumar)

  This oversight would only cause a problem if the same session attempted to export a snapshot again. The most likely scenario for that is creation of a replication slot (followed by rollback) and then creation of another replication slot.

- Prevent wraparound of overflowed-subtransaction tracking on standby servers (Kyotaro Horiguchi, Alexander Korotkov)

  This oversight could cause significant performance degradation (manifesting as excessive SubtransSLRU traffic) on standby servers.

- Ensure that prepared transactions are properly accounted for during promotion of a standby server (Michael Paquier, Andres Freund)

  There was a narrow window where a prepared transaction could be omitted from a snapshot taken by a concurrently-running session. If that session then used the snapshot to perform data updates, erroneous results or data corruption could occur.

- Fix “could not find RecursiveUnion” error when `EXPLAIN` tries to print a filter condition attached to a WorkTableScan node (Tom Lane)

- Ensure that the correct lock level is used when renaming a table (Nathan Bossart, Álvaro Herrera)

  For historical reasons, `ALTER INDEX ... RENAME` can be applied to any sort of relation. The lock level required to rename an index is lower than that required to rename a table or other kind of relation, but the code got this wrong and would use the weaker lock level whenever the command is spelled `ALTER INDEX`.

- Avoid null-pointer-dereference crash when dropping a role that owns objects being dropped concurrently (Álvaro Herrera)

- Prevent “snapshot reference leak” warning when `lo_export()` or a related function fails (Heikki Linnakangas)

- Fix inefficient code generation for CoerceToDomain expression nodes (Ranier Vilela)
- Avoid O(N^2) behavior in some list-manipulation operations (Nathan Bossart, Tom Lane)

  These changes fix slow processing in several scenarios, including: when a standby replays a transaction that held many exclusive locks on the primary; when many files are due to be unlinked after a checkpoint; when hash aggregation involves many batches; and when `pg_trgm` extracts indexable conditions from a complex regular expression. Only the first of these scenarios has actually been reported from the field, but they all seem like plausible consequences of inefficient list deletions.
- Add more defensive checks around B-tree posting list splits (Peter Geoghegan)

  This change should help detect index corruption involving duplicate table TIDs.
- Avoid assertion failure when inserting NaN into a BRIN float8 or float4 minmax_multi_ops index (Tomas Vondra)

  In production builds, such cases would result in a somewhat inefficient, but not actually incorrect, index.
- Allow the autovacuum launcher process to respond to `pg_log_backend_memory_contexts()` requests more quickly (Koyu Tanigawa)
- Fix memory leak in HMAC hash calculations (Sergey Shinderuk)
- Disallow setting `huge_pages` to `on` when `shared_memory_type` is `sysv` (Thomas Munro)

  Previously, this setting was accepted, but it did nothing for lack of any implementation.
- Fix checking of query type in PL/pgSQL's `RETURN QUERY` statement (Tom Lane)

  `RETURN QUERY` should accept any query that can return tuples, e.g. `UPDATE RETURNING`. v14 accidentally disallowed anything but `SELECT`; moreover, the `RETURN QUERY EXECUTE` variant failed to apply any query-type check at all.
- Fix pg_dump to dump non-global default privileges correctly (Neil Chen, Masahiko Sawada)

  If a global (unrestricted) `ALTER DEFAULT PRIVILEGES` command revoked some present-by-default privilege, for example `EXECUTE` for functions, and then a restricted `ALTER DEFAULT PRIVILEGES` command granted that privilege again for a selected role or schema, pg_dump failed to dump the restricted privilege grant correctly.
- Make pg_dump acquire shared lock on partitioned tables that are to be dumped (Tom Lane)

  This oversight was usually pretty harmless, since once pg_dump has locked any of the leaf partitions, that would suffice to prevent significant DDL on the partitioned table itself. However problems could ensue when dumping a childless partitioned table, since no relevant lock would be held.
- Fix crash in pg_dump when attempting to dump trigger definitions from a pre-8.3 server (Tom Lane)
- Fix incorrect filename in pg_restore's error message about an invalid large object TOC file (Daniel Gustafsson)
- Ensure that pgbench exits with non-zero status after a socket-level failure (Yugo Nagata, Fabien Coelho)

  The desired behavior is to finish out the run but then exit with status 2. Also, fix the reporting of such errors.
- Prevent pg_amcheck from checking temporary relations, as well as indexes that are invalid or not ready (Mark Dilger)

  This avoids unhelpful checks of relations that will almost certainly appear inconsistent.
- Make `contrib/amcheck` skip unlogged tables when running on a standby server (Mark Dilger)

It's appropriate to do this since such tables will be empty, and unlogged indexes were already handled similarly.

- Change `contrib/pg_stat_statements` to read its “query texts” file in units of at most 1GB (Tom Lane)

  Such large query text files are very unusual, but if they do occur, the previous coding would fail on Windows 64 (which rejects individual read requests of more than 2GB).

- Fix null-pointer crash when `contrib/postgres_fdw` tries to report a data conversion error (Tom Lane)

- Ensure that `GetSharedSecurityLabel()` can be used in a newly-started session that has not yet built its critical relation cache entries (Jeff Davis)

- When running a TAP test, include the module's own directory in `PATH` (Andrew Dunstan)

  This allows tests to find built programs that are not installed, such as custom test drivers.

- Use the CLDR project's data to map Windows time zone names to IANA time zones (Tom Lane)

  When running on Windows, initdb attempts to set the new cluster's `timezone` parameter to the IANA time zone matching the system's prevailing time zone. We were using a mapping table that we'd generated years ago and updated only fitfully; unsurprisingly, it contained a number of errors as well as omissions of recently-added zones. It turns out that CLDR has been tracking the most appropriate mappings, so start using their data. This change will not affect any existing installation, only newly-initialized clusters.

- Update time zone data files to tzdata release 2021e for DST law changes in Fiji, Jordan, Palestine, and Samoa, plus historical corrections for Barbados, Cook Islands, Guyana, Niue, Portugal, and Tonga. (Tom Lane)

  Also, the Pacific/Enderbury zone has been renamed to Pacific/Kanton. Also, the following zones have been merged into nearby, more-populous zones whose clocks have agreed with them since 1970: Africa/Accra, America/Atikokan, America/Blanc-Sablon, America/Creston, America/Curacao, America/Nassau, America/Port_of_Spain, Antarctica/DumontDUrville, and Antarctica/Syowa. In all these cases, the previous zone name remains as an alias.

E.40. Release 14

Release date: 2021-09-30

E.40.1. Overview

PostgreSQL 14 contains many new features and enhancements, including:

- Stored procedures can now return data via `OUT` parameters.
- The SQL-standard `SEARCH` and `CYCLE` options for common table expressions have been implemented.
- Subscripting can now be applied to any data type for which it is a useful notation, not only arrays. In this release, the `jsonb` and `hstore` types have gained subscripting operators.
- Range types have been extended by adding multiranges, allowing representation of noncontiguous data ranges.
- Numerous performance improvements have been made for parallel queries, heavily-concurrent workloads, partitioned tables, logical replication, and vacuuming.
- B-tree index updates are managed more efficiently, reducing index bloat.
- `VACUUM` automatically becomes more aggressive, and skips inessential cleanup, if the database starts to approach a transaction ID wraparound condition.

- Extended statistics can now be collected on expressions, allowing better planning results for complex queries.
- libpq now has the ability to pipeline multiple queries, which can boost throughput over high-latency connections.

The above items and other new features of PostgreSQL 14 are explained in more detail in the sections below.

E.40.2. Migration to Version 14

A dump/restore using pg_dumpall or use of pg_upgrade or logical replication is required for those wishing to migrate data from any previous release. See Section 18.6 for general information on migrating to new major releases.

Version 14 contains a number of changes that may affect compatibility with previous releases. Observe the following incompatibilities:

- User-defined objects that reference certain built-in array functions along with their argument types must be recreated (Tom Lane)

  Specifically, `array_append()`, `array_prepend()`, `array_cat()`, `array_position()`, `array_positions()`, `array_remove()`, `array_replace()`, and `width_bucket()` used to take `anyarray` arguments but now take `anycompatiblearray`. Therefore, user-defined objects like aggregates and operators that reference those array function signatures must be dropped before upgrading, and recreated once the upgrade completes.

- Remove deprecated containment operators `@` and `~` for built-in geometric data types and contrib modules cube, hstore, intarray, and seg (Justin Pryzby)

  The more consistently named `<@` and `@>` have been recommended for many years.

- Fix `to_tsquery()` and `websearch_to_tsquery()` to properly parse query text containing discarded tokens (Alexander Korotkov)

  Certain discarded tokens, like underscore, caused the output of these functions to produce incorrect tsquery output, e.g., both `websearch_to_tsquery('"pg_class pg"')` and `to_tsquery('pg_class <-> pg')` used to output `( 'pg' & 'class' ) <-> 'pg'`, but now both output `'pg' <-> 'class' <-> 'pg'`.

- Fix `websearch_to_tsquery()` to properly parse multiple adjacent discarded tokens in quotes (Alexander Korotkov)

  Previously, quoted text that contained multiple adjacent discarded tokens was treated as multiple tokens, causing incorrect tsquery output, e.g., `websearch_to_tsquery('"aaa: bbb"')` used to output `'aaa' <2> 'bbb'`, but now outputs `'aaa' <-> 'bbb'`.

- Change `EXTRACT()` to return type `numeric` instead of `float8` (Peter Eisentraut)

  This avoids loss-of-precision issues in some usages. The old behavior can still be obtained by using the old underlying function `date_part()`.

  Also, `EXTRACT(date)` now throws an error for units that are not part of the `date` data type.

- Change `var_samp()` and `stddev_samp()` with numeric parameters to return NULL when the input is a single NaN value (Tom Lane)

  Previously `NaN` was returned.

- Return false for `has_column_privilege()` checks on non-existent or dropped columns when using attribute numbers (Joe Conway)

  Previously such attribute numbers returned an invalid-column error.

- Fix handling of infinite window function ranges (Tom Lane)

  Previously window frame clauses like `'inf' PRECEDING AND 'inf' FOLLOWING` returned incorrect results.

- Remove factorial operators `!` and `!!`, as well as function `numeric_fac()` (Mark Dilger)

  The `factorial()` function is still supported.

- Disallow `factorial()` of negative numbers (Peter Eisentraut)

  Previously such cases returned 1.

- Remove support for postfix (right-unary) operators (Mark Dilger)

  pg_dump and pg_upgrade will warn if postfix operators are being dumped.

- Allow `\D` and `\W` shorthands to match newlines in regular expression newline-sensitive mode (Tom Lane)

  Previously they did not match newlines in this mode, but that disagrees with the behavior of other common regular expression engines. `[^[:digit:]]` or `[^[:word:]]` can be used to get the old behavior.

- Disregard constraints when matching regular expression back-references (Tom Lane)

  For example, in `(^\d+).*\1`, the `^` constraint should be applied at the start of the string, but not when matching `\1`.

- Disallow `\w` as a range start or end in regular expression character classes (Tom Lane)

  This previously was allowed but produced unexpected results.

- Require custom server parameter names to use only characters that are valid in unquoted SQL identifiers (Tom Lane)

- Change the default of the password_encryption server parameter to `scram-sha-256` (Peter Eisentraut)

  Previously it was `md5`. All new passwords will be stored as SHA256 unless this server setting is changed or the password is specified in MD5 format. Also, the legacy (and undocumented) Boolean-like values which were previously synonyms for `md5` are no longer accepted.

- Remove server parameter `vacuum_cleanup_index_scale_factor` (Peter Geoghegan)

  This setting was ignored starting in PostgreSQL version 13.3.

- Remove server parameter `operator_precedence_warning` (Tom Lane)

  This setting was used for warning applications about PostgreSQL 9.5 changes.

- Overhaul the specification of `clientcert` in `pg_hba.conf` (Kyotaro Horiguchi)

  Values `1`/`0`/`no-verify` are no longer supported; only the strings `verify-ca` and `verify-full` can be used. Also, disallow `verify-ca` if cert authentication is enabled since cert requires `verify-full` checking.

- Remove support for SSL compression (Daniel Gustafsson, Michael Paquier)

  This was already disabled by default in previous PostgreSQL releases, and most modern OpenSSL and TLS versions no longer support it.

- Remove server and libpq support for the version 2 wire protocol (Heikki Linnakangas)

  This was last used as the default in PostgreSQL 7.3 (released in 2002).

- Disallow single-quoting of the language name in the `CREATE/DROP LANGUAGE` command (Peter Eisentraut)
- Remove the composite types that were formerly created for sequences and toast tables (Tom Lane)
- Process doubled quote marks in ecpg SQL command strings correctly (Tom Lane)

  Previously `'abc''def'` was passed to the server as `'abc'def'`, and `"abc""def"` was passed as `"abc"def"`, causing syntax errors.
- Prevent the containment operators (`<@` and `@>`) for intarray from using GiST indexes (Tom Lane)

  Previously a full GiST index scan was required, so just avoid that and scan the heap, which is faster. Indexes created for this purpose should be removed.
- Remove contrib program pg_standby (Justin Pryzby)
- Prevent tablefunc's function `normal_rand()` from accepting negative values (Ashutosh Bapat)

  Negative values produced undesirable results.

E.40.3. Changes

Below you will find a detailed account of the changes between PostgreSQL 14 and the previous major release.

E.40.3.1. Server

- Add predefined roles `pg_read_all_data` and `pg_write_all_data` (Stephen Frost)

  These non-login roles can be used to give read or write permission to all tables, views, and sequences.
- Add predefined role `pg_database_owner` that contains only the current database's owner (Noah Misch)

  This is especially useful in template databases.
- Remove temporary files after backend crashes (Euler Taveira)

  Previously, such files were retained for debugging purposes. If necessary, deletion can be disabled with the new server parameter remove_temp_files_after_crash.
- Allow long-running queries to be canceled if the client disconnects (Sergey Cherkashin, Thomas Munro)

  The server parameter client_connection_check_interval allows control over whether loss of connection is checked for intra-query. (This is supported on Linux and a few other operating systems.)
- Add an optional timeout parameter to `pg_terminate_backend()` (Magnus Hagander)
- Allow wide tuples to be always added to almost-empty heap pages (John Naylor, Floris van Nee)

  Previously tuples whose insertion would have exceeded the page's fill factor were instead added to new pages.
- Add Server Name Indication (SNI) in SSL connection packets (Peter Eisentraut)

  This can be disabled by turning off client connection option `sslsni`.

E.40.3.1.1. Vacuuming

- Allow vacuum to skip index vacuuming when the number of removable index entries is insignificant (Masahiko Sawada, Peter Geoghegan)

  The vacuum parameter `INDEX_CLEANUP` has a new default of `auto` that enables this optimization.

- Allow vacuum to more eagerly add deleted btree pages to the free space map (Peter Geoghegan)

  Previously vacuum could only add pages to the free space map that were marked as deleted by previous vacuums.

- Allow vacuum to reclaim space used by unused trailing heap line pointers (Matthias van de Meent, Peter Geoghegan)

- Allow vacuum to be more aggressive in removing dead rows during minimal-locking index operations (Álvaro Herrera)

  Specifically, `CREATE INDEX CONCURRENTLY` and `REINDEX CONCURRENTLY` no longer limit the dead row removal of other relations.

- Speed up vacuuming of databases with many relations (Tatsuhito Kasahara)

- Reduce the default value of vacuum_cost_page_miss to better reflect current hardware capabilities (Peter Geoghegan)

- Add ability to skip vacuuming of TOAST tables (Nathan Bossart)

  `VACUUM` now has a `PROCESS_TOAST` option which can be set to false to disable TOAST processing, and vacuumdb has a `--no-process-toast` option.

- Have `COPY FREEZE` appropriately update page visibility bits (Anastasia Lubennikova, Pavan Deolasee, Jeff Janes)

- Cause vacuum operations to be more aggressive if the table is near xid or multixact wraparound (Masahiko Sawada, Peter Geoghegan)

  This is controlled by vacuum_failsafe_age and vacuum_multixact_failsafe_age.

- Increase warning time and hard limit before transaction id and multi-transaction wraparound (Noah Misch)

  This should reduce the possibility of failures that occur without having issued warnings about wraparound.

- Add per-index information to autovacuum logging output (Masahiko Sawada)

E.40.3.1.2. Partitioning

- Improve the performance of updates and deletes on partitioned tables with many partitions (Amit Langote, Tom Lane)

  This change greatly reduces the planner's overhead for such cases, and also allows updates/deletes on partitioned tables to use execution-time partition pruning.

- Allow partitions to be detached in a non-blocking manner (Álvaro Herrera)

  The syntax is `ALTER TABLE ... DETACH PARTITION ... CONCURRENTLY`, and `FINALIZE`.

- Ignore `COLLATE` clauses in partition boundary values (Tom Lane)

  Previously any such clause had to match the collation of the partition key; but it's more consistent to consider that it's automatically coerced to the collation of the partition key.

E.40.3.1.3. Indexes

- Allow btree index additions to remove expired index entries to prevent page splits (Peter Geoghegan)

  This is particularly helpful for reducing index bloat on tables whose indexed columns are frequently updated.

- Allow BRIN indexes to record multiple min/max values per range (Tomas Vondra)

This is useful if there are groups of values in each page range.

- Allow BRIN indexes to use bloom filters (Tomas Vondra)

  This allows BRIN indexes to be used effectively with data that is not well-localized in the heap.

- Allow some GiST indexes to be built by presorting the data (Andrey Borodin)

  Presorting happens automatically and allows for faster index creation and smaller indexes.

- Allow SP-GiST indexes to contain `INCLUDE`'d columns (Pavel Borisov)

E.40.3.1.4. Optimizer

- Allow hash lookup for `IN` clauses with many constants (James Coleman, David Rowley)

  Previously the code always sequentially scanned the list of values.

- Increase the number of places extended statistics can be used for `OR` clause estimation (Tomas Vondra, Dean Rasheed)

- Allow extended statistics on expressions (Tomas Vondra)

  This allows statistics on a group of expressions and columns, rather than only columns like previously. System view `pg_stats_ext_exprs` reports such statistics.

- Allow efficient heap scanning of a range of `TIDs` (Edmund Horner, David Rowley)

  Previously a sequential scan was required for non-equality `TID` specifications.

- Fix `EXPLAIN CREATE TABLE AS` and `EXPLAIN CREATE MATERIALIZED VIEW` to honor `IF NOT EXISTS` (Bharath Rupireddy)

  Previously, if the object already existed, `EXPLAIN` would fail.

E.40.3.1.5. General Performance

- Improve the speed of computing MVCC visibility snapshots on systems with many CPUs and high session counts (Andres Freund)

  This also improves performance when there are many idle sessions.

- Add executor method to memoize results from the inner side of a nested-loop join (David Rowley)

  This is useful if only a small percentage of rows is checked on the inner side. It can be disabled via server parameter enable_memoize.

- Allow window functions to perform incremental sorts (David Rowley)

- Improve the I/O performance of parallel sequential scans (Thomas Munro, David Rowley)

  This was done by allocating blocks in groups to parallel workers.

- Allow a query referencing multiple foreign tables to perform foreign table scans in parallel (Robert Haas, Kyotaro Horiguchi, Thomas Munro, Etsuro Fujita)

  postgres_fdw supports this type of scan if `async_capable` is set.

- Allow analyze to do page prefetching (Stephen Frost)

  This is controlled by maintenance_io_concurrency.

- Improve performance of regular expression searches (Tom Lane)

- Dramatically improve Unicode normalization performance (John Naylor)

  This speeds `normalize()` and `IS NORMALIZED`.

- Add ability to use LZ4 compression on TOAST data (Dilip Kumar)

This can be set at the column level, or set as a default via server parameter default_toast_compression. The server must be compiled with `--with-lz4` to support this feature. The default setting is still pglz.

E.40.3.1.6. Monitoring

- If server parameter compute_query_id is enabled, display the query id in `pg_stat_activity`, `EXPLAIN VERBOSE`, csvlog, and optionally in log_line_prefix (Julien Rouhaud)

  A query id computed by an extension will also be displayed.

- Improve logging of auto-vacuum and auto-analyze (Stephen Frost, Jakub Wartak)

  This reports I/O timings for auto-vacuum and auto-analyze if track_io_timing is enabled. Also, report buffer read and dirty rates for auto-analyze.

- Add information about the original user name supplied by the client to the output of log_connections (Jacob Champion)

E.40.3.1.7. System Views

- Add system view `pg_stat_progress_copy` to report `COPY` progress (Josef Šimánek, Matthias van de Meent)
- Add system view `pg_stat_wal` to report WAL activity (Masahiro Ikeda)
- Add system view `pg_stat_replication_slots` to report replication slot activity (Masahiko Sawada, Amit Kapila, Vignesh C)

  The function `pg_stat_reset_replication_slot()` resets slot statistics.

- Add system view `pg_backend_memory_contexts` to report session memory usage (Atsushi Torikoshi, Fujii Masao)
- Add function `pg_log_backend_memory_contexts()` to output the memory contexts of arbitrary backends (Atsushi Torikoshi)
- Add session statistics to the `pg_stat_database` system view (Laurenz Albe)
- Add columns to `pg_prepared_statements` to report generic and custom plan counts (Atsushi Torikoshi, Kyotaro Horiguchi)
- Add lock wait start time to `pg_locks` (Atsushi Torikoshi)
- Make the archiver process visible in `pg_stat_activity` (Kyotaro Horiguchi)
- Add wait event `WalReceiverExit` to report WAL receiver exit wait time (Fujii Masao)
- Implement information schema view `routine_column_usage` to track columns referenced by function and procedure default expressions (Peter Eisentraut)

E.40.3.1.8. Authentication

- Allow an SSL certificate's distinguished name (DN) to be matched for client certificate authentication (Andrew Dunstan)

  The new `pg_hba.conf` option `clientname=DN` allows comparison with certificate attributes beyond the `CN` and can be combined with ident maps.

- Allow `pg_hba.conf` and `pg_ident.conf` records to span multiple lines (Fabien Coelho)

  A backslash at the end of a line allows record contents to be continued on the next line.

- Allow the specification of a certificate revocation list (CRL) directory (Kyotaro Horiguchi)

  This is controlled by server parameter ssl_crl_dir and libpq connection option sslcrldir. Previously only single CRL files could be specified.

- Allow passwords of an arbitrary length (Tom Lane, Nathan Bossart)

E.40.3.1.9. Server Configuration

- Add server parameter idle_session_timeout to close idle sessions (Li Japin)

  This is similar to idle_in_transaction_session_timeout.
- Change checkpoint_completion_target default to 0.9 (Stephen Frost)

  The previous default was 0.5.
- Allow `%P` in log_line_prefix to report the parallel group leader's PID for a parallel worker (Justin Pryzby)
- Allow unix_socket_directories to specify paths as individual, comma-separated quoted strings (Ian Lawrence Barwick)

  Previously all the paths had to be in a single quoted string.
- Allow startup allocation of dynamic shared memory (Thomas Munro)

  This is controlled by min_dynamic_shared_memory. This allows more use of huge pages.
- Add server parameter huge_page_size to control the size of huge pages used on Linux (Odin Ugedal)

E.40.3.2. Streaming Replication and Recovery

- Allow standby servers to be rewound via pg_rewind (Heikki Linnakangas)
- Allow the restore_command setting to be changed during a server reload (Sergei Kornilov)

  You can also set `restore_command` to an empty string and reload to force recovery to only read from the `pg_wal` directory.
- Add server parameter log_recovery_conflict_waits to report long recovery conflict wait times (Bertrand Drouvot, Masahiko Sawada)
- Pause recovery on a hot standby server if the primary changes its parameters in a way that prevents replay on the standby (Peter Eisentraut)

  Previously the standby would shut down immediately.
- Add function `pg_get_wal_replay_pause_state()` to report the recovery state (Dilip Kumar)

  It gives more detailed information than `pg_is_wal_replay_paused()`, which still exists.
- Add new read-only server parameter in_hot_standby (Haribabu Kommi, Greg Nancarrow, Tom Lane)

  This allows clients to easily detect whether they are connected to a hot standby server.
- Speed truncation of small tables during recovery on clusters with a large number of shared buffers (Kirk Jamison)
- Allow file system sync at the start of crash recovery on Linux (Thomas Munro)

  By default, PostgreSQL opens and fsyncs each data file in the database cluster at the start of crash recovery. A new setting, recovery_init_sync_method=`syncfs`, instead syncs each filesystem used by the cluster. This allows for faster recovery on systems with many database files.
- Add function `pg_xact_commit_timestamp_origin()` to return the commit timestamp and replication origin of the specified transaction (Movead Li)
- Add the replication origin to the record returned by `pg_last_committed_xact()` (Movead Li)
- Allow replication origin functions to be controlled using standard function permission controls (Martín Marqués)

Previously these functions could only be executed by superusers, and this is still the default.

E.40.3.2.1. Logical Replication

- Allow logical replication to stream long in-progress transactions to subscribers (Dilip Kumar, Amit Kapila, Ajin Cherian, Tomas Vondra, Nikhil Sontakke, Stas Kelvich)

  Previously transactions that exceeded logical_decoding_work_mem were written to disk until the transaction completed.

- Enhance the logical replication API to allow streaming large in-progress transactions (Tomas Vondra, Dilip Kumar, Amit Kapila)

  The output functions begin with `stream`. test_decoding also supports these.

- Allow multiple transactions during table sync in logical replication (Peter Smith, Amit Kapila, Takamichi Osumi)

- Immediately WAL-log subtransaction and top-level `XID` association (Tomas Vondra, Dilip Kumar, Amit Kapila)

  This is useful for logical decoding.

- Enhance logical decoding APIs to handle two-phase commits (Ajin Cherian, Amit Kapila, Nikhil Sontakke, Stas Kelvich)

  This is controlled via `pg_create_logical_replication_slot()`.

- Add cache invalidation messages to the WAL during command completion when using logical replication (Dilip Kumar, Tomas Vondra, Amit Kapila)

  This allows logical streaming of in-progress transactions. When logical replication is disabled, invalidation messages are generated only at transaction completion.

- Allow logical decoding to more efficiently process cache invalidation messages (Dilip Kumar)

  This allows logical decoding to work efficiently in presence of a large amount of DDL.

- Allow control over whether logical decoding messages are sent to the replication stream (David Pirotte, Euler Taveira)

- Allow logical replication subscriptions to use binary transfer mode (Dave Cramer)

  This is faster than text mode, but slightly less robust.

- Allow logical decoding to be filtered by xid (Markus Wanner)

E.40.3.3. `SELECT`, `INSERT`

- Reduce the number of keywords that can't be used as column labels without `AS` (Mark Dilger)

  There are now 90% fewer restricted keywords.

- Allow an alias to be specified for `JOIN`'s `USING` clause (Peter Eisentraut)

  The alias is created by writing `AS` after the `USING` clause. It can be used as a table qualification for the merged `USING` columns.

- Allow `DISTINCT` to be added to `GROUP BY` to remove duplicate `GROUPING SET` combinations (Vik Fearing)

  For example, `GROUP BY CUBE (a,b), CUBE (b,c)` will generate duplicate grouping combinations without `DISTINCT`.

- Properly handle `DEFAULT` entries in multi-row `VALUES` lists in `INSERT` (Dean Rasheed)

Such cases used to throw an error.

- Add SQL-standard `SEARCH` and `CYCLE` clauses for common table expressions (Peter Eisentraut)

  The same results could be accomplished using existing syntax, but much less conveniently.

- Allow column names in the `WHERE` clause of `ON CONFLICT` to be table-qualified (Tom Lane)

  Only the target table can be referenced, however.

E.40.3.4. Utility Commands

- Allow `REFRESH MATERIALIZED VIEW` to use parallelism (Bharath Rupireddy)
- Allow `REINDEX` to change the tablespace of the new index (Alexey Kondratov, Michael Paquier, Justin Pryzby)

  This is done by specifying a `TABLESPACE` clause. A `--tablespace` option was also added to reindexdb to control this.

- Allow `REINDEX` to process all child tables or indexes of a partitioned relation (Justin Pryzby, Michael Paquier)
- Allow index commands using `CONCURRENTLY` to avoid waiting for the completion of other operations using `CONCURRENTLY` (Álvaro Herrera)
- Improve the performance of `COPY FROM` in binary mode (Bharath Rupireddy, Amit Langote)
- Preserve SQL standard syntax for SQL-defined functions in view definitions (Tom Lane)

  Previously, calls to SQL-standard functions such as `EXTRACT()` were shown in plain function-call syntax. The original syntax is now preserved when displaying a view or rule.

- Add the SQL-standard clause `GRANTED BY` to `GRANT` and `REVOKE` (Peter Eisentraut)
- Add `OR REPLACE` option for `CREATE TRIGGER` (Takamichi Osumi)

  This allows pre-existing triggers to be conditionally replaced.

- Allow `TRUNCATE` to operate on foreign tables (Kazutaka Onishi, Kohei KaiGai)

  The postgres_fdw module also now supports this.

- Allow publications to be more easily added to and removed from a subscription (Japin Li)

  The new syntax is `ALTER SUBSCRIPTION ... ADD/DROP PUBLICATION`. This avoids having to specify all publications to add/remove entries.

- Add primary keys, unique constraints, and foreign keys to system catalogs (Peter Eisentraut)

  These changes help GUI tools analyze the system catalogs. The existing unique indexes of catalogs now have associated `UNIQUE` or `PRIMARY KEY` constraints. Foreign key relationships are not actually stored or implemented as constraints, but can be obtained for display from the function pg_get_catalog_foreign_keys().

- Allow `CURRENT_ROLE` every place `CURRENT_USER` is accepted (Peter Eisentraut)

E.40.3.5. Data Types

- Allow extensions and built-in data types to implement subscripting (Dmitry Dolgov)

  Previously subscript handling was hard-coded into the server, so that subscripting could only be applied to array types. This change allows subscript notation to be used to extract or assign portions of a value of any type for which the concept makes sense.

- Allow subscripting of `JSONB` (Dmitry Dolgov)

JSONB subscripting can be used to extract and assign to portions of JSONB documents.

- Add support for multirange data types (Paul Jungwirth, Alexander Korotkov)

  These are like range data types, but they allow the specification of multiple, ordered, non-overlapping ranges. An associated multirange type is automatically created for every range type.

- Add support for the stemming of languages Armenian, Basque, Catalan, Hindi, Serbian, and Yiddish (Peter Eisentraut)

- Allow tsearch data files to have unlimited line lengths (Tom Lane)

  The previous limit was 4K bytes. Also remove function t_readline().

- Add support for Infinity and -Infinity values in the numeric data type (Tom Lane)

  Floating-point data types already supported these.

- Add point operators <<| and |>> representing strictly above/below tests (Emre Hasegeli)

  Previously these were called >^ and <^, but that naming is inconsistent with other geometric data types. The old names remain available, but may someday be removed.

- Add operators to add and subtract LSN and numeric (byte) values (Fujii Masao)

- Allow binary data transfer to be more forgiving of array and record OID mismatches (Tom Lane)

- Create composite array types for system catalogs (Wenjing Zeng)

  User-defined relations have long had composite types associated with them, and also array types over those composite types. System catalogs now do as well. This change also fixes an inconsistency that creating a user-defined table in single-user mode would fail to create a composite array type.

E.40.3.6. Functions

- Allow SQL-language functions and procedures to use SQL-standard function bodies (Peter Eisentraut)

  Previously only string-literal function bodies were supported. When writing a function or procedure in SQL-standard syntax, the body is parsed immediately and stored as a parse tree. This allows better tracking of function dependencies, and can have security benefits.

- Allow procedures to have OUT parameters (Peter Eisentraut)

- Allow some array functions to operate on a mix of compatible data types (Tom Lane)

  The functions array_append(), array_prepend(), array_cat(), array_position(), array_positions(), array_remove(), array_replace(), and width_bucket() now take anycompatiblearray instead of anyarray arguments. This makes them less fussy about exact matches of argument types.

- Add SQL-standard trim_array() function (Vik Fearing)

  This could already be done with array slices, but less easily.

- Add bytea equivalents of ltrim() and rtrim() (Joel Jacobson)

- Support negative indexes in split_part() (Nikhil Benesch)

  Negative values start from the last field and count backward.

- Add string_to_table() function to split a string on delimiters (Pavel Stehule)

  This is similar to the regexp_split_to_table() function.

- Add `unistr()` function to allow Unicode characters to be specified as backslash-hex escapes in strings (Pavel Stehule)

  This is similar to how Unicode can be specified in literal strings.
- Add `bit_xor()` XOR aggregate function (Alexey Bashtanov)
- Add function `bit_count()` to return the number of bits set in a bit or byte string (David Fetter)
- Add `date_bin()` function (John Naylor)

  This function "bins" input timestamps, grouping them into intervals of a uniform length aligned with a specified origin.
- Allow `make_timestamp()`/`make_timestamptz()` to accept negative years (Peter Eisentraut)

  Negative values are interpreted as `BC` years.
- Add newer regular expression `substring()` syntax (Peter Eisentraut)

  The new SQL-standard syntax is `SUBSTRING(text SIMILAR pattern ESCAPE escapechar)`. The previous standard syntax was `SUBSTRING(text FROM pattern FOR escapechar)`, which is still accepted by PostgreSQL.
- Allow complemented character class escapes \D, `\S`, and `\W` within regular expression brackets (Tom Lane)
- Add `[[:word:]]` as a regular expression character class, equivalent to `\w` (Tom Lane)
- Allow more flexible data types for default values of `lead()` and `lag()` window functions (Vik Fearing)
- Make non-zero floating-point values divided by infinity return zero (Kyotaro Horiguchi)

  Previously such operations produced underflow errors.
- Make floating-point division of NaN by zero return NaN (Tom Lane)

  Previously this returned an error.
- Cause `exp()` and `power()` for negative-infinity exponents to return zero (Tom Lane)

  Previously they often returned underflow errors.
- Improve the accuracy of geometric computations involving infinity (Tom Lane)
- Mark built-in type coercion functions as leakproof where possible (Tom Lane)

  This allows more use of functions that require type conversion in security-sensitive situations.
- Change `pg_describe_object()`, `pg_identify_object()`, and `pg_identify_object_as_address()` to always report helpful error messages for non-existent objects (Michael Paquier)

E.40.3.7. PL/pgSQL

- Improve PL/pgSQL's expression and assignment parsing (Tom Lane)

  This change allows assignment to array slices and nested record fields.
- Allow plpgsql's `RETURN QUERY` to execute its query using parallelism (Tom Lane)
- Improve performance of repeated CALLs within plpgsql procedures (Pavel Stehule, Tom Lane)

E.40.3.8. Client Interfaces

- Add pipeline mode to libpq (Craig Ringer, Matthieu Garrigues, Álvaro Herrera)

  This allows multiple queries to be sent, only waiting for completion when a specific synchronization message is sent.

- Enhance libpq's `target_session_attrs` parameter options (Haribabu Kommi, Greg Nancarrow, Vignesh C, Tom Lane)

  The new options are `read-only`, `primary`, `standby`, and `prefer-standby`.
- Improve the output format of libpq's `PQtrace()` (Aya Iwata, Álvaro Herrera)
- Allow an ECPG SQL identifier to be linked to a specific connection (Hayato Kuroda)

  This is done via `DECLARE ... STATEMENT`.

E.40.3.9. Client Applications

- Allow vacuumdb to skip index cleanup and truncation (Nathan Bossart)

  The options are `--no-index-cleanup` and `--no-truncate`.
- Allow pg_dump to dump only certain extensions (Guillaume Lelarge)

  This is controlled by option `--extension`.
- Add pgbench `permute()` function to randomly shuffle values (Fabien Coelho, Hironobu Suzuki, Dean Rasheed)
- Include disconnection times in the reconnection overhead measured by pgbench with `-C` (Yugo Nagata)
- Allow multiple verbose option specifications (`-v`) to increase the logging verbosity (Tom Lane)

  This behavior is supported by pg_dump, pg_dumpall, and pg_restore.
- Allow psql's `\df` and `\do` commands to specify function and operator argument types (Greg Sabino Mullane, Tom Lane)

  This helps reduce the number of matches printed for overloaded names.
- Add an access method column to psql's `\d[i|m|t]+` output (Georgios Kokolatos)
- Allow psql's `\dt` and `\di` to show TOAST tables and their indexes (Justin Pryzby)
- Add psql command `\dX` to list extended statistics objects (Tatsuro Yamada)
- Fix psql's `\dT` to understand array syntax and backend grammar aliases, like `int` for `integer` (Greg Sabino Mullane, Tom Lane)
- When editing the previous query or a file with psql's `\e`, or using `\ef` and `\ev`, ignore the results if the editor exits without saving (Laurenz Albe)

  Previously, such edits would load the previous query into the query buffer, and typically execute it immediately. This was deemed to be probably not what the user wants.
- Improve tab completion (Vignesh C, Michael Paquier, Justin Pryzby, Georgios Kokolatos, Julien Rouhaud)

E.40.3.10. Server Applications

- Add command-line utility pg_amcheck to simplify running `contrib/amcheck` tests on many relations (Mark Dilger)
- Add `--no-instructions` option to initdb (Magnus Hagander)

  This suppresses the server startup instructions that are normally printed.
- Stop pg_upgrade from creating `analyze_new_cluster` script (Magnus Hagander)

  Instead, give comparable vacuumdb instructions.

- Remove support for the postmaster `-o` option (Magnus Hagander)

  This option was unnecessary since all passed options could already be specified directly.

E.40.3.11. Documentation

- Rename "Default Roles" to "Predefined Roles" (Bruce Momjian, Stephen Frost)
- Add documentation for the `factorial()` function (Peter Eisentraut)

  With the removal of the ! operator in this release, `factorial()` is the only built-in way to compute a factorial.

E.40.3.12. Source Code

- Add configure option `--with-ssl={openssl}` to allow future choice of the SSL library to use (Daniel Gustafsson, Michael Paquier)

  The spelling `--with-openssl` is kept for compatibility.
- Add support for abstract Unix-domain sockets (Peter Eisentraut)

  This is currently supported on Linux and Windows.
- Allow Windows to properly handle files larger than four gigabytes (Juan José Santamaría Flecha)

  For example this allows `COPY`, WAL files, and relation segment files to be larger than four gigabytes.
- Add server parameter debug_discard_caches to control cache flushing for test purposes (Craig Ringer)

  Previously this behavior could only be set at compile time. To invoke it during initdb, use the new option `--discard-caches`.
- Various improvements in valgrind error detection ability (Álvaro Herrera, Peter Geoghegan)
- Add a test module for the regular expression package (Tom Lane)
- Add support for LLVM version 12 (Andres Freund)
- Change SHA1, SHA2, and MD5 hash computations to use the OpenSSL EVP API (Michael Paquier)

  This is more modern and supports FIPS mode.
- Remove separate build-time control over the choice of random number generator (Daniel Gustafsson)

  This is now always determined by the choice of SSL library.
- Add direct conversion routines between EUC_TW and Big5 encodings (Heikki Linnakangas)
- Add collation version support for FreeBSD (Thomas Munro)
- Add `amadjustmembers` to the index access method API (Tom Lane)

  This allows an index access method to provide validity checking during creation of a new operator class or family.
- Provide feature-test macros in `libpq-fe.h` for recently-added libpq features (Tom Lane, Álvaro Herrera)

  Historically, applications have usually used compile-time checks of `PG_VERSION_NUM` to test whether a feature is available. But that's normally the server version, which might not be a good guide to libpq's version. `libpq-fe.h` now offers `#define` symbols denoting application-visible features added in v14; the intent is to keep adding symbols for such features in future versions.

E.40.3.13. Additional Modules

- Allow subscripting of hstore values (Tom Lane, Dmitry Dolgov)
- Allow GiST/GIN pg_trgm indexes to do equality lookups (Julien Rouhaud)

  This is similar to `LIKE` except no wildcards are honored.
- Allow the cube data type to be transferred in binary mode (KaiGai Kohei)
- Allow `pgstattuple_approx()` to report on TOAST tables (Peter Eisentraut)
- Add contrib module pg_surgery which allows changes to row visibility (Ashutosh Sharma)

  This is useful for correcting database corruption.
- Add contrib module old_snapshot to report the `XID`/time mapping used by an active old_snapshot_threshold (Robert Haas)
- Allow amcheck to also check heap pages (Mark Dilger)

  Previously it only checked B-Tree index pages.
- Allow pageinspect to inspect GiST indexes (Andrey Borodin, Heikki Linnakangas)
- Change pageinspect block numbers to be `bigints` (Peter Eisentraut)
- Mark btree_gist functions as parallel safe (Steven Winfield)

E.40.3.13.1. pg_stat_statements

- Move query hash computation from pg_stat_statements to the core server (Julien Rouhaud)

  The new server parameter compute_query_id's default of `auto` will automatically enable query id computation when this extension is loaded.
- Cause pg_stat_statements to track top and nested statements separately (Julien Rohaud)

  Previously, when tracking all statements, identical top and nested statements were tracked as a single entry; but it seems more useful to separate such usages.
- Add row counts for utility commands to pg_stat_statements (Fujii Masao, Katsuragi Yuta, Seino Yuki)
- Add `pg_stat_statements_info` system view to show pg_stat_statements activity (Katsuragi Yuta, Yuki Seino, Naoki Nakamichi)

E.40.3.13.2. postgres_fdw

- Allow postgres_fdw to `INSERT` rows in bulk (Takayuki Tsunakawa, Tomas Vondra, Amit Langote)
- Allow postgres_fdw to import table partitions if specified by `IMPORT FOREIGN SCHEMA ... LIMIT TO` (Matthias van de Meent)

  By default, only the root of a partitioned table is imported.
- Add postgres_fdw function `postgres_fdw_get_connections()` to report open foreign server connections (Bharath Rupireddy)
- Allow control over whether foreign servers keep connections open after transaction completion (Bharath Rupireddy)

  This is controlled by `keep_connections` and defaults to on.
- Allow postgres_fdw to reestablish foreign server connections if necessary (Bharath Rupireddy)

  Previously foreign server restarts could cause foreign table access errors.
- Add postgres_fdw functions to discard cached connections (Bharath Rupireddy)

E.40.4. Acknowledgments

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Andres Freund
Andrew Bille
Andrew Dunstan
Andrew Gierth
Andrey Borodin
Andrey Lepikhov
Andy Fan
Anton Voloshin
Antonin Houska
Arne Roland
Arseny Sher
Arthur Nascimento
Arthur Zakirov
Ashutosh Bapat
Ashutosh Sharma
Ashwin Agrawal
Asif Rehman
Asim Praveen
Atsushi Torikoshi
Aya Iwata
Barry Pederson
Bas Poot
Bauyrzhan Sakhariyev
Beena Emerson
Benoît Lobréau
Bernd Helmle
Bernhard M. Wiedemann

Bertrand Drouvot
Bharath Rupireddy
Boris Kolpackov
Brar Piening
Brian Ye
Bruce Momjian
Bryn Llewellyn
Cameron Daniel
Chapman Flack
Charles Samborski
Charlie Hornsby
Chen Jiaoqian
Chris Wilson
Christian Quest
Christoph Berg
Christophe Courtois
Corey Huinker
Craig Ringer
Dagfinn Ilmari Mannsåker
Dana Burd
Daniel Cherniy
Daniel Gustafsson
Daniel Vérité
Daniel Westermann
Daniele Varrazzo
Dar Alathar-Yemen
Darafei Praliaskouski
Dave Cramer
David Christensen
David Fetter
David G. Johnston
David Geier
David Gilman
David Pirotte
David Rowley
David Steele
David Turon
David Zhang
Dean Rasheed
Denis Patron
Dian Fay
Dilip Kumar
Dimitri Nüscheler
Dmitriy Kuzmin
Dmitry Dolgov
Dmitry Marakasov
Domagoj Smoljanovic
Dong Wook
Douglas Doole
Duncan Sands
Edmund Horner
Edson Richter
Egor Rogov
Ekaterina Kiryanova
Elena Indrupskaya
Emil Iggland
Emre Hasegeli
Eric Thinnes

Erik Rijkers
Erwin Brandstetter
Etienne Stalmans
Etsuro Fujita
Eugen Konkov
Euler Taveira
Fabien Coelho
Fabrízio de Royes Mello
Federico Caselli
Felix Lechner
Filip Gospodinov
Floris Van Nee
Frank Gagnepain
Frits Jalvingh
Georgios Kokolatos
Greg Nancarrow
Greg Rychlewski
Greg Sabino Mullane
Gregory Smith
Grigory Smolkin
Guillaume Lelarge
Guy Burgess
Guyren Howe
Haiying Tang
Hamid Akhtar
Hans Buschmann
Hao Wu
Haribabu Kommi
Harisai Hari
Hayato Kuroda
Heath Lord
Heikki Linnakangas
Henry Hinze
Herwig Goemans
Himanshu Upadhyaya
Hironobu Suzuki
Hiroshi Inoue
Hisanori Kobayashi
Honza Horak
Hou Zhijie
Hubert Lubaczewski
Hubert Zhang
Ian Barwick
Ibrar Ahmed
Ildus Kurbangaliev
Isaac Morland
Israel Barth
Itamar Gafni
Jacob Champion
Jaime Casanova
Jaime Soler
Jakub Wartak
James Coleman
James Hilliard
James Hunter
James Inform
Jan Mussler
Japin Li

Jasen Betts
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Jeff Janes
Jelte Fennema
Jeremy Evans
Jeremy Finzel
Jeremy Smith
Jesse Kinkead
Jesse Zhang
Jie Zhang
Jim Doty
Jim Nasby
Jimmy Angelakos
Jimmy Yih
Jiri Fejfar
Joe Conway
Joel Jacobson
John Naylor
John Thompson
Jonathan Katz
Josef Šimánek
Joseph Nahmias
Josh Berkus
Juan José Santamaría Flecha
Julien Rouhaud
Junfeng Yang
Jürgen Purtz
Justin Pryzby
Kazutaka Onishi
Keisuke Kuroda
Kelly Min
Kensuke Okamura
Kevin Sweet
Kevin Yeap
Kirk Jamison
Kohei KaiGai
Konstantin Knizhnik
Kota Miyake
Krzysztof Gradek
Kuntal Ghosh
Kyle Kingsbury
Kyotaro Horiguchi
Laurent Hasson
Laurenz Albe
Lee Dong Wook
Li Japin
Liu Huailing
Luc Vlaming
Ludovic Kuty
Luis Roberto
Lukas Eder
Ma Liangzhu
Maciek Sakrejda
Madan Kumar
Magnus Hagander

Mahendra Singh Thalor
Maksim Milyutin
Marc Boeren
Marcin Krupowicz
Marco Atzeri
Marek Szuba
Marina Polyakova
Mario Emmenlauer
Mark Dilger
Mark Wong
Mark Zhao
Markus Wanner
Martín Marqués
Martin Visser
Masahiko Sawada
Masahiro Ikeda
Masao Fujii
Mathis Rudolf
Matthias van de Meent
Matthieu Garrigues
Matthijs van der Vleuten
Maxim Orlov
Melanie Plageman
Merlin Moncure
Michael Banck
Michael Brown
Michael Meskes
Michael Paquier
Michael Paul Killian
Michael Powers
Michael Vastola
Michail Nikolaev
Michal Albrycht
Mikael Gustavsson
Movead Li
Muhammad Usama
Nagaraj Raj
Naoki Nakamichi
Nathan Bossart
Nathan Long
Nazli Ugur Koyluoglu
Neha Sharma
Neil Chen
Nick Cleaton
Nico Williams
Nikhil Benesch
Nikhil Sontakke
Nikita Glukhov
Nikita Konev
Nikolai Berkoff
Nikolay Samokhvalov
Nikolay Shaplov
Nitin Jadhav
Noah Misch
Noriyoshi Shinoda
Odin Ugedal
Oleg Bartunov
Oleg Samoilov

Önder Kalaci
Pascal Legrand
Paul Förster
Paul Guo
Paul Jungwirth
Paul Martinez
Paul Sivash
Pavan Deolasee
Pavel Boev
Pavel Borisov
Pavel Luzanov
Pavel Stehule
Pengcheng Liu
Peter Eisentraut
Peter Geoghegan
Peter Smith
Peter Vandivier
Petr Fedorov
Petr Jelínek
Phil Krylov
Philipp Gramzow
Philippe Beaudoin
Phillip Menke
Pierre Giraud
Prabhat Sahu
Quan Zongliang
Rafi Shamim
Rahila Syed
Rajkumar Raghuwanshi
Ranier Vilela
Regina Obe
Rémi Lapeyre
Robert Foggia
Robert Grange
Robert Haas
Robert Kahlert
Robert Sosinski
Robert Treat
Robin Abbi
Robins Tharakan
Roger Mason
Rohit Bhogate
Roman Zharkov
Ron L. Johnson
Ronan Dunklau
Ryan Lambert
Ryo Matsumura
Saeed Hubaishan
Sait Talha Nisanci
Sandro Mani
Santosh Udupi
Scott Ribe
Sehrope Sarkuni
Sergei Kornilov
Sergey Bernikov
Sergey Cherkashin
Sergey Koposov
Sergey Shinderuk

Sergey Zubkovsky
Shawn Wang
Shay Rojansky
Shi Yu
Shinya Kato
Shinya Okano
Sigrid Ehrenreich
Simon Norris
Simon Riggs
Sofoklis Papasofokli
Soumyadeep Chakraborty
Stas Kelvich
Stephan Springl
Stéphane Lorek
Stephen Frost
Steven Winfield
Surafel Temesgen
Suraj Kharage
Sven Klemm
Takamichi Osumi
Takashi Menjo
Takayuki Tsunakawa
Tang Haiying
Tatsuhito Kasahara
Tatsuo Ishii
Tatsuro Yamada
Theodor Arsenij Larionov-Trichkin
Thomas Kellerer
Thomas Munro
Thomas Trenz
Tijs van Dam
Tom Ellis
Tom Gottfried
Tom Lane
Tom Vijlbrief
Tomas Barton
Tomas Vondra
Tomohiro Hiramitsu
Tony Reix
Vaishnavi Prabakaran
Valentin Gatien-Baron
Victor Wagner
Victor Yegorov
Vignesh C
Vik Fearing
Vitaly Ustinov
Vladimir Sitnikov
Vyacheslav Shablistyy
Wang Shenhao
Wei Wang
Wells Oliver
Wenjing Zeng
Wolfgang Walther
Yang Lin
Yanliang Lei
Yaoguang Chen
Yaroslav Pashinsky
Yaroslav Schekin

Yasushi Yamashita
Yoran Heling
YoungHwan Joo
Yugo Nagata
Yuki Seino
Yukun Wang
Yulin Pei
Yura Sokolov
Yuta Katsuragi
Yuta Kondo
Yuzuko Hosoya
Zhihong Yu
Zhiyong Wu
Zsolt Ero

E.41. Prior Releases

Release notes for prior versions can be found online. At the time of Postgres Pro Enterprise 14 release, these prior versions were supported:

- Postgres Pro Enterprise 13: *https://postgrespro.com/docs/enterprise/13/release.html*
- Postgres Pro Enterprise 12: *https://postgrespro.com/docs/enterprise/12/release.html*
- Postgres Pro Enterprise 11: *https://postgrespro.com/docs/enterprise/11/release.html*
- Postgres Pro Enterprise 10: *https://postgrespro.com/docs/enterprise/10/release.html*

Appendix F. Additional Supplied Modules and Extensions Shipped in postgrespro-ent-14-contrib

This appendix, Appendix G, and Appendix I contain information on the optional components available in the Postgres Pro Enterprise distribution. These include porting tools, analysis utilities, and plug-in features that are not part of the core Postgres Pro system. They are separate mainly because they address a limited audience or are too experimental to be part of the main source tree. This does not preclude their usefulness.

This appendix and Appendix G cover the extensions and other server plug-in modules. Appendix I covers the utility programs.

Many modules supply new user-defined functions, operators, or types. To make use of one of these modules, after you have installed the code you need to register the new SQL objects in the database system. This is done by executing a CREATE EXTENSION command. In a fresh database, you can simply do

```
CREATE EXTENSION module_name;
```

This command registers the new SQL objects in the current database only, so you need to run it in each database that you want the module's facilities to be available in. Alternatively, run it in database `template1` so that the extension will be copied into subsequently-created databases by default.

For all these modules, `CREATE EXTENSION` must be run by a database superuser, unless the module is considered "trusted", in which case it can be run by any user who has `CREATE` privilege on the current database. Modules that are trusted are identified as such in the sections that follow. Generally, trusted modules are ones that cannot provide access to outside-the-database functionality.

Many modules allow you to install their objects in a schema of your choice. To do that, add `SCHEMA` *schema_name* to the `CREATE EXTENSION` command. By default, the objects will be placed in your current creation target schema, which in turn defaults to `public`.

Note, however, that some of these modules are not "extensions" in this sense, but are loaded into the server in some other way, for instance by way of shared_preload_libraries. See the documentation of each module for details.

This appendix contains modules and extensions that are made available in Postgres Pro Enterprise as a separate subpackage `postgrespro-ent-14-contrib`.

F.1. adminpack

`adminpack` provides a number of support functions which pgAdmin and other administration and management tools can use to provide additional functionality, such as remote management of server log files. Use of all these functions is only allowed to the superuser by default but may be allowed to other users by using the `GRANT` command.

The functions shown in Table F.1 provide write access to files on the machine hosting the server. (See also the functions in Table 9.97, which provide read-only access.) Only files within the database cluster directory can be accessed, unless the user is a superuser or given one of the pg_read_server_files, or pg_write_server_files roles, as appropriate for the function, but either a relative or absolute path is allowable.

Table F.1. `adminpack` Functions

Function Description	
`pg_catalog.pg_file_write`	(*filename* `text`, *data* `text`, *append* `boolean`) → `bigint`

Function Description
Writes, or appends to, a text file.
pg_catalog.pg_file_sync (*filename* text) → void Flushes a file or directory to disk.
pg_catalog.pg_file_rename (*oldname* text, *newname* text [, *archivename* text]) → boolean Renames a file.
pg_catalog.pg_file_unlink (*filename* text) → boolean Removes a file.
pg_catalog.pg_logdir_ls () → setof record Lists the log files in the log_directory directory.

pg_file_write writes the specified *data* into the file named by *filename*. If *append* is false, the file must not already exist. If *append* is true, the file can already exist, and will be appended to if so. Returns the number of bytes written.

pg_file_sync fsyncs the specified file or directory named by *filename*. An error is thrown on failure (e.g., the specified file is not present). Note that data_sync_retry has no effect on this function, and therefore a PANIC-level error will not be raised even on failure to flush database files.

pg_file_rename renames a file. If *archivename* is omitted or NULL, it simply renames *oldname* to *newname* (which must not already exist). If *archivename* is provided, it first renames *newname* to *archivename* (which must not already exist), and then renames *oldname* to *newname*. In event of failure of the second rename step, it will try to rename *archivename* back to *newname* before reporting the error. Returns true on success, false if the source file(s) are not present or not writable; other cases throw errors.

pg_file_unlink removes the specified file. Returns true on success, false if the specified file is not present or the unlink() call fails; other cases throw errors.

pg_logdir_ls returns the start timestamps and path names of all the log files in the log_directory directory. The log_filename parameter must have its default setting (postgresql-%Y-%m-%d_%H%M%S.log) to use this function.

F.2. amcheck

The amcheck module provides functions that allow you to verify the logical consistency of the structure of relations.

The B-Tree checking functions verify various *invariants* in the structure of the representation of particular relations. The correctness of the access method functions behind index scans and other important operations relies on these invariants always holding. For example, certain functions verify, among other things, that all B-Tree pages have items in "logical" order (e.g., for B-Tree indexes on text, index tuples should be in collated lexical order). If that particular invariant somehow fails to hold, we can expect binary searches on the affected page to incorrectly guide index scans, resulting in wrong answers to SQL queries. If the structure appears to be valid, no error is raised.

Verification is performed using the same procedures as those used by index scans themselves, which may be user-defined operator class code. For example, B-Tree index verification relies on comparisons made with one or more B-Tree support function 1 routines. See Section 40.16.3 for details of operator class support functions.

Unlike the B-Tree checking functions which report corruption by raising errors, the heap checking function verify_heapam checks a table and attempts to return a set of rows, one row per corruption detected.

Despite this, if facilities that `verify_heapam` relies upon are themselves corrupted, the function may be unable to continue and may instead raise an error.

Permission to execute `amcheck` functions may be granted to non-superusers, but before granting such permissions careful consideration should be given to data security and privacy concerns. Although the corruption reports generated by these functions do not focus on the contents of the corrupted data so much as on the structure of that data and the nature of the corruptions found, an attacker who gains permission to execute these functions, particularly if the attacker can also induce corruption, might be able to infer something of the data itself from such messages.

> **Note**
>
> Using `amcheck` 1.1.1 is not recommended as the `bt_index_parent_check` function works incorrectly in that version.

F.2.1. Functions

```
bt_index_check(index regclass, heapallindexed boolean) returns void
bt_index_check(index regclass, heapallindexed boolean, checkunique boolean) returns void
```

`bt_index_check` tests that its target, a B-Tree index, respects a variety of invariants. Example usage:

```
test=# SELECT bt_index_check(index => c.oid, heapallindexed => i.indisunique),
               c.relname,
               c.relpages
FROM pg_index i
JOIN pg_opclass op ON i.indclass[0] = op.oid
JOIN pg_am am ON op.opcmethod = am.oid
JOIN pg_class c ON i.indexrelid = c.oid
JOIN pg_namespace n ON c.relnamespace = n.oid
WHERE am.amname = 'btree' AND n.nspname = 'pg_catalog'
-- Don't check temp tables, which may be from another session:
AND c.relpersistence != 't'
-- Function may throw an error when this is omitted:
AND c.relkind = 'i' AND i.indisready AND i.indisvalid
ORDER BY c.relpages DESC LIMIT 10;
 bt_index_check |             relname             | relpages
----------------+---------------------------------+----------
                | pg_depend_reference_index       |       43
                | pg_depend_depender_index        |       40
                | pg_proc_proname_args_nsp_index  |       31
                | pg_description_o_c_o_index      |       21
                | pg_attribute_relid_attnam_index |       14
                | pg_proc_oid_index               |       10
                | pg_attribute_relid_attnum_index |        9
                | pg_amproc_fam_proc_index        |        5
                | pg_amop_opr_fam_index           |        5
                | pg_amop_fam_strat_index         |        5
(10 rows)
```

This example shows a session that performs verification of the 10 largest catalog indexes in the database “test”. Verification of the presence of heap tuples as index tuples is requested for the subset that are unique indexes. Since no error is raised, all indexes tested appear to be logically consistent. Naturally, this query could easily be changed to call `bt_index_check` for every index in the database where verification is supported.

`bt_index_check` acquires an `AccessShareLock` on the target index and the heap relation it belongs to. This lock mode is the same lock mode acquired on relations by simple `SELECT` statements. `bt_in-`

dex_check does not verify invariants that span child/parent relationships, but will verify the presence of all heap tuples as index tuples within the index when *heapallindexed* is true. bt_index_check with three arguments verifies unique constraints when *checkunique* is true. When a routine, lightweight test for corruption is required in a live production environment, using bt_index_check often provides the best trade-off between thoroughness of verification and limiting the impact on application performance and availability.

bt_index_parent_check(index regclass, heapallindexed boolean, rootdescend boolean) returns void
bt_index_parent_check(index regclass, heapallindexed boolean, rootdescend boolean, checkunique boolean) returns void

bt_index_parent_check tests that its target, a B-Tree index, respects a variety of invariants. Optionally, when the *heapallindexed* argument is true, the function verifies the presence of all heap tuples that should be found within the index. bt_index_parent_check with four arguments verifies unique constraints when *checkunique* is true. When the optional *rootdescend* argument is true, verification re-finds tuples on the leaf level by performing a new search from the root page for each tuple. The checks that can be performed by bt_index_parent_check are a superset of the checks that can be performed by bt_index_check. bt_index_parent_check can be thought of as a more thorough variant of bt_index_check: unlike bt_index_check, bt_index_parent_check also checks invariants that span parent/child relationships, including checking that there are no missing downlinks in the index structure. bt_index_parent_check follows the general convention of raising an error if it finds a logical inconsistency or other problem.

A ShareLock is required on the target index by bt_index_parent_check (a ShareLock is also acquired on the heap relation). These locks prevent concurrent data modification from INSERT, UPDATE, and DELETE commands. The locks also prevent the underlying relation from being concurrently processed by VACUUM, as well as all other utility commands. Note that the function holds locks only while running, not for the entire transaction.

bt_index_parent_check's additional verification is more likely to detect various pathological cases. These cases may involve an incorrectly implemented B-Tree operator class used by the index that is checked, or, hypothetically, undiscovered bugs in the underlying B-Tree index access method code. Note that bt_index_parent_check cannot be used when Hot Standby mode is enabled (i.e., on read-only physical replicas), unlike bt_index_check.

Tip

bt_index_check and bt_index_parent_check both output log messages about the verification process at DEBUG1 and DEBUG2 severity levels. These messages provide detailed information about the verification process that may be of interest to PostgreSQL developers. Advanced users may also find this information helpful, since it provides additional context should verification actually detect an inconsistency. Running:

```
SET client_min_messages = DEBUG1;
```

in an interactive psql session before running a verification query will display messages about the progress of verification with a manageable level of detail.

verify_heapam(relation regclass, on_error_stop boolean, check_toast boolean, skip text, startblock bigint, endblock bigint, blkno OUT bigint, offnum OUT integer, attnum OUT integer, msg OUT text) returns setof record

Checks a table for structural corruption, where pages in the relation contain data that is invalidly formatted, and for logical corruption, where pages are structurally valid but inconsistent with the rest of the database cluster.

The following optional arguments are recognized:

`on_error_stop`

If true, corruption checking stops at the end of the first block in which any corruptions are found.

Defaults to false.

`check_toast`

If true, toasted values are checked against the target relation's TOAST table.

This option is known to be slow. Also, if the toast table or its index is corrupt, checking it against toast values could conceivably crash the server, although in many cases this would just produce an error.

Defaults to false.

`skip`

If not `none`, corruption checking skips blocks that are marked as all-visible or all-frozen, as specified. Valid options are `all-visible`, `all-frozen` and `none`.

Defaults to `none`.

`startblock`

If specified, corruption checking begins at the specified block, skipping all previous blocks. It is an error to specify a *`startblock`* outside the range of blocks in the target table.

By default, checking begins at the first block.

`endblock`

If specified, corruption checking ends at the specified block, skipping all remaining blocks. It is an error to specify an *`endblock`* outside the range of blocks in the target table.

By default, all blocks are checked.

For each corruption detected, `verify_heapam` returns a row with the following columns:

`blkno`

The number of the block containing the corrupt page.

`offnum`

The OffsetNumber of the corrupt tuple.

`attnum`

The attribute number of the corrupt column in the tuple, if the corruption is specific to a column and not the tuple as a whole.

`msg`

A message describing the problem detected.

F.2.2. Optional *`heapallindexed`* Verification

When the *`heapallindexed`* argument to B-Tree verification functions is `true`, an additional phase of verification is performed against the table associated with the target index relation. This consists of a "dummy" `CREATE INDEX` operation, which checks for the presence of all hypothetical new index tuples against a temporary, in-memory summarizing structure (this is built when needed during the basic first phase of verification). The summarizing structure "fingerprints" every tuple found within the target index. The high level principle behind *`heapallindexed`* verification is that a new index that is equivalent to the existing, target index must only have entries that can be found in the existing structure.

The additional *heapallindexed* phase adds significant overhead: verification will typically take several times longer. However, there is no change to the relation-level locks acquired when *heapallindexed* verification is performed.

The summarizing structure is bound in size by `maintenance_work_mem`. In order to ensure that there is no more than a 2% probability of failure to detect an inconsistency for each heap tuple that should be represented in the index, approximately 2 bytes of memory are needed per tuple. As less memory is made available per tuple, the probability of missing an inconsistency slowly increases. This approach limits the overhead of verification significantly, while only slightly reducing the probability of detecting a problem, especially for installations where verification is treated as a routine maintenance task. Any single absent or malformed tuple has a new opportunity to be detected with each new verification attempt.

F.2.3. Using `amcheck` Effectively

`amcheck` can be effective at detecting various types of failure modes that data checksums will fail to catch. These include:

- Structural inconsistencies caused by incorrect operator class implementations.

  This includes issues caused by the comparison rules of operating system collations changing. Comparisons of datums of a collatable type like `text` must be immutable (just as all comparisons used for B-Tree index scans must be immutable), which implies that operating system collation rules must never change. Though rare, updates to operating system collation rules can cause these issues. More commonly, an inconsistency in the collation order between a primary server and a standby server is implicated, possibly because the *major* operating system version in use is inconsistent. Such inconsistencies will generally only arise on standby servers, and so can generally only be detected on standby servers.

  If a problem like this arises, it may not affect each individual index that is ordered using an affected collation, simply because *indexed* values might happen to have the same absolute ordering regardless of the behavioral inconsistency. See Section 23.1 and Section 23.2 for further details about how Postgres Pro uses operating system locales and collations.

- Structural inconsistencies between indexes and the heap relations that are indexed (when *heapallindexed* verification is performed).

  There is no cross-checking of indexes against their heap relation during normal operation. Symptoms of heap corruption can be subtle.

- Corruption caused by hypothetical undiscovered bugs in the underlying Postgres Pro access method code, sort code, or transaction management code.

  Automatic verification of the structural integrity of indexes plays a role in the general testing of new or proposed Postgres Pro features that could plausibly allow a logical inconsistency to be introduced. Verification of table structure and associated visibility and transaction status information plays a similar role. One obvious testing strategy is to call `amcheck` functions continuously when running the standard regression tests.

- File system or storage subsystem faults where checksums happen to simply not be enabled.

  Note that `amcheck` examines a page as represented in some shared memory buffer at the time of verification if there is only a shared buffer hit when accessing the block. Consequently, `amcheck` does not necessarily examine data read from the file system at the time of verification. Note that when checksums are enabled, `amcheck` may raise an error due to a checksum failure when a corrupt block is read into a buffer.

- Corruption caused by faulty RAM, or the broader memory subsystem.

  Postgres Pro does not protect against correctable memory errors and it is assumed you will operate using RAM that uses industry standard Error Correcting Codes (ECC) or better protection. However, ECC memory is typically only immune to single-bit errors, and should not be assumed to provide *absolute* protection against failures that result in memory corruption.

When *heapallindexed* verification is performed, there is generally a greatly increased chance of detecting single-bit errors, since strict binary equality is tested, and the indexed attributes within the heap are tested.

Structural corruption can happen due to faulty storage hardware, or relation files being overwritten or modified by unrelated software. This kind of corruption can also be detected with data page checksums.

Relation pages which are correctly formatted, internally consistent, and correct relative to their own internal checksums may still contain logical corruption. As such, this kind of corruption cannot be detected with checksums. Examples include toasted values in the main table which lack a corresponding entry in the toast table, and tuples in the main table with a Transaction ID that is older than the oldest valid Transaction ID in the database or cluster.

Multiple causes of logical corruption have been observed in production systems, including bugs in the PostgreSQL server software, faulty and ill-conceived backup and restore tools, and user error.

Corrupt relations are most concerning in live production environments, precisely the same environments where high risk activities are least welcome. For this reason, `verify_heapam` has been designed to diagnose corruption without undue risk. It cannot guard against all causes of backend crashes, as even executing the calling query could be unsafe on a badly corrupted system. Access to catalog tables is performed and could be problematic if the catalogs themselves are corrupted.

In general, `amcheck` can only prove the presence of corruption; it cannot prove its absence.

F.2.4. Repairing Corruption

No error concerning corruption raised by `amcheck` should ever be a false positive. `amcheck` raises errors in the event of conditions that, by definition, should never happen, and so careful analysis of `amcheck` errors is often required.

There is no general method of repairing problems that `amcheck` detects. An explanation for the root cause of an invariant violation should be sought. pageinspect may play a useful role in diagnosing corruption that `amcheck` detects. A `REINDEX` may not be effective in repairing corruption.

F.3. apache_age

apache_age is a Postgres Pro extension that provides graph database functionality. AGE is an acronym for A Graph Extension. The goal of the project is to create single storage that can handle both relational and graph model data so that users can use standard ANSI SQL along with openCypher, the graph query language.

> **Important**
>
> User tables in apache_age databases contain columns using `reg*` OID-referencing system data types, therefore upgrading to a major version with pg_upgrade is not supported.

F.3.1. Installation and Setup

The `apache_age` extension is included into Postgres Pro Enterprise. Once you have Postgres Pro Enterprise installed, create the `apache_age` extension:

```
CREATE EXTENSION age;
```

For every connection of apache_age you start, load the apache_age library.

```
LOAD 'age';
```

Non-superusers must specify the full path to load the apache_age library.

```
LOAD '$libdir/plugins/age.so';
```

Add `ag_catalog` to the `search_path` to simplify queries:

```
SET search_path = ag_catalog, '$user', public;
```

In order to use apache_age, non-superusers need `USAGE` privileges on the `ag_catalog` schema (example for user `db_user`):

```
GRANT USAGE ON SCHEMA ag_catalog TO db_user;
GRANT ALL PRIVILEGES ON ALL TABLES IN SCHEMA ag_catalog TO db_user;
```

F.3.2. Graphs

A graph consists of a set of vertices and edges, where each individual node and edge possesses a map of properties. A vertex is the basic object of a graph, that can exist independently of everything else in the graph. An edge creates a directed connection between two vertices.

F.3.2.1. Create a Graph

To create a graph, use the `create_graph` function, located in the `ag_catalog` namespace.

`create_graph(`*`graph_name`* `text) returns void`

This function will not return any results. The graph is created if there is no error message. Tables needed to set up the graph are created automatically.

```
SELECT * FROM ag_catalog.create_graph('graph_name');
```

F.3.2.2. Grant Privileges

As a superuser, you can grant privilege on a specific existing graph to a non-superuser (example for graph `graph1` and user `db_user`):

```
GRANT USAGE ON SCHEMA graph1 TO db_user;
GRANT ALL PRIVILEGES ON SCHEMA graph1 TO db_user;
GRANT ALL PRIVILEGES ON ALL TABLES IN SCHEMA graph1 TO db_user;
GRANT ALL PRIVILEGES ON TABLE graph1._ag_label_vertex TO db_user;
```

F.3.2.3. Delete a Graph

To delete a graph, use the `drop_graph` function, located in the `ag_catalog` namespace.

`drop_graph(`*`graph_name`* `text,` *`cascade`* `boolean) returns void`

This function will not return any results. If there is no error message the graph has been deleted. It is recommended to set the *`cascade`* option to true, otherwise everything in the graph must be manually dropped with SQL DDL commands.

```
SELECT * FROM ag_catalog.drop_graph('graph_name', true);
```

F.3.2.4. How Graphs Are Stored In Postgres Pro

When creating graphs with apache_age, a Postgres Pro namespace will be generated for every individual graph. The name and namespace of the created graphs can be seen within the `ag_graph` table from the `ag_catalog` namespace:

```
SELECT create_graph('new_graph');

NOTICE:  graph 'new_graph' has been created
 create_graph
--------------
```

```
(1 row)

SELECT * FROM ag_catalog.ag_graph;

   name    | namespace
-----------+-----------
 new_graph | new_graph
(1 row)
```

After creating the graph, two tables are going to be created under the graph namespace to store vertices and edges: `_ag_label_vertex` and `_ag_label_edge`. These will be the parent tables of any new vertex or edge label. The query below shows how to retrieve the edge and vertex labels for all the graphs in the database.

```
-- Before creating a new vertex label.
SELECT * FROM ag_catalog.ag_label;

       name       | graph | id | kind |          relation          |        seq_name
------------------+-------+----+------+----------------------------
+-------------------------
 _ag_label_vertex | 68484 |  1 | v    | new_graph._ag_label_vertex |
 _ag_label_vertex_id_seq
 _ag_label_edge   | 68484 |  2 | e    | new_graph._ag_label_edge   |
 _ag_label_edge_id_seq
(2 rows)

-- Creating a new vertex label.
SELECT create_vlabel('new_graph', 'Person');
NOTICE:  VLabel 'Person' has been created
 create_vlabel
---------------

(1 row)

-- After creating a new vertex label.
SELECT * FROM ag_catalog.ag_label;
       name       | graph | id | kind |          relation          |        seq_name
------------------+-------+----+------+----------------------------
+-------------------------
 _ag_label_vertex | 68484 |  1 | v    | new_graph._ag_label_vertex |
 _ag_label_vertex_id_seq
 _ag_label_edge   | 68484 |  2 | e    | new_graph._ag_label_edge   |
 _ag_label_edge_id_seq
 Person           | 68484 |  3 | v    | new_graph.'Person'         | Person_id_seq
(3 rows)
```

Whenever a vertex label is created with the `create_vlabel()` function, a new table is generated within the `new_graph` namespace: `new_graph.'label'`. The same works for the `create_elabel()` function for the creation of edge labels. Creating vertices and edges with Cypher will automatically make these tables.

```
-- Creating two vertices and one edge.
SELECT * FROM cypher('new_graph', $$
CREATE (:Person {name: 'Daedalus'})-[:FATHER_OF]->(:Person {name: 'Icarus'})
$$) AS (a agtype);
 a
---
(0 rows)
```

```
-- Showing the newly created tables.
SELECT * FROM ag_catalog.ag_label;
       name       | graph | id | kind |          relation          |        seq_name
------------------+-------+----+------+----------------------------
+-------------------------
 _ag_label_vertex | 68484 |  1 | v    | new_graph._ag_label_vertex |
 _ag_label_vertex_id_seq
 _ag_label_edge   | 68484 |  2 | e    | new_graph._ag_label_edge   |
 _ag_label_edge_id_seq
 Person           | 68484 |  3 | v    | new_graph.'Person'         | Person_id_seq
 FATHER_OF        | 68484 |  4 | e    | new_graph.'FATHER_OF'      | FATHER_OF_id_seq
(4 rows)
```

> **Note**
>
> It is recommended that no DML or DDL commands are executed in the namespace that is reserved for the graph.

F.3.3. The apache_age Cypher Query Format

Cypher queries are constructed using a function called `cypher` in `ag_catalog`, which returns a Postgres Pro SETOF records.

`cypher(`*`graph_name`* `name, `*`query_string`* `cstring, `*`parameters`* `agtype) returns setof record`

Executes the Cypher query passed as an argument. If the Cypher query does not return results, a record definition still needs to be defined. The parameter map specified as *`parameters`* can only be used with prepared statements. An error will be thrown otherwise.

```
SELECT * FROM cypher('graph_name', $$
/* Cypher Query Here */
$$) AS (result1 agtype, result2 agtype);
```

F.3.3.1. Cypher in an Expression

Cypher may not be used as part of an expression, use a subquery instead. See Advanced Cypher Queries for information about how to use Cypher queries with expressions.

F.3.3.2. SELECT Clause

Calling Cypher in the `SELECT` clause as an independent column is not allowed. However, Cypher may be used when it belongs as a conditional.

```
SELECT
    cypher('graph_name', $$
         MATCH (v:Person)
         RETURN v.name
     $$);

ERROR:  cypher(...) in expressions is not supported
LINE 3:     cypher('graph_name', $$
            ^
HINT:  Use subquery instead if possible.
```

F.3.4. Data Types — Introduction to `agtype`

apache_age uses a custom data type called `agtype`, which is the only data type returned by apache_age. `agtype` is a superset of `json` and a custom implementation of `jsonb`.

F.3.4.1. Simple Data Types

F.3.4.1.1. Null

In Cypher, `null` is used to represent missing or undefined values. Conceptually, `null` means “a missing unknown value”, and it is treated differently from other values. For example, getting a property from a vertex that does not have said property produces `null`. Most expressions that take `null` as input will produce `null`. This includes boolean expressions that are used as predicates in the `WHERE` clause. In this case, anything that is not true is interpreted as being false. `null` is not equal to `null`. Not knowing two values does not imply that they are the same value. So the expression `null = null` yields `null` and not true.

The following query returns `null` as an empty space.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN NULL
$$) AS (null_result agtype);

 null_result
--------------

(1 row)
```

The concept of `NULL` in `agtype` and Postgres Pro is the same as it is in Cypher.

F.3.4.1.2. Integer

The `integer` type stores whole numbers, i.e. numbers without fractional components. Integer data type is a 64-bit field that stores values from -9,223,372,036,854,775,808 to 9,223,372,036,854,775,807. Attempts to store values outside this range will result in an error.

The type `integer` is the common choice, as it offers the best balance between range, storage size, and performance. The `smallint` type is generally used only if disk space is at a premium. The `bigint` type is designed to be used when the range of the integer type is insufficient.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN 1
$$) AS (int_result agtype);

 int_result
--------------
1
(1 row)
```

F.3.4.1.3. Float

The data type `float` is an inexact, variable-precision numeric type, conforming to the IEEE 754 Standard.

Inexact means that some values cannot be converted exactly to the internal format and are stored as approximations, so that storing and retrieving a value might show slight discrepancies. Managing these errors and how they propagate through calculations is the subject of an entire branch of mathematics and computer science and will not be discussed here, except for the following points:

- If you require exact storage and calculations (such as for monetary amounts), use the `numeric` type instead.
- If you want to do complicated calculations with these types for anything important, especially if you rely on certain behavior in boundary cases (infinity, underflow), you should evaluate the implementation carefully.
- Comparing two floating-point values for equality might not always work as expected.

Values that are too large or too small will cause an error. Rounding might take place if the precision of an input number is too high. Numbers too close to zero that are not representable as distinct from zero will cause an underflow error.

In addition to ordinary numeric values, the floating-point types have several special values:

- Infinity
- -Infinity
- NaN

These represent the IEEE 754 special values “infinity”, “negative infinity”, and “not-a-number”, respectively. When writing these values as constants in a Cypher command, you must put quotes around them and typecast them, for example:

```
SET x.float_value = '-Infinity'::float
```

On input, these strings are recognized in a case-insensitive manner.

> **Note**
>
> Note that IEEE 754 specifies that NaN should not compare equal to any other floating-point value (including NaN). However, in order to allow floats to be sorted correctly, apache_age evaluates `'NaN'::float = 'NaN'::float` to true. See Comparability and Equality for more details.

To use a float, denote a decimal value.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN 1.0
$$) AS (float_result agtype);

float_result
--------------
1.0
(1 row)
```

F.3.4.1.4. Numeric

The type `numeric` can store numbers with a very large number of digits. It is especially recommended for storing monetary amounts and other quantities where exactness is required. Calculations with `numeric` values yield exact results where possible, e.g., addition, subtraction, multiplication. However, calculations on `numeric` values are very slow compared to the integer types, or to the floating-point types.

We use the following terms below: The *precision* of a `numeric` is the total count of significant digits in the whole number, that is, the number of digits to both sides of the decimal point. The *scale* of a `numeric` is the count of decimal digits in the fractional part, to the right of the decimal point. So the number 23.5141 has a precision of 6 and a scale of 4. Integers can be considered to have a scale of zero.

Specifying `NUMERIC` without any precision or scale creates a column in which numeric values of any precision and scale can be stored, up to the implementation limit on precision. A column of this kind will not coerce input values to any particular scale, whereas `numeric` columns with a declared scale will coerce input values to that scale. (The SQL standard requires a default scale of 0, i.e., coercion to integer precision. We find this a bit useless. If you are concerned about portability, always specify the precision and scale explicitly.)

> **Note**
>
> The maximum allowed precision when explicitly specified in the type declaration is 1000; `NUMERIC` without a specified precision is subject to the limits described in Table 8.2.

If the scale of a value to be stored is greater than the declared scale of the column, the system will round the value to the specified number of fractional digits. Then, if the number of digits to the left of the decimal point exceeds the declared precision minus the declared scale, an error is raised.

Numeric values are physically stored without any extra leading or trailing zeroes. Thus, the declared precision and scale of a column are maximums, not fixed allocations. (In this sense the `numeric` type is more akin to `varchar(n)` than to `char(n)`.) The actual storage requirement is two bytes for each group of four decimal digits, plus three to eight bytes overhead.

In addition to ordinary numeric values, the `numeric` type allows the special value `NaN`, meaning "not-a-number". Any operation on `NaN` yields another `NaN`. When writing this value as a constant in an SQL command, you must put quotes around it, for example `UPDATE table SET x = 'NaN'`. On input, the string `NaN` is recognized in a case-insensitive manner.

> **Note**
>
> In most implementations of the "not-a-number" concept, `NaN` is not considered equal to any other numeric value (including `NaN`). However, in order to allow floats to be sorted correctly, apache_age evaluates `'NaN'::numeric = 'NaN':numeric` to true. See Comparability and Equality for more details.

When rounding values, the `numeric` type rounds ties away from zero, while (on most machines) the `real` and `double precision` types round ties to the nearest even number.

When creating a `numeric` data type, the `::numeric` data annotation is required.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN 1.0::numeric
$$) AS (numeric_result agtype);

numeric_result
--------------
1.0::numeric
(1 row)
```

F.3.4.1.5. Bool

apache_age provides the standard Cypher type `boolean`. The `boolean` type can have several states: `true`, `false`, and a third state, `unknown`, which is represented by the `agtype` `null` value.

Boolean constants can be represented in Cypher queries by the keywords `TRUE`, `FALSE`, and `NULL`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN TRUE
$$) AS (boolean_result agtype);

boolean_result
--------------
true
(1 row)
```

Unlike Postgres Pro, in apache_age boolean outputs as the full word, i.e. `true` and `false` as opposed to `t` and `f`.

F.3.4.1.6. String

`agtype` string literals can contain the following escape sequences:

Table F.2. Escape Sequences

Escape Sequence	Character
\t	Tab
\b	Backspace
\n	Newline
\r	Carriage Return
\f	Form Feed
\'	Single Quote
\"	Double Quote
\\	Backslash
\uXXXX	Unicode UTF-16 code point (4 hex digits must follow `\u`)

Use single (') quotes to identify a string. The output will use double (") quotes.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN 'This is a string'
$$) AS (string_result agtype);

string_result
--------------
"This is a string"
(1 row)
```

F.3.4.2. Composite Data Types

F.3.4.2.1. List

All examples will use the `WITH` clause and `RETURN` clause.

A literal list is created by using brackets and separating the elements in the list with commas.

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst
$$) AS (lst agtype);

                lst
------------------------------------
 [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
(1 row)
```

A list can hold the value `null`, unlike when a `null` is an independent value, it will appear as the word `null` in a list.

```
SELECT *
FROM cypher('graph_name', $$
    WITH [null] as lst
    RETURN lst
$$) AS (lst agtype);

  lst
--------
 [null]
```

```
(1 row)
```

To access individual elements in the list, we use the square brackets again. This will extract from the start index and up to but not including the end index.

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[3]
$$) AS (element agtype);

 element
---------
 3
(1 row)
```

Map elements in lists:

```
SELECT *
FROM cypher('graph_name', $$
   WITH [0, {key: 'key_value'}, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst
$$) AS (map_value agtype);

                        map_value
-----------------------------------------------------
 [0, {"key": "key_value"}, 2, 3, 4, 5, 6, 7, 8, 9, 10]
(1 row)
```

Accessing map elements in lists:

```
SELECT *
FROM cypher('graph_name', $$
   WITH [0, {key: 'key_value'}, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[1].key
$$) AS (map_value agtype);

  map_value
-------------
 "key_value"
(1 row)
```

You can also use negative numbers, to start from the end of the list instead.

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[-3]
$$) AS (element agtype);

 element
---------
 8
(1 row)
```

Finally, you can use ranges inside the brackets to return ranges of the list.

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[0..3]
$$) AS (element agtype);
```

```
  element
-----------
 [0, 1, 2]
(1 row)
```

Negative index ranges:

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[0..-5]
$$) AS (lst agtype);

        lst
--------------------
 [0, 1, 2, 3, 4, 5]
(1 row)
```

Positive slices:

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[..4]
$$) AS (lst agtype);

     lst
--------------
 [0, 1, 2, 3]
(1 row)
```

Negative slices:

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[-5..]
$$) AS (lst agtype);

       lst
------------------
 [6, 7, 8, 9, 10]
(1 row)
```

Out-of-bound slices are simply truncated, but out-of-bound single elements return null.

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
    RETURN lst[15]
$$) AS (element agtype);

 element
---------

(1 row)
```

```
SELECT *
FROM cypher('graph_name', $$
    WITH [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] as lst
```

```
    RETURN lst[5..15]
$$) AS (element agtype);

       element
---------------------
 [5, 6, 7, 8, 9, 10]
(1 row)
```

F.3.4.2.2. Map

Maps can be constructed using Cypher.

You can construct a simple map with simple `agtype` values.

```
SELECT *
FROM cypher('graph_name', $$
    WITH {int_key: 1, float_key: 1.0, numeric_key: 1::numeric, bool_key: true,
 string_key: 'Value'} as m
    RETURN m
$$) AS (m agtype);

                                                    m
-------------------------------------------------------------------------------------------
 {"int_key": 1, "bool_key": true, "float_key": 1.0, "string_key": "Value",
 "numeric_key": 1::numeric}
(1 row)
```

A map can also contain composite data types, i.e. lists and other maps.

```
SELECT *
FROM cypher('graph_name', $$
    WITH {listKey: [{inner: 'Map1'}, {inner: 'Map2'}], mapKey: {i: 0}} as m
    RETURN m
$$) AS (m agtype);

                                    m
-------------------------------------------------------------------------
 {"mapKey": {"i": 0}, "listKey": [{"inner": "Map1"}, {"inner": "Map2"}]}
(1 row)
```

Property access of a map:

```
SELECT *
FROM cypher('graph_name', $$
    WITH {int_key: 1, float_key: 1.0, numeric_key: 1::numeric, bool_key: true,
 string_key: 'Value'} as m
    RETURN m.int_key
$$) AS (int_key agtype);

 int_key
---------
 1
(1 row)
```

Accessing list elements in maps:

```
SELECT *
FROM cypher('graph_name', $$
    WITH {listKey: [{inner: 'Map1'}, {inner: 'Map2'}], mapKey: {i: 0}} as m
    RETURN m.listKey[0]
$$) AS (m agtype);
```

```
          m
--------------------
 {"inner": "Map1"}
(1 row)
```

F.3.4.3. Simple Entities

An entity has a unique, comparable identity which defines whether or not two entities are equal.

An entity is assigned a set of properties, each of which are uniquely identified in the set by the irrespective property keys.

F.3.4.3.1. Graph ID

Simple entities are assigned a unique `graphid`. A `graphid` is a unique composition of the entity label id and a unique sequence assigned to each label. Note that there will be overlap in IDs when comparing entities from different graphs.

A label is an identifier that classifies vertices and edges into certain categories.

- Edges are required to have a label, but vertices do not.
- The names of labels between vertices and edges cannot overlap.

See `CREATE` clause for information about how to make entities with labels.

Both vertices and edges may have properties. Properties are attribute values, and each attribute name should be defined only as a string type.

F.3.4.4. Vertex

- A vertex is the basic entity of the graph, with the unique attribute of being able to exist in and of itself.
- A vertex may be assigned a label.
- A vertex may have zero or more outgoing edges.
- A vertex may have zero or more incoming edges.

Table F.3. Data Format

Attribute Name	Description
id	Graph ID for this vertex
label	Name of the label this vertex has
properties	Properties associated with this vertex

```
{id:1; label: 'label_name'; properties: {prop1: value1, prop2: value2}}::vertex
```

Type casting a map to a vertex:

```
SELECT *
FROM cypher('graph_name', $$
    WITH {id: 0, label: 'label_name', properties: {i: 0}}::vertex as v
    RETURN v
$$) AS (v agtype);

                                 v
-------------------------------------------------------------------
 {"id": 0, "label": "label_name", "properties": {"i": 0}}::vertex
(1 row)
```

F.3.4.5. Edge

An edge is an entity that encodes a directed connection between exactly two nodes, the source node and the target node. An outgoing edge is a directed relationship from the point of view of its source

node. An incoming edge is a directed relationship from the point of view of its target node. An edge is assigned exactly one edge type.

Table F.4. Data Format

Attribute Name	Description
id	Graph ID for this edge
startid	Graph ID for the source node
endid	Graph ID for the target node
label	Name of the label this vertex has
properties	Properties associated with this vertex

```
{id: 3; startid: 1; endid: 2; label: 'edge_label' properties{prop1: value1, prop2:
 value2}}::edge
```

Type casting a map to an edge:

```
SELECT *
FROM cypher('graph_name', $$
    WITH {id: 2, start_id: 0, end_id: 1, label: 'label_name', properties: {i: 0}}::edge
 as e
    RETURN e
$$) AS (e agtype);

                                                  e
-------------------------------------------------------------------------------------------
 {"id": 2, "label": "label_name", "end_id": 1, "start_id": 0, "properties": {"i":
 0}}::edge
(1 row)
```

F.3.4.6. Composite Entities

A path is a series of alternating vertices and edges. A path must start with a vertex, and have at least one edge.

Type casting a list to a path:

```
SELECT *
FROM cypher('graph_name', $$
    WITH [{id: 0, label: 'label_name_1', properties: {i: 0}}::vertex,
             {id: 2, start_id: 0, end_id: 1, label: 'edge_label', properties: {i:
 0}}::edge,
           {id: 1, label: 'label_name_2', properties: {}}::vertex
           ]::path as p
    RETURN p
$$) AS (p agtype);


                             p
-------------------------------------------------------------------------------------------
 [{"id": 0, "label": "label_name_1", "properties": {"i": 0}}::vertex, {"id": 2,
 "label": "edge_label", "end_id": 1, "start_id": 0, "properties": {"i": 0}}::edge,
 {"id": 1, "label": "label_name_2", "properties": {}}::vertex]::path
(1 row)
```

F.3.5. Comparability, Equality, Orderability and Equivalence

apache_age already has good semantics for equality within the primitive types (booleans, strings, integers, and floats) and maps. Furthermore, Cypher has good semantics for comparability and orderability

for integers, floats, and strings, within each of the types. However, working with values of different types deviates from Postgres Pro defined logic and the openCypher specification:

- Comparability between values of different types is defined. This deviation is particularly pronounced when it occurs as part of the evaluation of predicates (in `WHERE`).
- `ORDER BY` will not fail if the values passed to it have different types.

The underlying conceptual model is complex and sometimes inconsistent. This leads to an unclear relationship between comparison operators, equality, grouping, and `ORDER BY`. Comparability and orderability are aligned with each other consistently, as all types can be ordered and compared. The difference between equality and equivalence, as exposed by `IN`, `=`, `DISTINCT`, and grouping, in apache_age is limited to testing two instances of the value `null` to each other. In equality, `null = null` is `null`. In equivalence, used by `DISTINCT` and when grouping values, two null values are always treated as being the same value. However, equality treats `null` values differently if they are an element of a list or a map value.

F.3.5.1. Concepts

The openCypher specification features four distinct concepts related to equality and ordering:

- Comparability is used by the inequality operators (>, <, >=, <=) and defines the underlying semantics of how to compare two values.
- Equality is used by the equality operators (=, <>), and the list membership operator (`IN`). It defines the underlying semantics to determine if two values are the same in these contexts. Equality is also used implicitly by literal maps in node and relationship patterns, since such literal maps are merely a shorthand notation for equality predicates.
- Orderability is used by the `ORDER BY` clause, and defines the underlying semantics of how to order values.
- Equivalence is used by the `DISTINCT` modifier and by grouping in projection clauses (`WITH`, `RETURN`), and defines the underlying semantics to determine if two values are the same in these contexts.

F.3.5.2. Comparability and Equality

Comparison operators need to function as one would expect comparison operators to function — equality and comparability. But, at the same time, they need to allow the sorting of column data — equivalence and orderability.

Unfortunately, it may not be possible to implement separate comparison operators for equality and comparison operations, and, equivalence and orderability operations, in Postgres Pro, for the same query. So we prioritize equivalence and orderability over equality and comparability to allow for ordering of output data.

F.3.5.2.1. Comparability

Comparability is defined between any pair of values, as specified below.

- Numbers
  - Numbers of different types (excluding NaN values and the Infinities) are compared to each other as if both numbers would have been coerced to arbitrary precision `bigdecimal` (currently outside the Cypher type system) before comparing them with each other numerically in ascending order.
  - Comparison to any value that is not also number follows the rules of orderability.
  - Floats do not have the required precision to represent all of the whole numbers in the range of `agtype integer` and `agtype numeric`. When casting an `integer` or `agtype numeric` to a `float`, unexpected results can occur when casting values in the high and low range.
  - Integers
    - Integers are compared numerically in ascending order.
  - Floats
    - Floats (excluding NaN values and the Infinities) are compared numerically in ascending order.

    - Positive infinity is of type `FLOAT`, equal to itself and greater than any other number, except NaN values.
    - Negative infinity is of type `FLOAT`, equal to itself and less than any other number.
    - NaN values are comparable to each and greater than any other float value.
  - Numeric

    - Numerics are compared numerically in ascending order.
- Booleans

  - Booleans are compared such that false is less than true.
  - Comparison to any value that is not also a boolean follows the rules of orderability.
- Strings

  - Strings are compared in dictionary order, i.e. characters are compared pairwise in ascending order from the start of the string to the end. Characters missing in a shorter string are considered to be less than any other character. For example, `'a' < 'aa'`.
  - Comparison to any value that is not also a string follows the rules of orderability.
- Lists

  - Lists are compared in sequential order, i.e. list elements are compared pairwise in ascending order from the start of the list to the end. Elements missing in a shorter list are considered to be less than any other value (including `null` values), for example, `[1] < [1, 0]` but also `[1] < [1, null]`.
  - Comparison to any value that is not also a list follows the rules of orderability.
- Maps

  - The comparison order for maps is unspecified and left to implementations.
  - The comparison order for maps must align with the equality semantics outlined below. In consequence, any map that contains an entry that maps its key to a null value is incomparable. For example, `{a: 1} <= {a: 1, b: null}` evaluates to null.
  - Comparison to any value that is not also a regular map follows the rules of orderability.

Entities:

- Vertices: The comparison order for vertices is based on the assigned `graphid`.
- Edges: The comparison order for edges is based on the assigned `graphid`.
- Paths: Paths are compared as if they were a list of alternating nodes and relationships of the path from the start node to the end node. For example, given nodes `n1`, `n2`, `n3`, and relationships `r1` and `r2`, and given that `n1 < n2 < n3` and `r1 < r2`, then the path `p1` from `n1` to `n3` via `r1` would be less than the path `p2` to `n1` from `n2` via `r2`. Paths are expressed in terms of lists:

  ```
  p1 < p2
  <=> [n1, r1, n3] < [n1, r2, n2]
  <=> n1 < n1 || (n1 = n1 && [r1, n3] < [r2, n2])
  <=> false || (true && [r1, n3] < [r2, n2]) <=> [r1, n3] < [r2, n2]
  <=> r1 < r2 || (r1 = r2 && n3 < n2)
  <=> true || (false && false)
  <=> true
  ```

  Note

  Comparison to any value that is not also a path will return false.

- NULL: `null` is incomparable with any other value (including other `null` values.)

F.3.5.3. Orderability Between Different `agtype` Types

The ordering of different `agtype` types, when using <, <=, >, >= from the smallest value to the largest value is:

1. Path
2. Edge
3. Vertex
4. Object
5. Array
6. String
7. Bool
8. Numeric, Integer, Float
9. NULL

> **Note**
>
> This is subject to change in future releases.

F.3.6. Operators

F.3.6.1. String Specific Comparison Operators

```
SELECT * FROM cypher('graph_name', $$
CREATE (:Person {name: 'John'}),
       (:Person {name: 'Jeff'}),
       (:Person {name: 'Joan'}),
       (:Person {name: 'Bill'})
$$) AS (result agtype);
```

Starts With

Performs case-sensitive prefix searching on strings.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name STARTS WITH "J"
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "John"
 "Jeff"
 "Joan"
(3 rows)
```

Contains

Performs case-sensitive inclusion searching in strings.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name CONTAINS "o"
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "John"
 "Joan"
(2 rows)
```

Ends With

Performs case-sensitive suffix searching on strings.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name ENDS WITH "n"
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "John"
 "Joan"
(2 rows)
```

F.3.6.1.1. Regular Expressions

apache_age supports the use of POSIX regular expressions using the =~ operator. By default =~ is case sensitve.

Basic String Matching

The =~ operator when no special characters are given, act like the = operator.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name =~ 'John'
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "John"
(1 row)
```

Case-Insensitive Search

Adding `(?i)` at the beginning of the string will make the comparison case insensitive.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name =~ '(?i)JoHn'
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "John"
(1 row)
```

The . Wildcard

The . operator acts as a wildcard to match any single character.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name =~ 'Jo.n'
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "John"
 "Joan"
```

```
(2 rows)
```

The * Wildcard

The * wildcard after a character will match to 0 or more of the previous character.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name =~ 'Johz*n'
 RETURN v.name
$$) AS (names agtype);

names
--------
 "John"
(1 row)
```

The + Operator

The + operator matches to 1 or more the previous character.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name =~ 'Bil+'
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "Bill"
(1 row)
```

The . and * Wildcards Together

You can use the . and * wildcards together to represent the rest of the string.

```
SELECT * FROM cypher('graph_name', $$
 MATCH (v:Person)
 WHERE v.name =~ 'J.*'
 RETURN v.name
$$) AS (names agtype);

 names
--------
 "John"
 "Jeff"
 "Joan"
(3 rows)
```

F.3.6.2. Operator Precedence

Operator precedence in apache_age is shown below:

Table F.5. Operator Precedence

Precedence	Operator	Description
1	.	Property Access
2	[]	Map and List Subscripting
	()	Function Call
3	STARTS WITH	Case-sensitive prefix searching on strings

Precedence	Operator	Description
	ENDS WITH	Case-sensitive suffix searching on strings
	CONTAINS	Case-sensitive inclusion searching on strings
	=~	Regular expression string matching
4	-	Unary Minus
5	IN	Checking if an element exists in a list
	IS NULL	Checking a value is NULL
	IS NOT NULL	Checking a value is not NULL
6	^	Exponentiation
7	* / %	Multiplication, division and remainder
8	+ -	Addition and Subtraction
9	= <>	For relational = and ≠ respectively
	< <=	For relational < and ≤ respectively
	> >=	For relational > and ≥ respectively
10	NOT	Logical NOT
11	AND	Logical AND
12	OR	Logical OR

F.3.7. Aggregation

Generally an aggregation `aggr(expr)` processes all matching rows for each aggregation key found in an incoming record (keys are compared using equivalence).

In a regular aggregation (i.e. of the form `aggr(expr)`), the list of aggregated values is the list of candidate values with all `null` values removed from it.

```
SELECT * FROM cypher('graph_name', $$
    CREATE (a:Person {name: 'A', age: 13}),
    (b:Person {name: 'B', age: 33, eyes: "blue"}),
    (c:Person {name: 'C', age: 44, eyes: "blue"}),
    (d1:Person {name: 'D', eyes: "brown"}),
    (d2:Person {name: 'D'}),
    (a)-[:KNOWS]->(b),
    (a)-[:KNOWS]->(c),
    (a)-[:KNOWS]->(d1),
    (b)-[:KNOWS]->(d2),
    (c)-[:KNOWS]->(d2)
$$) as (a agtype);
```

F.3.7.1. Auto Group By

To calculate aggregated data, Cypher offers aggregation, analogous to SQL `GROUP BY`.

Aggregating functions take a set of values and calculate an aggregated value over them. Examples are `avg()` that calculates the average of multiple numeric values, or `min()` that finds the smallest numeric

or string value in a set of values. When we say below that an aggregating function operates on a set of values, we mean these to be the result of the application of the inner expression (such as `n.age`) to all the records within the same aggregation group.

Aggregation can be computed over all the matching subgraphs, or it can be further divided by introducing grouping keys. These are non-aggregate expressions, that are used to group the values going into the aggregate functions.

Assume we have the following `RETURN` statement:

```
SELECT * FROM cypher('graph_name', $$
    MATCH (v:Person)
    RETURN v.name, count(*)
$$) as (grouping_key agtype, count agtype);

 grouping_key | count
--------------+-------
 "A"          | 1
 "D"          | 2
 "B"          | 1
 "C"          | 1
(4 rows)
```

We have two return expressions: `grouping_key`, and `count(*)`. The first, `grouping_key`, is not an aggregate function, and so it will be the grouping key. The latter, `count(*)` is an aggregate expression. The matching subgraphs will be divided into different buckets, depending on the grouping key. The aggregate function will then be run on these buckets, calculating an aggregate value per bucket.

F.3.7.2. Sorting on Aggregate Functions

To use aggregations to sort the result set, the aggregation must be included in the `RETURN` to be used in the `ORDER BY`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (me:Person)-[]->(friend:Person)
    RETURN count(friend), me
    ORDER BY count(friend)
$$) as (friends agtype, me agtype);
```

F.3.7.3. Distinct aggregation

In a distinct aggregation (i.e. of the form `aggr(DISTINCT expr)`), the list of aggregated values is the list of candidate values with all `null` values removed from it. Furthermore, in a distinct aggregation, only one of all equivalent candidate values is included in the list of aggregated values, i.e. duplicates under equivalence are removed.

The `DISTINCT` operator works in conjunction with aggregation. It is used to make all values unique before running them through an aggregate function.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (v:Person)
    RETURN count(DISTINCT v.eyes), count(v.eyes)
$$) as (distinct_eyes agtype, eyes agtype);

 distinct_eyes | eyes
---------------+------
 2             | 3
(1 row)
```

F.3.7.4. Ambiguous Grouping Statements

This feature of not requiring the user to specify their grouping keys for a query allows for ambiguity on what Cypher should qualify as their grouping keys.

```
SELECT * FROM cypher('graph_name', $$
CREATE (:L {a: 1, b: 2, c: 3}),
       (:L {a: 2, b: 3, c: 1}),
       (:L {a: 3, b: 1, c: 2})
$$) as (a agtype);
```

F.3.7.4.1. Invalid Query in apache_age

apache_age solution to this problem is to not allow a `WITH` or `RETURN` column to combine aggregate functions with variables that are not explicitly listed in another column of the same `WITH` or `RETURN` clause.

```
SELECT * FROM cypher('graph_name', $$
    MATCH (x:L)
    RETURN x.a + count(*) + x.b + count(*) + x.c
$$) as (a agtype);

ERROR:  'x' must be either part of an explicitly listed key or used inside an aggregate
 function
LINE 3: RETURN x.a + count(*) + x.b + count(*) + x.c
```

F.3.7.4.2. Valid Query in apache_age

Columns that do not include an aggregate function in apache_age are considered to be the grouping keys for that `WITH` or `RETURN` clause.

For the above query, the user could rewrite the query in several ways that will return results.

```
SELECT * FROM cypher('graph_name', $$
    MATCH (x:L)
    RETURN (x.a + x.b + x.c) + count(*) + count(*), x.a + x.b + x.c
$$) as (count agtype, key agtype);

count  | key
-------+-----
 12    | 6
(1 row)
```

`x.a + x.b + x.c` is the grouping key. Grouping keys created like this must include parenthesis.

```
SELECT * FROM cypher('graph_name', $$
    MATCH (x:L)
    RETURN x.a + count(*) + x.b + count(*) + x.c, x.a, x.b, x.c
$$) as (count agtype, a agtype, b agtype, c agtype);

 count | a | b | c
-------+---+---+---
 10    | 3 | 1 | 2
 10    | 2 | 3 | 1
 10    | 1 | 2 | 3
(3 rows)
```

`x.a`, `x.b`, and `x.c` will be considered different grouping keys.

F.3.7.4.3. Vertices and Edges in Ambiguous Grouping

Alternatively, the grouping key can be a vertex or edge, and then any properties of the vertex or edge can be specified without being explicitly stated in a `WITH` or `RETURN` column.

```
SELECT * FROM cypher('graph_name', $$
    MATCH (x:L)
    RETURN count(*) + count(*) + x.a + x.b + x.c, x
$$) as (count agtype, key agtype);

 count |                                          key
-------
+-----------------------------------------------------------------------------------------
 8     | {"id": 1407374883553283, "label": "L", "properties": {"a": 3, "b": 1, "c":
 2}}::vertex
 8     | {"id": 1407374883553281, "label": "L", "properties": {"a": 1, "b": 2, "c":
 3}}::vertex
 8     | {"id": 1407374883553282, "label": "L", "properties": {"a": 2, "b": 3, "c":
 1}}::vertex
(3 rows)
```

Results will be grouped on `x`, because it is safe to assume that properties considered unnecessary for grouping are unambiguous.

F.3.7.4.4. Hiding Unwanted Grouping Keys

If the grouping key is considered unnecessary for the query output, the aggregation can be done in a `WITH` clause then passing information to the `RETURN` clause.

```
SELECT * FROM cypher('graph_name', $$
    MATCH (x:L)
    WITH count(*) + count(*) + x.a + x.b + x.c as column, x
    RETURN column
$$) as (a agtype);

 a
---
 8
 8
 8
(3 rows)
```

F.3.8. Importing Graph from Files

You can use the following instructions to create a graph from the files:

- Functions to load graphs from files
- Structure of CSV files that load functions as input
- Simple source code example to load countries and cities from the files

> **Note**
>
> User must create graph and labels before loading data from files.

F.3.8.1. Load Graph Functions

Following are the details about the functions to create vertices and edges from the file.

Function `load_labels_from_file` is used to load vertices from CSV files.

```
load_labels_from_file('graph_name',
                      'label_name',
                      'file_path')
```

By adding the fourth parameter user can exclude the `id` field. Use this when there is no `id` field in the file.

```
load_labels_from_file('graph_name',
                      'label_name',
                      'file_path',
                      false)
```

Function `load_edges_from_file` can be used to load edges from the CSV file. See the file structure below.

> **Note**
>
> Make sure that IDs in the edge file are identical to ones that are in vertices files.

```
load_edges_from_file('graph_name',
                     'label_name',
                     'file_path');
```

F.3.8.2. Explanation about the CSV format

Following is the explanation about the structure for CSV files for vertices and edges.

A CSV file for nodes is formatted as follows:

Table F.6. CSV File Format for Nodes

Field name	Field description
id	The first column of the file. All values are a positive integer. This is an optional field when `id_field_exists` is `false`. However, it should be present when `id_field_exists` is *not* set to false.
Properties	All other columns contain the properties for the nodes. Header row contains the name of property.

Similarly, a CSV file for edges is formatted as follows:

Table F.7. CSV File Format for Edges

Field name	Field description
start_id	Node ID of the node from where the edge is started. This ID is present in `nodes.csv` file.
start_vertex_type	Class of the node
end_id	End ID of the node at which the edge is terminated.
end_vertex_type	Class of the node
properties	Properties of the edge. The header contains the property name.

F.3.8.3. Example SQL Script

- Load apache_age and create a graph.

```
LOAD 'age';

SET search_path TO ag_catalog;
SELECT create_graph('agload_test_graph');
```

- Create label `Country` and load vertices from the CSV file. Note that this CSV file has the `id` field.

```
SELECT create_vlabel('agload_test_graph','Country');
SELECT load_labels_from_file('agload_test_graph',
                             'Country',
                             '/age/regress/age_load/data/countries.csv');
```

- Create label `City` and load vertices from the CSV file. Note that this CSV file has the `id` field.

```
SELECT create_vlabel('agload_test_graph','City');
SELECT load_labels_from_file('agload_test_graph',
                             'City',
                             '/age/regress/age_load/data/cities.csv');
```

- Create label `has_city` and load edges from the CSV file.

```
SELECT create_elabel('agload_test_graph','has_city');
SELECT load_edges_from_file('agload_test_graph', 'has_city',
     '/age/regress/age_load/data/edges.csv');
```

- Check if the graph has been loaded properly.

```
SELECT table_catalog, table_schema, table_name, table_type
FROM information_schema.tables
WHERE table_schema = 'agload_test_graph';

SELECT COUNT(*) FROM agload_test_graph."Country";
SELECT COUNT(*) FROM agload_test_graph."City";
SELECT COUNT(*) FROM agload_test_graph."has_city";

SELECT COUNT(*) FROM cypher('agload_test_graph', $$MATCH(n) RETURN n$$) as (n
 agtype);
SELECT COUNT(*) FROM cypher('agload_test_graph', $$MATCH (a)-[e]->(b) RETURN e$$) as
 (n agtype);
```

F.3.8.3.1. Creating Vertices Without ID Field in the File

- Create label `Country2` and load vertices from the CSV file. Note that this CSV file has no `id` field.

```
SELECT create_vlabel('agload_test_graph','Country2');
SELECT load_labels_from_file('agload_test_graph',
                             'Country2',
                             '/age/regress/age_load/data/countries.csv',
                             false);
```

- Create label `City2` and load vertices from CSV file. Note this CSV file has no `id` field.

```
SELECT create_vlabel('agload_test_graph','City2');
SELECT load_labels_from_file('agload_test_graph',
                             'City2',
                             '/age/regress/age_load/data/cities.csv',
                             false);
```

- Check if the graph has been loaded properly and perform difference analysis between IDs created automatically and picked from the files.

  Labels `Country` and `City` were created with the `id` field in the file.

  Labels `Country2` and `City2` were created with no `id` field in the file.

```
SELECT COUNT(*) FROM agload_test_graph."Country2";
SELECT COUNT(*) FROM agload_test_graph."City2";

SELECT id FROM agload_test_graph."Country" LIMIT 10;
SELECT id FROM agload_test_graph."Country2" LIMIT 10;
```

```
SELECT * FROM cypher('agload_test_graph', $$MATCH(n:Country {iso2 : 'BE'})
    RETURN id(n), n.name, n.iso2 $$) as ('id(n)' agtype, 'n.name' agtype, 'n.iso2'
 agtype);
SELECT * FROM cypher('agload_test_graph', $$MATCH(n:Country2 {iso2 : 'BE'})
    RETURN id(n), n.name, n.iso2 $$) as ('id(n)' agtype, 'n.name' agtype, 'n.iso2'
 agtype);

SELECT * FROM cypher('agload_test_graph', $$MATCH(n:Country {iso2 : 'AT'})
    RETURN id(n), n.name, n.iso2 $$) as ('id(n)' agtype, 'n.name' agtype, 'n.iso2'
 agtype);
SELECT * FROM cypher('agload_test_graph', $$MATCH(n:Country2 {iso2 : 'AT'})
    RETURN id(n), n.name, n.iso2 $$) as ('id(n)' agtype, 'n.name' agtype, 'n.iso2'
 agtype);

SELECT drop_graph('agload_test_graph', true);
```

F.3.9. MATCH

The `MATCH` clause allows you to specify the patterns a query will search for in the database. This is the primary way of retrieving data for use in a query.

A `WHERE` clause often follows a `MATCH` clause to add user-defined restrictions to the matched patterns to manipulate the set of data returned. The predicates are part of the pattern description, and should not be considered a filter applied only after the matching is done. This means that `WHERE` should always be put together with the `MATCH` clause it belongs to.

`MATCH` can occur at the beginning of the query or later, possibly after a `WITH`. If it is the first clause, nothing will have been bound yet, and Cypher will design a search to find the results matching the clause and any associated predicates specified in any `WHERE` clause. Vertices and edges found by this search are available as bound pattern elements and can be used for pattern matching of sub-graphs. They can also be used in any future clauses where Cypher will use the known elements, and from there find further unknown elements.

Cypher is a declarative language, and so typically the query itself does not specify the algorithm to use to perform the search. Predicates in `WHERE` parts can be evaluated before pattern matching, during pattern matching, or after the match is found.

F.3.9.1. Basic Vertex Finding

F.3.9.1.1. Get All Vertices

By specifying a pattern with a single vertex and no labels, all vertices in the graph will be returned.

```
SELECT * FROM cypher('graph_name', $$
MATCH (v)
RETURN v
$$) as (v agtype);
```

```
                                        v
-------------------------------------------------------------------------------
{id: 0; label: 'Person'; properties: {name: 'Charlie Sheen'}}::vertex
{id: 1; label: 'Person'; properties: {name: 'Martin Sheen'}}::vertex
{id: 2; label: 'Person'; properties: {name: 'Michael Douglas'}}::vertex
{id: 3; label: 'Person'; properties: {name: 'Oliver Stone'}}::vertex
{id: 4; label: 'Person'; properties: {name: 'Rob Reiner'}}::vertex
{id: 5; label: 'Movie'; properties: {name: 'Wall Street'}}::vertex
{id: 6; label: 'Movie'; properties: {title: 'The American President'}}::vertex
(7 rows)
```

Returns all vertices in the database.

F.3.9.1.2. Get All Vertices with a Label

Getting all vertices with a label is done with a single node pattern where the vertex has the label specified as follows:

```
SELECT * FROM cypher('graph_name', $$
MATCH (movie:Movie)
RETURN movie.title
$$) as (title agtype);

         title
-----------------------
'Wall Street'
'The American President'
(2 rows)
```

Returns all the movies in the database.

F.3.9.1.3. Related Vertices

The symbol `-[]-` specifies an edge, without specifying the type or direction of the edge.

```
SELECT * FROM cypher('graph_name', $$
MATCH (director {name: 'Oliver Stone'})-[]-(movie)
RETURN movie.title
$$) as (title agtype);

    title
-------------
'Wall Street'
(1 row)
```

Returns all the movies directed by “Oliver Stone”.

F.3.9.1.4. Match with Labels

To constrain your pattern with labels on vertices, add it to the vertex in the pattern, using the label syntax.

```
SELECT * FROM cypher('graph_name', $$
MATCH (:Person {name: 'Oliver Stone'})-[]-(movie:Movie)
RETURN movie.title
$$) as (title agtype);

    title
-------------
'Wall Street'
(1 row)
```

Returns any vertices connected with the `Person` “Oliver” that are labeled `Movie`.

F.3.9.2. Edge Basics

F.3.9.2.1. Outgoing Edges

To return directed edges, you may use `->` or `<-` to specify the direction of which the edge points.

```
SELECT * FROM cypher('graph_name', $$
MATCH (:Person {name: 'Oliver Stone'})-[]->(movie)
RETURN movie.title
$$) as (title agtype);

    title
-------------
```

```
'Wall Street'
(1 row)
```

Returns any vertices connected with the `Person` "Oliver" by an outgoing edge.

F.3.9.2.2. Directed Edges and Variable

If a variable is required, either for filtering on properties of the edge, or to return the edge, specify the variable within the edge or vertex you wish to use.

```
SELECT * FROM cypher('graph_name', $$
MATCH (:Person {name: 'Oliver Stone'})-[r]->(movie)
RETURN type(r)
$$) as (title agtype);

  title
----------
'DIRECTED'
(1 row)
```

Returns the type of each outgoing edge from "Oliver".

F.3.9.2.3. Match on Edge Label

When you know the edge label you want to match on, you can specify it by using a colon together with the edge label

```
SELECT * FROM cypher('graph_name', $$
MATCH (:Movie {title: 'Wall Street'})<-[:ACTED_IN]-(actor)
RETURN actor.name
$$) as (actors_name agtype);

   actors_name
-----------------
'Charlie Sheen'
'Martin Sheen'
'Michael Douglas'
(3 rows)
```

Returns all actors that `ACTED_IN` "Wall Street".

F.3.9.2.4. Match on Edge Label with a Variable

If you want to use a variable to hold the edge, and specify the edge label you want, you can do so by specifying them both.

```
SELECT * FROM cypher('graph_name', $$
MATCH ({title: 'Wall Street'})<-[r:ACTED_IN]-(actor)
RETURN r.role
$$) as (role agtype);

     role
--------------
'Gordon Gekko'
'Carl Fox'
'Bud Fox'
(3 rows)
```

Returns `ACTED_IN` roles for "Wall Street".

F.3.9.2.5. Multiple Edges

Edges can be strung together to match an infinite number of edges. As long as the base pattern `()-[]-()` is followed, users can chain together edges and vertices to match specific patterns.

```
SELECT * FROM cypher('graph_name', $$
    MATCH (charlie {name: 'Charlie Sheen'})-[:ACTED_IN]->(movie)<-[:DIRECTED]-
(director)
    RETURN movie.title, director.name
$$) as (title agtype, name agtype);

    title     |     name
--------------+--------------
'Wall Street' | 'Oliver Stone'
(1 row)
```

Returns the movie “Charlie Sheen” acted in and its director.

F.3.9.3. Variable Length Edges

When the connection between two vertices is of variable length, the list of edges that form the connection can be returned using the following connection.

Rather than describing a long path using a sequence of many vertex and edge descriptions in a pattern, many edges (and the intermediate vertices) can be described by specifying a length in the edge description of a pattern.

```
(u)-[*2]->(v)
```

Which describes a right directed path of three vertices and two edges can be rewritten to:

```
(u)-[]->()-[]->(v)
```

A range length can also be given:

```
(u)-[*3..5]->(v)
```

Which is equivalent to:

```
(u)-[]->()-[]->()-[]->(v) and
(u)-[]->()-[]->()-[]->()-[]->(v) and
(u)-[]->()-[]->()-[]->()-[]->()-[]->(v)
```

The previous example provided gave the path both a lower and upper bound for the number of edges (and vertices) between `u` and `v`. Either one or both of these binding values can be excluded.

```
(u)-[*3..]->(v)
```

Returns all paths between `u` and `v` that have three or more edges included.

```
(u)-[*..5]->(v)
```

Returns all paths between `u` and `v` that have 5 or fewer edges included.

```
(u)-[*]->(v)
```

Returns all paths between `u` and `v`.

F.3.9.3.1. Example

```
SELECT * FROM cypher('graph_name', $$
    MATCH p = (actor {name: 'Willam Dafoe'})-[:ACTED_IN*2]-(co_actor)
    RETURN relationships(p)
$$) as (r agtype);

                                                                                r
-------------------------------------------------------------------------------------------
[{id: 0; label:"ACTED_IN"; properties: {role: "Green Goblin"}}::edge, {id: 1; label:
 "ACTED_IN; properties: {role: "Spiderman", actor: "Toby Maguire}}::edge]
[{id: 0; label:"ACTED_IN"; properties: {role: "Green Goblin"}}::edge, {id: 2; label:
 "ACTED_IN; properties: {role: "Spiderman", actor: "Andrew Garfield"}}::edge]
```

```
(2 rows)
```

Returns the list of edges, including the one that “Willam Dafoe” acted in and the two “Spiderman” actors he worked with.

F.3.10. WITH

Using `WITH`, you can manipulate the output before it is passed on to the following query parts. The manipulations can be of the shape and/or number of entries in the result set.

`WITH` can also, like `RETURN`, alias expressions that are introduced into the results using the aliases as the binding name.

`WITH` is also used to separate the reading of the graph from updating of the graph. Every part of a query must be either read-only or write-only. When going from a writing part to a reading part, an optional `WITH` clause can be used to do so.

F.3.10.1. Filter on Aggregate Function Results

Aggregated results have to pass through a `WITH` clause to be able to filter on.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (david {name: 'David'})-[]-(otherPerson)-[]->()
    WITH otherPerson, count(*) AS foaf
    WHERE foaf > 1
    RETURN otherPerson.name
$$) as (name agtype);

  name
--------
"Anders"
(1 row)
```

The name of the person connected to “David” with the at least more than one outgoing relationship will be returned by the query.

F.3.10.2. Sort Results Before Using `collect`

You can sort results before passing them to `collect`, thus sorting the resulting list.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)WITH n
    ORDER BY n.name DESC LIMIT 3
    RETURN collect(n.name)
$$) as (names agtype);

         names
-------------------------
["Emil","David","Ceasar"]
(1 row)
```

A list of the names of people in reverse order, limited to 3, is returned.

F.3.10.3. Limit Branching of a Path Search

You can match paths, limit to a certain number, and then match again using those paths as a base, as well as any number of similar limited searches.

```
SELECT *
FROM cypher('graph_name', $$
```

```
    MATCH (n {name: 'Anders'})-[]-(m)WITH m
    ORDER BY m.name DESC LIMIT 1
    MATCH (m)-[]-(o)
    RETURN o.name
$$) as (name agtype);

  name
-------
"Anders"
"Bossman"
(2 rows)
```

Starting at “Anders”, find all matching nodes, order by name descending and get the top result, then find all the nodes connected to that top result, and return their names.

F.3.11. RETURN

In the `RETURN` part of your query, you define which parts of the pattern you want to output. Output can include `agtype` values, nodes, relationships, or properties.

F.3.11.1. Return Nodes

To return a node, list it in the `RETURN` statement.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'B'})
    RETURN n
$$) as (n agtype);

                         n
-----------------------------------------------------
{id: 0; label: '' properties: {name: 'B'}}::vertex
(1 row)
```

The example will return the node.

F.3.11.2. Return Edges

To return `n` edges, just include it in the `RETURN` list.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)-[r:KNOWS]->()
    WHERE n.name = 'A'
    RETURN r
$$) as (r agtype);

                                r
-------------------------------------------------------------------
 {id: 2; startid: 0; endid: 1; label: 'KNOWS' properties: {}}::edge
(1 row)
```

The relationship is returned by the example.

F.3.11.3. Return Property

To return a property, use the dot separator, as follows:

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'A'})
```

```
    RETURN n.name
$$) as (name agtype);

 name
------
 'A'
(1 row)
```

The value of the property `name` gets returned.

F.3.11.4. Return All Elements

When you want to return all vertices, edges and paths found in a query, you can use the `*` symbol.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (a {name: 'A'})-[r]->(b)
    RETURN *
$$) as (a agtype, b agtype, r agtype);

                                                a
                 |                                                                  b
                                                          |
   r
-------------------------------------------------------------------------------------------------
+-------------------------------------------------------------------------------------------------
+-------------------------------------------------------------------------
 {"id": 281474976710659, "label": "", "properties": {"age": 55, "name": "A",
 "happy": "Yes!"}}::vertex | {"id": 1125899906842625, "label": "BLOCKS", "end_id":
 281474976710660, "start_id": 281474976710659, "properties": {}}::edge | {"id":
 281474976710660, "label": "", "properties": {"name": "B"}}::vertex
 {"id": 281474976710659, "label": "", "properties": {"age": 55, "name": "A",
 "happy": "Yes!"}}::vertex | {"id": 1407374883553281, "label": "KNOWS", "end_id":
 281474976710660, "start_id": 281474976710659, "properties": {}}::edge | {"id":
 281474976710660, "label": "", "properties": {"name": "B"}}::vertex
(2 rows)
```

This returns the two vertices, and the edge used in the query.

F.3.11.5. Variable with Uncommon Characters

To introduce a placeholder that is made up of characters that are not contained in the English alphabet, you can use the ` to enclose the variable, like this:

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (`This isn\'t a common variable`)
    WHERE `This isn\'t a common variable`.name = 'A'
    RETURN `This isn\'t a common variable`.happy
$$) as (happy agtype);

 happy
-------
 "Yes!"
(1 row)
```

The node with name “A” is returned.

F.3.11.6. Aliasing a Field

If the name of the field should be different from the expression used, you can rename it by changing the name in the column list definition.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'A'})
    RETURN n.name
$$) as (objects_name agtype);

 objects_name
--------------
 'A'
(1 row)
```

Returns the property of a node, but renames the field.

F.3.11.7. Optional Properties

If a property might or might not be there, it will be treated as `null` if it is missing.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    RETURN n.age
$$) as (age agtype);

 age
-----
 55
 NULL
(2 rows)
```

This query returns the property if it exists, or `null` if the property does not exist.

F.3.11.8. Other Expressions

Any expression can be used as a return item—literals, predicates, properties, functions, and everything else.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (a)
    RETURN a.age > 30, 'I\'m a literal', id(a)
$$) as (older_than_30 agtype, literal agtype, id agtype);

 older_than_30 | literal         | id
---------------+-----------------+----
 true          | 'I'm a literal' | 1
(1 row)
```

Returns a predicate, a literal and function call with a pattern expression parameter.

F.3.11.9. Unique Results

`DISTINCT` retrieves only unique records depending on the fields that have been selected to output.

```
SELECT *
FROM cypher('graph_name', $$
MATCH (a {name: 'A'})-[]->(b)
RETURN DISTINCT b
$$) as (b agtype);

                            b
-----------------------------------------------------
 {id: 1; label: '' properties: {name: 'B'}}::vertex
```

```
(1 row)
```

The node named “B” is returned by the query, but only once.

F.3.12. ORDER BY

`ORDER BY` is a sub-clause following `WITH`. `ORDER BY` specifies that the output should be sorted and how it will be sorted.

Note that you cannot sort on nodes or relationships, sorting must be done on properties. `ORDER BY` relies on comparisons to sort the output. See ordering and comparison of values.

In terms of scope of variables, `ORDER BY` follows special rules, depending on if the projecting `RETURN` or `WITH` clause is either aggregating or `DISTINCT`. If it is an aggregating or `DISTINCT` projection, only the variables available in the projection are available. If the projection does not alter the output cardinality (which aggregation and `DISTINCT` do), variables available from before the projecting clause are also available. When the projection clause shadows already existing variables, only the new variables are available.

Lastly, it is not allowed to use aggregating expressions in the `ORDER BY` sub-clause if they are not also listed in the projecting clause. This last rule is to make sure that `ORDER BY` does not change the results, only the order of them.

F.3.12.1. Order Nodes by Property

`ORDER BY` is used to sort the output.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    WITH n.name as name, n.age as age
    ORDER BY n.name
    RETURN name, age
$$) as (name agtype, age agtype);

  name   | age
---------+-----
  "A"    | 34
  "B"    | 34
  "C"    | 32
(3 rows)
```

The nodes are returned, sorted by their name.

F.3.12.2. Order Nodes by Multiple Properties

You can order by multiple properties by stating each variable in the `ORDER BY` clause. Cypher will sort the result by the first variable listed, and for equal values, go to the next property in the `ORDER BY` clause, and so on.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    WITH n.name as name, n.age as age
    ORDER BY n.age, n.name
    RETURN name, age
$$) as (name agtype, age agtype);

  name   | age
---------+-----
  "C"    | 32
```

```
  "A"   | 34
  "B"   | 34
(3 rows)
```

This returns the nodes, sorted first by their age, and then by their name.

F.3.12.3. Order Nodes in Descending Order

By adding `DESC[ENDING]` after the variable to sort on, the sort will be done in reverse order.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    WITH n.name AS name, n.age AS age
    ORDER BY n.name DESC
    RETURN name, age
$$) as (name agtype, age agtype);

  name  | age
--------+-----
  "C"   | 32
  "B"   | 34
  "A"   | 34
(3 rows)
```

The example returns the nodes, sorted by their name in reverse order.

F.3.12.4. Ordering null

When sorting the result set, `null` will always come at the end of the result set for ascending sorting, and first for descending sorting.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    WITH n.name AS name, n.age AS age, n.height AS height
    ORDER BY n.height
    RETURN name, age, height
$$) as (name agtype, age agtype, height agtype);

  name  | age | height
--------+-----+--------
  "A"   | 34  | 170
  "C"   | 32  | 185
  "B"   | 34  | NULL
(3 rows)
```

The nodes are returned sorted by the length property, with a node without that property last.

F.3.13. SKIP

`SKIP` defines from which record to start including the records in the output.

By using `SKIP`, the result set will get trimmed from the top. Please note that no guarantees are made on the order of the returned results unless specified by the `ORDER BY` clause. `SKIP` accepts any expression that evaluates to a positive integer.

F.3.13.1. Skip First Three Rows

To return a subset of the result, starting from the top, use the following syntax:

```
SELECT *
```

```
FROM cypher('graph_name', $$
    MATCH (n)
    RETURN n.name
    ORDER BY n.name
    SKIP 3
$$) as (names agtype);

 names
-------
 "D"
 "E"
(2 rows)
```

The name property of the matched node `n` is returned, with a limit of 3.

F.3.13.2. Return Middle Two Rows

To return a subset of the result, starting in the middle, use this syntax:

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    RETURN n.name
    ORDER BY n.name
    SKIP 1
    LIMIT 2
$$) as (names agtype);

 names
-------
 "B"
 "C"
(2 rows)
```

Two vertices from the middle are returned.

F.3.13.3. Using an Expression with SKIP to Return a Subset of Rows

Using an expression with `SKIP` to return a subset of the rows.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    RETURN n.name
    ORDER BY n.name
    SKIP (3 * rand())+ 1
$$) as (a agtype);

 names
-------
 "C"
 "D"
 "E"
(3 rows)
```

The first two vertices are skipped, and only the last three are returned in the result.

F.3.14. LIMIT

`LIMIT` constrains the number of records in the output.

`LIMIT` accepts any expression that evaluates to a positive integer.

F.3.14.1. Return a Subset of the Rows

To return a subset of the result, starting from the top, use this syntax:

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)RETURN n.name
    ORDER BY n.name
    LIMIT 3
$$) as (names agtype);

names
"A"
"B"
"C"
3 rows
```

The node is returned, and no property `age` exists on it.

F.3.14.2. Using an Expression with LIMIT to Return a Subset of Rows

`LIMIT` accepts any expression that evaluates to a positive integer as long as it is not referring to any external variables:

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n)
    RETURN n.name
    ORDER BY n.name
    LIMIT toInteger(3 * rand()) + 1
$$) as (names agtype);

 names
-------
 "A"
 "B"
(2 rows)
```

Returns one to three top items.

F.3.15. CREATE

The `CREATE` clause is used to create graph vertices and edges.

F.3.15.1. Terminal CREATE Clauses

A `CREATE` clause that is not followed by another clause is a terminal clause. When the Cypher query ends with a terminal clause, no results will be returned from the Cypher function call. However, the Cypher function call still requires a column list definition. When the Cypher query ends with a terminal node, define a single value in the column list definition: no data will be returned in this variable.

```
SELECT *
FROM cypher('graph_name', $$
    CREATE /* Create clause here, no following clause */
$$) as (a agtype);

 a
---
(0 rows)
```

F.3.15.2. Create Single Vertex

Creating a single vertex is done by issuing the following query.

```
SELECT *
FROM cypher('graph_name', $$
    CREATE (n)
$$) as (v agtype);

 v
---
(0 rows)
```

Nothing is returned from this query.

F.3.15.3. Create Multiple Vertices

Creating multiple vertices is done by separating them with a comma.

```
SELECT *
FROM cypher('graph_name', $$
    CREATE (n), (m)
$$) as (v agtype);

   a
-------
(0 rows)
```

F.3.15.4. Create a Vertex with a Label

To add a label when creating a vertex, use the syntax below.

```
SELECT *
FROM cypher('graph_name', $$
    CREATE (:Person)
$$) as (v agtype);

   v
-------
(0 rows)
```

Nothing is returned from this query.

F.3.15.5. Create Vertex and Add Labels and Properties

You can create a vertex with labels and properties at the same time.

```
SELECT *
FROM cypher('graph_name', $$
    CREATE (:Person {name: 'Andres', title: 'Developer'})
$$) as (n agtype);

   n
-------
(0 rows)
```

Nothing is returned from this query.

F.3.15.6. Return Created Node

You can create and return a node within the same query as follows:

```
SELECT *
FROM cypher('graph_name', $$
    CREATE (a {name: 'Andres'})
    RETURN a
$$) as (a agtype);
```

```
                                        a
-------------------------------------------------------------------------------
 {"id": 281474976710660, "label": "", "properties": {"name": "Andres"}}::vertex
(1 row)
```

The newly-created node is returned.

F.3.15.7. Create an Edge Between Two Nodes

To create an edge between two vertices, we first `MATCH` the two vertices. Once the nodes are matched, we create an edge between them.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (a:Person), (b:Person)
    WHERE a.name = 'Node A' AND b.name = 'Node B'
    CREATE (a)-[e:RELTYPE]->(b)
    RETURN e
$$) as (e agtype);

                              e
-----------------------------------------------------------------------
{id: 3; startid: 0, endid: 1; label: 'RELTYPE'; properties: {}}::edge
(1 row)
```

The created edge is returned by the query.

F.3.15.8. Create an Edge and Set Properties

Setting properties on edges is done in a similar manner to setting properties when creating vertices. Note that the values can be any expression.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (a:Person), (b:Person)
    WHERE a.name = 'Node A' AND b.name = 'Node B'
    CREATE (a)-[e:RELTYPE {name:a.name + '<->' + b.name}]->(b)
    RETURN e
$$) as (e agtype);

                                          e
-------------------------------------------------------------------------------------------
 {id: 3; startid: 0, endid: 1; label: 'RELTYPE'; properties: {name: 'Node A<->Node
 B'}}::edge
(1 row)
```

The newly created edge is returned by the example query.

F.3.15.9. Create a Full Path

When you use `CREATE` and a pattern, all parts of the patterns that are not already in scope at this time will be created.

```
SELECT *
FROM cypher('graph_name', $$
    CREATE p = (andres {name:'Andres'})-[:WORKS_AT]->(neo)<-[:WORKS_AT]-(michael
 {name:'Michael'})
    RETURN p
$$) as (p agtype);

                      p
```

```
-------------------------------------------------------------------------------------------
 [{"id": 281474976710661, "label": "", "properties": {"name": "Andres"}}::vertex,
 {"id": 1407374883553282, "label": "WORKS_AT", "end_id": 281474976710662, "start_id":
 281474976710661, "properties": {}}::edge, {"id": 281474976710662, "label": "",
 "properties": {}}::vertex, {"id": 1407374883553281, "label": "WORKS_AT", "end_id":
 281474976710662, "start_id": 281474976710663, "properties": {}}::edge, {"id":
 281474976710663, "label": "", "properties": {"name": "Michael"}}::vertex]::path
(1 row)
```

This query creates three nodes and two relationships simultaneously, assigns the pattern to a path variable, and returns the said pattern.

F.3.16. DELETE

The `DELETE` clause is used to delete graph elements — nodes, relationships, or paths.

A `DELETE` clause that is not followed by another clause is called a terminal clause. When the Cypher query ends with a terminal clause, no results will be returned from the Cypher function call. However, the Cypher function call still requires a column list definition. When the Cypher query ends with a terminal node, define a single value in the column list definition: no data will be returned in this variable.

For removing properties, see Section F.3.17.4.

You cannot delete a node without also deleting edges that start or end on said vertex. Either explicitly delete the vertices,or use `DETACH DELETE`.

F.3.16.1. Delete Isolated Vertices

To delete a vertex, use the `DELETE` clause.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (v:Useless)
    DELETE v
$$) as (v agtype);

   v
-------
(0 rows)
```

This will delete the vertices (with label Useless) that have no edges. Nothing is returned from this query.

F.3.16.2. Delete All Vertices and Edges Associated with Them

Running a `MATCH` clause will collect all nodes — use the `DETACH` option to delete vertice edges first, and then delete the vertex itself.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (v:Useless)
    DETACH DELETE v
$$) as (v agtype);

   v
-------
(0 rows)
```

Nothing is returned from this query.

F.3.16.3. Delete Edges Only

To delete an edge, use the `MATCH` clause to find your edges, then add the variable to the `DELETE` clause.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'Andres'})-[r:KNOWS]->()
    DELETE r
$$) as (v agtype);

   v
-------
(0 rows)
```

Nothing is returned from this query.

F.3.16.4. Return a Deleted Vertex

You can return vertices that have been deleted with a `RETURN` clause.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'A'})
    DELETE n
    RETURN n
$$) as (a agtype);

                                    a
-------------------------------------------------------------------------
 {"id": 281474976710659, "label": "", "properties": {"name": "A"}}::vertex
(1 rows)
```

F.3.17. SET

The `SET` clause is used to update labels and properties on vertices and edges.

F.3.17.1. Terminal SET Clauses

A `SET` clause that is not followed by another clause is a terminal clause. When the Cypher query ends with a terminal clause, no results will be returned from the Cypher function call. However, the Cypher function call still requires a column list definition. When the Cypher query ends with a terminal node, define a single value in the column list definition: no data will be returned in this variable.

F.3.17.2. Set a Property

To set a property on a node or relationship, use `SET`.

```
SELECT *
FROM cypher('graph_name', $$
   MATCH (v {name: 'Andres'})
   SET v.surname = 'Taylor'
$$) as (v agtype);

   v
-------
(0 rows)
```

The newly changed node is returned by the query.

F.3.17.3. Return Created Vertex

Creating a single vertex is done with the following query:

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (v {name: 'Andres'})
```

```
    SET v.surname = 'Taylor'
    RETURN v
$$) as (v agtype);

                                                    v
------------------------------------------------------------------------------------------
 {id: 3; label: 'Person'; properties: {surname:"Taylor", name:"Andres", age:36,
 hungry:true}}::vertex
(1 row)
```

The newly changed vertex is returned by the query.

F.3.17.4. Remove a Property

Normally a property can be removed by using `REMOVE`, but users can also remove properties using the `SET` command. One example is if the property comes from a parameter.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (v {name: 'Andres'})
    SET v.name = NULL
    RETURN v
$$) as (v agtype);

                                          v
-------------------------------------------------------------------------------
 {id: 3; label: 'Person'; properties: {surname:"Taylor", age:36, hungry:true}}::vertex
(1 row)
```

The node is returned by the query, and the name property is now missing.

F.3.17.5. Set Multiple Properties Using One SET Clause

If you want to set multiple properties in one query, you can separate them with a comma.

```
SELECT *
FROM cypher('graph_name', $$
MATCH (v {name: 'Andres'})
SET v.position = 'Developer', v.surname = 'Taylor'
RETURN v
$$) as (v agtype);

                                                  v
------------------------------------------------------------------------------------------
{"id": 281474976710661, "label": "", "properties": {"name": "Andres", "surname":
 "Taylor", "position": "Developer"}}: :vertex
(1 row)
```

F.3.18. REMOVE

The `REMOVE` clause is used to remove properties from vertex and edges.

A `REMOVE` clause that is not followed by another clause is called a terminal clause. When the Cypher query ends with a terminal clause, no results will be returned from the Cypher function call. However, the Cypher function call still requires a column list definition. When the Cypher query ends with a terminal node, define a single value in the column list definition: no data will be returned in this variable.

Cypher does not allow storing `null` in properties. Instead, if no value exists, the property is just not there. So, removing a property value on a node or a relationship is also done with `REMOVE`.

```
SELECT *
```

```
FROM cypher('graph_name', $$
    MATCH (andres {name: 'Andres'})
    REMOVE andres.age
    RETURN andres
$$) as (andres agtype);

                          andres
---------------------------------------------------------------
 {id: 3; label: 'Person'; properties: {name:"Andres"}}::vertex
(1 row)
```

The node is returned, and no property `age` exists on it.

F.3.19. MERGE

The `MERGE` clause ensures that a pattern exists in the graph. Either the pattern already exists, or it needs to be created.

`MERGE` either matches existing nodes, or creates new data. It is a combination of `MATCH` and `CREATE`.

For example, you can specify that the graph must contain a node for a user with a certain name. If there is not a node with the correct name, a new node will be created and its name property set. When using `MERGE` on full patterns, the behavior is that either the whole pattern matches, or the whole pattern is created. `MERGE` will not partially use existing patterns. If partial matches are needed, this can be accomplished by splitting a pattern up into multiple `MERGE` clauses.

As with `MATCH`, `MERGE` can match multiple occurrences of a pattern. If there are multiple matches, they will all be passed on to later stages of the query.

```
SELECT * from cypher('graph_name', $$
CREATE (A:Person {name: 'Charlie Sheen', bornIn: 'New York'}),
    (B:Person {name: 'Michael Douglas', bornIn: 'New Jersey'}),
    (C:Person {name: 'Rob Reiner', bornIn: 'New York'}),
    (D:Person {name: 'Oliver Stone', bornIn: 'New York'}),
    (E:Person {name: 'Martin Sheen', bornIn: 'Ohio'})
$$) as (result agtype);
```

F.3.19.1. Merge Nodes

F.3.19.1.1. Merge a Node with a Label

By just specifying a pattern with a single vertex and no labels, all vertices in the graph will be returned.

```
SELECT * FROM cypher('graph_name', $$
MERGE (v:Critic)
RETURN v
$$) as (v agtype);

                     v
-----------------------------------------------
 {id: 0; label: 'Critic': properties:{}}::vertex
(1 row)
```

If there exists a vertex with the label “Critic”, that vertex will be returned. Otherwise, the vertex will be created and returned.

F.3.19.1.2. Merge Single Vertex with Properties

Merging a vertex node with properties where not all properties match any existing vertex.

```
SELECT * FROM cypher('graph_name', $$
MERGE (charlie {name: 'Charlie Sheen', age: 10})
```

```
RETURN charlie
$$) as (v agtype);

                                  v
------------------------------------------------------------------------------
 {id: 0; label: 'Actor': properties:{name: 'Charlie Sheen', age: 10}}::vertex
(1 row)
```

If there exists a vertex with the label “Critic”, that vertex will be returned. Otherwise, the vertex will be created and returned.

If there exists a vertex with all properties, that vertex will be returned. Otherwise, a new vertex with the name “Charlie Sheen” will be created and returned.

F.3.19.1.3. Merge a Single Vertex Specifying Both Label and Property

Merging a vertex where both label and property constraints match an existing vertex.

```
SELECT * FROM cypher('graph_name', $$
MERGE (michael:Person {name: 'Michael Douglas'})
RETURN michael.name, michael.bornIn
$$) as (Name agtype, BornIn agtype);

       name        |    bornin
-------------------+--------------
 "Michael Douglas" | "New Jersey"
(1 row)
```

“Michael Douglas” will match the existing vertex, and the vertex `name` and `bornIn` properties will be returned.

F.3.20. Predicate Functions

Predicates are boolean functions that return true or false for a given set of input. They are most commonly used to filter out subgraphs in the `WHERE` part of a query.

`exists(`*property* `agtype) returns agtype boolean`

`exists()` returns `true` if the specified property exists in the node, relationship or map. This is different from the `EXISTS` clause.

```
SELECT *
FROM cypher('graph_name', $$
     MATCH (n)
     WHERE exists(n.surname)
     RETURN n.first_name, n.last_name
$$) as (first_name agtype, last_name agtype);

 first_name |  last_name
------------+------------
   'John'   |   'Smith'
   'Patty' | 'Patterson'
(2 rows)
```

`exists(`*path* `agtype) returns agtype boolean`

`exists()` returns `true` if for the given path, there already exists the given path.

```
SELECT *
FROM cypher('graph_name', $$
     MATCH (n)
     WHERE exists((n)-[]-({name: 'Willem Defoe'}))
     RETURN n.full_name
```

```
$$) as (full_name agtype);

  full_name
--------------
'Toby Maguire'
'Tom Holland'
(2 rows)
```

F.3.21. Scalar Functions

`id(`*`expression`* `agtype) returns agtype integer`

`id()` returns the ID of a vertex or edge.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (a)
    RETURN id(a)
$$) as (id agtype);

 id
----
 0
 1
 2
 3
(4 rows)
```

`start_id(`*`expression`* `agtype) returns agtype integer`

`start_id()` returns the ID of the vertex that is the starting vertex for the edge.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH ()-[e]->()
    RETURN start_id(e)
$$) as (start_id agtype);

 start_id
----------
 0
 1
 2
 3
(4 rows)
```

`end_id(`*`expression`* `agtype) returns agtype integer`

`end_id()` returns the ID of the vertex that is the ending vertex for the edge.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH ()-[e]->()
    RETURN end_id(e)
$$) as (end_id agtype);

 end_id
--------
 4
 5
 6
```

```
 7
(4 rows)
```

`type(`*edge* `agtype) returns agtype string`

`type()` returns the string representation of the edge type.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH ()-[e]->()
    RETURN type(e)
$$) as (type agtype);

 type
------
'KNOWS'
'KNOWS'
(2 rows)
```

`properties(`*expression* `agtype) returns agtype map`

`properties()` returns an agtype map containing all the properties of a vertex or edge. If the argument is already a map, it is returned unchanged. `properties(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    CREATE (p:Person {name: 'Stefan', city: 'Berlin'})
    RETURN properties(p)
$$) as (type agtype);

                  type
-------------------------------------
 {"city": "Berlin", "name": "Stefan"}
(1 row)
```

`head(`*list* `agtype) returns agtype`

`head()` returns the first element in an agtype list. `head(null)` returns `null`. If the first element in the list is `null`, `head(list)` will return `null`.

```
SELECT *
FROM cypher('graph_name', $$
   MATCH (a)
   WHERE a.name = 'Eskil'
   RETURN a.array, head(a.array)
$$) as (lst agtype, lst_head agtype);

          lst           | lst_head
------------------------+----------
 ["one","two","three"] | "one"
(1 row)
```

`last(`*list* `agtype) returns agtype`

`last()` returns the last element in an agtype list. `last(null)` returns `null`. If the last element in the list is `null`, `last(list)` will return `null`.

```
SELECT *
FROM cypher('graph_name', $$
MATCH (a)
WHERE a.name = 'Eskil'
RETURN a.array, last(a.array)
$$) as (lst agtype, lst_tail agtype);
```

```
           lst          | lst_tail
----------------------+----------
 ["one","two","three"] | "three"
(1 row)
```

`length(`*path* `agtype) returns agtype integer`

`length()` returns the length of a path. `length(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
   MATCH p = (a)-[]->(b)-[]->(c)
   WHERE a.name = 'Alice'
   RETURN length(p)
$$) as (length_of_path agtype);

 length_of_path
----------------
 2
 2
 2
(3 rows)
```

`size(`*list* `variadic "any") returns agtype integer`

`size()` returns the length of a list. `size(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN size(['Alice', 'Bob'])
$$) as (size_of_list agtype);

 size_of_list
--------------
 2
(1 row)
```

`startNode(`*edge* `agtype) returns agtype`

`startNode()` returns the start node of an edge. `startNode(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (x:Developer)-[r]-()
    RETURN startNode(r)
$$) as (v agtype);

                    v
-----------------------------------------
Node[0]{name:"Alice",age:38,eyes:"brown"}
Node[0]{name:"Alice",age:38,eyes:"brown"}
(2 rows)
```

`endNode(`*edge* `agtype) returns agtype`

`endNode()` returns the end node of an edge. `endNode(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (x:Developer)-[r]-()
    RETURN endNode(r)
$$) as (v agtype);
```

```
                      v
-----------------------------------------
Node[2]{name:"Charlie",age:53,eyes:"green"}
Node[1]{name:"Bob",age:25,eyes:"blue"}
(2 rows)
```

`timestamp() returns agtype integer`

`timestamp()` returns the difference, measured in milliseconds, between the current time and midnight, January 1, 1970 UTC. `timestamp` will return the same value during one entire query, even for long-running queries.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN timestamp()
$$) as (t agtype);

       t
---------------
1613496720760
(1 row)
```

`toBoolean(`*`expression`* `variadic "any") returns agtype boolean`

`toBoolean()` converts a string value to a boolean value. `toBoolean(null)` returns `null`. If expression is a boolean value, it will be returned unchanged. If the parsing fails, `null` will be returned.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN toBoolean('TRUE'), toBoolean('not a boolean')
$$) as (a_bool agtype, not_a_bool agtype);

 a_bool | not_a_bool
--------+------------
 true   | NULL
(1 row)
```

`toFloat(`*`expression`* `variadic "any") returns agtype float`

`toFloat()` converts an integer or string value to a floating point number. `toFloat(null)` returns `null`. If expression is a floating point number, it will be returned unchanged. If the parsing fails, `null` will be returned.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN toFloat('11.5'), toFloat('not a number')
$$) as (a_float agtype, not_a_float agtype);

 a_float | not_a_float
---------+-------------
 11.5    | NULL
(1 row)
```

`toInteger(`*`expression`* `variadic "any") returns agtype integer`

`toInteger()` converts a floating point or string value to an integer value. `toInteger(null)` returns `null`. If expression is an integer value, it will be returned unchanged. If the parsing fails, `null` will be returned.

```
SELECT *
FROM cypher('graph_name', $$
     RETURN toInteger('42'), toInteger('not a number')
```

```
$$) as (an_integer agtype, not_an_integer agtype);

 an_integer | not_an_integer
------------+----------------
 42         | NULL
(1 row)
```

`coalesce(`*`expression`* `agtype [, `*`expression`* `agtype]*) returns agtype`

`coalesce()` returns the first non-null value in the given list of expressions. `null` will be returned if all the arguments are `null`.

```
SELECT *
FROM cypher('graph_name', $$
MATCH (a)
WHERE a.name = 'Alice'
RETURN coalesce(a.hairColor, a.eyes), a.hair_color, a.eyes
$$) as (color agtype, hair_color agtype, eyes agtype);

 color | hair_color |  eyes
-------+------------+--------
“brown”| NULL       | “Brown”
(1 row)
```

F.3.22. List Functions

```
SELECT * from cypher('graph_name', $$
CREATE (A:Person {name: 'Alice', age: 38, eyes: 'brown'}),
    (B:Person {name: 'Bob', age: 25, eyes: 'blue'}),
    (C:Person {name: 'Charlie', age: 53, eyes: 'green'}),
    (D:Person {name: 'Daniel', age: 54, eyes: 'brown'}),
    (E:Person {name: 'Eskil', age: 41, eyes: 'blue', array: ['one', 'two', 'three']}),
    (A)-[:KNOWS]->(B),
    (A)-[:KNOWS]->(C),
    (B)-[:KNOWS]->(D),
    (C)-[:KNOWS]->(D),
    (B)-[:KNOWS]->(E)
$$) as (result agtype);
```

`keys(`*`expression`* `agtype) returns agtype list`

`keys()` returns a list containing the string representations for all the property names of a vertex, edge, or map. `keys(null)` returns `null`.

```
SELECT * from cypher('graph_name', $$
    MATCH (a)
    WHERE a.name = 'Alice'
    RETURN keys(a)
$$) as (result agtype);

          result
------------------------
 ["age", "eyes", "name"]
(1 row)
```

A list containing the names of all the properties on the vertex bound to `a` is returned.

`range(`*`start`* `variadic "any", `*`end`* `variadic "any" [, `*`step`* `variadic "any"]) returns agtype list`

`range()` returns a list comprising all integer values within a range bounded by a start value *`start`* and end value *`end`*, where the difference *`step`* between any two consecutive values is constant; i.e. an

arithmetic progression. The range is inclusive, and the arithmetic progression will therefore always contain *start* and — depending on the values of *start*, *step*, and *end* — *end*.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN range(0, 10), range(2, 18, 3)
$$) as (no_step agtype, step agtype);

              no_step               |         step
------------------------------------+-----------------------
 [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] | [2, 5, 8, 11, 14, 17]
(1 row)
```

Two lists of numbers in the given ranges are returned.

`labels(vertex agtype) returns agtype list`

`labels()` returns a list containing the string representations for all the labels of a node. `labels(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (a)
    WHERE a.name = 'Alice'
    RETURN labels(a)
$$) as (edges agtype);

   edges
------------
 ["Person"]
(1 row)
```

A list containing all the labels of the node bound to `a` is returned.

`nodes(path agtype) returns agtype list`

`nodes()` returns a list containing all the vertices in a path. `nodes(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH p = (a)-[]->(b)-[]->(c)
    WHERE a.name = 'Alice' AND c.name = 'Eskil'
    RETURN nodes(p)
$$) as (vertices agtype);



             vertices
-----------------------------------------------------------------------------------------
 [{"id": 844424930131969, "label": "Person", "properties": {"age": 38, "eyes":
 "brown", "name": "Alice"}}::vertex, {"id": 844424930131970, "label": "Person",
 "properties": {"age": 25, "eyes": "blue", "name": "Bob"}}::vertex, {"id":
 844424930131973, "label": "Person", "properties": {"age": 41, "eyes": "blue",
 "name": "Eskil", "array": ["one", "two", "three"]}}::vertex]
(1 row)
```

A list containing all the vertices in the path `p` is returned.

`relationships(path agtype) returns agtype list`

`relationships()` returns a list containing all the relationships in a path. `relationships(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH p = (a)-[]->(b)-[]->(c)
    WHERE a.name = 'Alice' AND c.name = 'Eskil'
    RETURN relationships(p)
$$) as (edges agtype);


                                        edges
-------------------------------------------------------------------------------------------
 [{"id": 1125899906842625, "label": "KNOWS", "end_id": 844424930131970, "start_id":
 844424930131969, "properties": {}}::edge, {"id": 1125899906842629, "label":
 "KNOWS", "end_id": 844424930131973, "start_id": 844424930131970, "properties":
 {}}::edge]
(1 row)
```

A list containing all the edges in the path `p` is returned.

`toBooleanList(`*`list`* `variadic "any") returns agtype list`

`toBooleanList()` converts a list of values and returns a list of boolean values. If any values are not convertible to boolean they will be `null` in the list returned. Any `null` element in list is preserved. Any boolean value in list is preserved. If the list is `null`, `null` will be returned.

```
SELECT * FROM cypher('expr', $$
    RETURN toBooleanList(['true', 'false', 'true'])
$$) AS (toBooleanList agtype);

   toBooleanList
--------------------
[true, false, true]
(1 row)
```

F.3.23. Numeric Functions

`rand() returns agtype float`

`rand()` returns a random floating point number in the range from 0 (inclusive) to 1 (exclusive); i.e. [0,1). The numbers returned follow an approximate uniform distribution.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN rand()
$$) as (random_number agtype);

   random_number
-------------------
0.3586784748902053
(1 row)
```

`abs(`*`list`* `variadic "any") returns agtype`

`abs()` returns the absolute value of the given number. `abs(null)` returns `null`. If expression is negative, `-(`*`expression`*`)` (i.e. the negation of expression) is returned.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (a), (e) WHERE a.name = 'Alice' AND e.name = 'Eskil'
    RETURN a.age, e.age, abs(a.age - e.age)
$$) as (alice_age agtype, eskil_age agtype, difference agtype);
```

```
 alice_age | eskil_age | difference
-----------+-----------+------------
 38        | 41        | 3
(1 row)
```

The absolute value of the age difference is returned.

`ceil(`*expression* `variadic "any") returns agtype float`

`ceil()` returns the smallest floating point number that is greater than or equal to the given number and equal to a mathematical integer. `ceil(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN ceil(0.1)
$$) as (ceil_value agtype);

 ceil_value
------------
 1.0
(1 row)
```

The ceiling of 0.1 is returned.

`floor(`*expression* `variadic "any") returns agtype float`

`floor()` returns the greatest floating point number that is less than or equal to the given number and equal to a mathematical integer. `floor(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN floor(0.1)
$$) as (flr agtype);

 flr
-----
 0.0
(1 row)
```

The floor of 0.1 is returned.

`round(`*expression* `variadic "any") returns agtype float`

`round()` returns the value of the given number rounded to the nearest integer. `round(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN round(3.141592)
$$) as (rounded_value agtype);

 rounded_value
---------------
 3.0
(1 row)
```

`sign(`*expression* `variadic "any") returns agtype integer`

`sign()` returns the signum of the given number: 0 if the number is 0, -1 for any negative number, and 1 for any positive number. `sign(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
```

```
        RETURN sign(-17), sign(0.1), sign(0)
    $$) as (negative_sign agtype, positive_sign agtype, zero_sign agtype);

     negative_sign | positive_sign | zero_sign
    ---------------+---------------+-----------
     -1            | 1             | 0
    (1 row)
```

The signs of -17 and 0.1 are returned.

F.3.24. Logarithmic Functions

`e() returns agtype float`

`e()` returns the base of the natural logarithm, `e`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN e()
$$) as (e agtype);

         e
--------------------
 2.718281828459045
(1 row)
```

`sqrt(`*`expression`* `variadic "any") returns agtype float`

`sqrt()` returns the square root of a number.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN sqrt(144)
$$) as (results agtype);

 results
---------
 12.0
(1 row)
```

`exp(`*`expression`* `variadic "any") returns agtype float`

`exp()` returns `e^n`, where `e` is the base of the natural logarithm, and `n` is the value of the argument expression. `exp(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN exp(2)
$$) as (e agtype);

        e
------------------
 7.38905609893065
(1 row)
```

`e` to the power of 2 is returned.

`log(`*`expression`* `variadic "any") returns agtype float`

`log()` returns the natural logarithm of a number. `log(null)` returns `null`. `log(0)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
```

```
        RETURN log(27)
    $$) as (natural_logarithm agtype);

     natural_logarithm
    -------------------
     3.295836866004329
    (1 row)
```

The natural logarithm of 27 is returned.

`log10(`*expression* `variadic "any") returns agtype float`

`log10()` returns the common logarithm (base 10) of a number. `log10(null)` returns `null`. `log10(0)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN log10(27)
$$) as (common_logarithm agtype);

  common_logarithm
--------------------
 1.4313637641589874
(1 row)
```

The common logarithm of 27 is returned.

F.3.25. Trigonometric Functions

`degrees(`*expression* `variadic "any") returns agtype float`

`degrees()` converts radians to degrees. `degrees(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN degrees(3.14159)
$$) as (deg agtype);

         deg
-------------------
 179.9998479605043
(1 row)
```

The number of degrees close to pi is returned.

`radians(`*expression* `variadic "any") returns agtype float`

`radians()` converts degrees to radians. `radians(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN radians(180)
$$) as (rad agtype);

         rad
-------------------
 3.141592653589793
(1 row)
```

The number of degrees close to pi is returned.

`pi() returns agtype float`

`pi()` returns the mathematical constant pi.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN pi()
$$) as (p agtype);

         p
------------------
 3.141592653589793
(1 row)
```

The constant pi is returned.

`sin(`*expression* variadic "any") returns agtype float

`sin()` returns the sine of a number. `sin(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN sin(0.5)
$$) as (s agtype);

         s
------------------
 0.479425538604203
(1 row)
```

The sine of 0.5 is returned.

`cos(`*expression* variadic "any") returns agtype float

`cos()` returns the sine of a number. `cos(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN cos(0.5)
$$) as (c agtype);

         c
-------------------
 0.8775825618903728
(1 row)
```

The cosine of 0.5 is returned.

`tan(`*expression* variadic "any") returns agtype float

`tan()` returns the tangent of a number. `tan(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN tan(0.5)
$$) as (t agtype);

         t
-------------------
 0.5463024898437905
(1 row)
```

The tangent of 0.5 is returned.

`cot(`*expression* variadic "any") returns agtype float

`cot()` returns the cotangent of a number. `cot(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN cot(0.5)
$$) as (t agtype);

         t
-------------------
 1.830487721712452
(1 row)
```

The cotangent of 0.5 is returned.

`asin(`*`expression`* `variadic "any") returns agtype float`

`asin()` returns the arcsine of a number. `asin(null)` returns `null`. If (expression < -1) or (expression > 1), then `asin(expression)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN asin(0.5)
$$) as (arc_s agtype);

       arc_s
--------------------
 0.5235987755982989
(1 row)
```

The arcsine of 0.5 is returned.

`acos(`*`expression`* `variadic "any") returns agtype float`

`acos()` returns the arcsine of a number. `acos(null)` returns `null`. If (expression < -1) or (expression > 1), then `acos(expression)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN acos(0.5)
$$) as (arc_c agtype);

       arc_c
--------------------
 1.0471975511965979
(1 row)
```

The arccosine of 0.5 is returned.

`atan(`*`expression`* `variadic "any") returns agtype float`

`atan()` returns the arctangent of a number. `atan(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN atan(0.5)
$$) as (arc_t agtype);

       arc_t
--------------------
 0.4636476090008061
(1 row)
```

The arctangent of 0.5 is returned.

atan2(*expression1* variadic "any", *expression2* variadic "any") returns agtype float

atan2() returns the arctangent of a set of coordinates in radians. atan2(null, null), atan2(null, expression2) and atan(expression1, null) all return null.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN atan2(0.5, 0.6)
$$) as (arc_t2 agtype);

       arc_t2
--------------------
 0.6947382761967033
(1 row)
```

The arctangent of 0.5 and 0.6 is returned.

F.3.26. String Functions

replace(*original*, *search* variadic "any", *replace* variadic "any") returns agtype string

replace() returns a string in which all occurrences of a specified string in the original string have been replaced by another (specified) string. If any argument is null, null will be returned. If search is not found in *original*, *original* will be returned.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN replace('hello', 'l', 'w')
$$) as (str_array agtype);

 str_array
-----------
 "hewwo"
(1 row)
```

split(*original* variadic "any", *split_delimiter* variadic "any") returns list of agtype strings

split() returns a list of strings resulting from the splitting of the original string around matches of the given delimiter. split(null, splitDelimiter) and split(original, null) both return null.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN split('one,two', ',')
$$) as (split_list agtype);

   split_list
----------------
 ["one", "two"]
(1 row)
```

left(*original* variadic "any", *length* variadic "any") returns agtype string

left() returns a string containing the specified number of leftmost characters of the original string. left(null, length) and left(null, null) both return null. left(original, null) will raise an error. If *length* is not a positive integer, an error is raised. If *length* exceeds the size of *original*, *original* is returned.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN left('Hello', 3)
$$) as (new_str agtype);
```

```
 new_str
---------
 "Hel"
(1 row)
```

`right(`*`original`* `variadic "any",` *`length`* `variadic "any") returns agtype string`

`right()` returns a string containing the specified number of rightmost characters of the original string. `right(null, length)` and `right(null, null)` both return `null`. `right(original, null)` will raise an error. If *`length`* is not a positive integer, an error is raised. If *`length`* exceeds the size of *`original`*, *`original`* is returned.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN right('hello', 3)
$$) as (new_str agtype);

 new_str
---------
 "llo"
(1 row)
```

`substring(`*`original`* `variadic "any",` *`start`* `variadic "any" [,` *`length`* `variadic "any"]) returns agtype string`

`substring()` returns a substring of the original string, beginning with a 0-based index start and length. *`start`* uses a zero-based index. If *`length`* is omitted, the function returns the substring starting at the position given by *`start`* and extending to the end of *`original`*. If *`original`* is `null`, `null` is returned. If either *`start`* or *`length`* is `null` or a negative integer, an error is raised. If *`start`* is 0, the substring will start at the beginning of *`original`*. If *`length`* is 0, the empty string will be returned.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN substring('hello', 1, 3), substring('hello', 2)
$$) as (sub_str1 agtype, sub_str2 agtype);

 sub_str1 | sub_str2
----------+----------
 "ell"    | "llo"
(1 row)
```

`rTrim(`*`original`* `variadic "any") returns agtype string`

`rTrim()` returns the original string with trailing whitespace removed. `rTrim(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN rTrim(' hello ')
$$) as (right_trimmed_str agtype);

 right_trimmed_str
-------------------
 " hello"
(1 row)
```

`lTrim(`*`original`* `variadic "any") returns agtype string`

`lTrim()` returns the original string with leading whitespace removed. `lTrim(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
```

```
        RETURN lTrim(' hello ')
    $$) as (left_trimmed_str agtype);

     left_trimmed_str
    ------------------
     "hello "
    (1 row)
```

`trim(`*`original`* `variadic "any") returns agtype string`

`trim()` returns the original string with leading and trailing whitespace removed. `trim(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN trim(' hello ')
$$) as (trimmed_str agtype);

 trimmed_str
-------------
 "hello"
(1 row)
```

`toLower(`*`original`* `variadic "any") returns agtype string`

`toLower()` returns the original string in lowercase. `toLower(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN toLower('HELLO')
$$) as (lower_str agtype);

 lower_str
-----------
 "hello"
(1 row)
```

`toUpper(`*`original`* `variadic "any") returns agtype string`

`toUpper()` returns the original string in uppercase. `toUpper(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN toUpper('hello')
$$) as (upper_str agtype);

 upper_str
-----------
 "HELLO"
(1 row)
```

`reverse(`*`original`* `variadic "any") returns agtype string`

`reverse()` returns a string in which the order of all characters in the original string have been reversed. `reverse(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN reverse('hello')
$$) as (reverse_str agtype);

 reverse_str
-------------
```

```
 "olleh"
(1 row)
```

`toString(`*`expression`* `agtype) returns string`

`toString()` converts an `integer`, `float` or `boolean` value to a string. `toString(null)` returns `null`. If *`expression`* is a string, it will be returned unchanged.

```
SELECT *
FROM cypher('graph_name', $$
    RETURN toString(11.5),toString('a string'), toString(true)
$$) as (float_to_str agtype, str_to_str agtype, bool_to_string agtype);

 float_to_str | str_to_str | bool_to_string
--------------+------------+----------------
 "11.5"       | "a string" | "true"
(1 row)
```

F.3.27. Aggregation Functions

Functions that activate auto aggregation.

```
LOAD 'age';
SET search_path TO ag_catalog;

SELECT create_graph('graph_name');

SELECT * FROM cypher('graph_name', $$
    CREATE (a:Person {name: 'A', age: 13}),
    (b:Person {name: 'B', age: 33, eyes: 'blue'}),
    (c:Person {name: 'C', age: 44, eyes: 'blue'}),
    (d1:Person {name: 'D', eyes: 'brown'}),
    (d2:Person {name: 'D'}),
    (a)-[:KNOWS]->(b),
    (a)-[:KNOWS]->(c),
    (a)-[:KNOWS]->(d1),
    (b)-[:KNOWS]->(d2),
    (c)-[:KNOWS]->(d2)
$$) as (a agtype);
```

`min(`*`expression`* `variadic "any") returns agtype`

`min()` returns the minimum value in a set of values. Any `null` values are excluded from the calculation. In a mixed set, any string value is always considered to be lower than any numeric value, and any list is always considered to be lower than any string. Lists are compared in dictionary order, i.e. list elements are compared pairwise in ascending order from the start of the list to the end. `min(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (v:Person)
    RETURN min(v.age)
$$) as (min_age agtype);

 min_age
---------
 13
(1 row)
```

The lowest of all the values in the property `age` is returned.

To clarify the following example, assume the next three commands are run first:

```
SELECT * FROM cypher('graph_name', $$
    CREATE (:min_test {val:'d'})
$$) as (result agtype);

SELECT * FROM cypher('graph_name', $$
    CREATE (:min_test {val:['a', 'b', 23]})
$$) as (result agtype);

SELECT * FROM cypher('graph_name', $$
    CREATE (:min_test {val:[1, 'b', 23]})
$$) as (result agtype);
```

The example below shows using `min()` with lists:

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (v:min_test)
    RETURN min(v.val)
$$) as (min_val agtype);

    min_val
----------------
 ["a", "b", 23]
(1 row)
```

The lowest of all the values in the set is returned (in this case, the list `["a", "b", 23]`), as the two lists are considered to be lower values than the string "d", and the string "a" is considered to be a lower value than the numerical value 1.

`max(`*expression* `variadic "any") returns agtype float`

`max()` returns the maximum value in a set of values. Any `null` values are excluded from the calculation. In a mixed set, any numeric value is always considered to be higher than any string value, and any string value is always considered to be higher than any list. Lists are compared in dictionary order, i.e. list elements are compared pairwise in ascending order from the start of the list to the end. `max(null)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n:Person)
    RETURN max(n.age)
$$) as (max_age agtype);

 max_age
---------
 44
(1 row)
```

The highest of all the values in the property `age` is returned.

`stDev(`*expression* `variadic "any") returns agtype float`

`stDev()` returns the standard deviation for the given value over a group. It uses a standard two-pass method, with N - 1 as the denominator, and should be used when taking a sample of the population for an unbiased estimate. When the standard deviation of the entire population is being calculated, `stDevP` should be used. Any `null` values are excluded from the calculation. `stDev(null)` returns 0.0 (zero).

```
SELECT *
FROM cypher('graph_name', $$
   MATCH (n:Person)
```

```
       RETURN stDev(n.age)
$$) as (stdev_age agtype);

     stdev_age
--------------------
 15.716233645501712
(1 row)
```

The standard deviation of the values in the property `age` is returned.

`stDevP(`*`expression`* `variadic "any") returns agtype float`

`stDev()` returns the standard deviation for the given value over a group. It uses a standard two-pass method, with N as the denominator, and should be used when calculating the standard deviation for an entire population. When the standard deviation of only a sample of the population is being calculated, `stDev` should be used. Any `null` values are excluded from the calculation. `stDevP(null)` returns 0.0 (zero).

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n:Person)
    RETURN stDevP(n.age)
$$) as (stdevp_age agtype);

     stdevp_age
--------------------
 12.832251036613439
(1 row)
```

The population standard deviation of the values in the property `age` is returned.

`percentileCont(`*`expression`* `agtype,` *`percentile`* `agtype) returns agtype float`

`percentileCont()` returns the percentile of the given value over a group, with a percentile from 0.0 to 1.0. It uses a linear interpolation method, calculating a weighted average between two values if the desired percentile lies between them. For nearest values using a rounding method, see `percentileDisc`. Any `null` values are excluded from the calculation. `percentileCont(null, percentile)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n:Person)
    RETURN percentileCont(n.age, 0.4)
$$) as (percentile_cont_age agtype);

 percentile_cont_age
---------------------
 29.0
(1 row)
```

The 40th percentile of the values in the property `age` is returned, calculated with a weighted average. In this case, 0.4 is the median, or 40th percentile.

`percentileDisc(`*`expression`* `agtype,` *`percentile`* `agtype) returns agtype float`

`percentileDisc()` returns the percentile of the given value over a group, with a percentile from 0.0 to 1.0. It uses a rounding method and calculates the nearest value to the percentile. For interpolated values, see `percentileCont`. Any `null` values are excluded from the calculation. `percentileDisc(null, percentile)` returns `null`.

```
SELECT *
FROM cypher('graph_name', $$
```

```
    MATCH (n:Person)
    RETURN percentileDisc(n.age, 0.5)
$$) as (percentile_disc_age agtype);

 percentile_disc_age
---------------------
 33.0
(1 row)
```

The 50th percentile of the values in the property `age` is returned.

`count(`*`expression`* `agtype) returns agtype integer`

`count()` returns the number of values or records, and appears in two variants:

- `count(*)` returns the number of matching records.
- `count(expr)` returns the number of non-null values returned by an expression.

`count(*)` includes records returning `null`. `count(expr)` ignores `null` values. `count(null)` returns 0 (zero). `count(*)` can be used to return the number of nodes; for example, the number of nodes connected to some node `n`.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'A'})-[]->(x)
    RETURN n.age, count(*)
$$) as (age agtype, number_of_people agtype);

 age | number_of_people
-----+------------------
 13  | 3
(1 row)
```

The `age` property of the start node `n` (with a name value of "A") and the number of nodes related to `n` are returned.

`count(*)` can be used to group and count relationship types, returning the number of relationships of each type.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'A'})-[r]->()
    RETURN type(r), count(*)
$$) as (label agtype, count agtype);

  label  | count
---------+-------
 "KNOWS" | 3
(1 row)
```

The relationship type and the number of relationships with that type are returned.

Instead of simply returning the number of records with `count(*)`, it may be more useful to return the actual number of values returned by an expression.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n {name: 'A'})-[]->(x)
    RETURN count(x)
$$) as (count agtype);

 count
```

```
-------
 3
(1 row)
```

The number of nodes connected to the start node `n` is returned.

`count(expression)` can be used to return the number of non-null values returned by the expression.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (n:Person)
    RETURN count(n.age)
$$) as (count agtype);

 count
-------
 3
(1 row)
```

The number of nodes with the label `Person` that have a non-null value for the `age` property is returned.

In the following example we are trying to find all our friends of friends, and count them. The first aggregate function, `count(DISTINCT friend_of_friend)`, will only count a `friend_of_friend` once, as *`DISTINCT`* removes the duplicates. The second aggregate function, `count(friend_of_friend)`, will consider the same `friend_of_friend` multiple times.

```
SELECT *
FROM cypher('graph_name', $$
    MATCH (me:Person)-[]->(friend:Person)-[]->(friend_of_friend:Person)
    WHERE me.name = 'A'
    RETURN count(DISTINCT friend_of_friend), count(friend_of_friend)
$$) as (friend_of_friends_distinct agtype, friend_of_friends agtype);

 friend_of_friends_distinct | friend_of_friends
----------------------------+-------------------
 1                          | 2
(1 row)
```

Both B and C know D and thus D will get counted twice when not using `DISTINCT`.

`avg(`*`expression`* `agtype) returns agtype integer`

`avg()` returns the average of a set of numeric values. Any `null` values are excluded from the calculation. `avg(null)` returns null.

```
SELECT *
FROM cypher('graph_name', $$
MATCH (n:Person)
RETURN avg(n.age)
$$) as (avg_age agtype);

 avg_age
---------
 30.0
(1 row)
```

The average of all the values in the property `age` is returned.

`sum(`*`expression`* `agtype) returns agtype float`

`sum()` returns the sum of a set of numeric values. Any `null` values are excluded from the calculation. `sum(null)` returns null.

```
SELECT *
FROM cypher('graph_name', $$
MATCH (n:Person)
RETURN sum(n.age)
$$) as (total_age agtype);

 total_age
-----------
 90
(1 row)
```

The sum of all the values in the property `age` is returned.

F.3.28. User-Defined Functions

Users may add custom functions to apache_age. When using Cypher functions, all function calls with a Cypher query use the default namespace of: `ag_catalog`. However, if a user wants to use a function outside of this namespace, they may do so by adding the namespace before the function name.

Syntax: *`namespace_name.function_name`*

```
SELECT *
FROM cypher('graph_name', $$
RETURN pg_catalog.sqrt(25)
$$) as (result agtype);

 result
--------
 25
(1 row)
```

F.3.29. apache_age Beyond Cypher

All queries so far have followed the same pattern: a `SELECT` clause followed by a single Cypher call in the `FROM` clause. However, a Cypher query can be used in many other ways. This section highlights some more advanced ways of using the Cypher call within a more complex SQL/Cypher Hybrid Query.

F.3.29.1. Using Cypher in a CTE Expression

There are no restrictions to using Cypher with CTEs (Common Table Expression).

```
WITH graph_query as (
    SELECT *
        FROM cypher('graph_name', $$
        MATCH (n)
        RETURN n.name, n.age
    $$) as (name agtype, age agtype)
)
SELECT * FROM graph_query;

 name       | age
------------+-----
 "Andres"   | 36
 "Tobias"   | 25
 "Peter"    | 35
(3 rows)
```

F.3.29.2. Using Cypher in a Join expression

A Cypher query can be part of a `JOIN` clause.

> **Note**
>
> Cypher queries using the CREATE, SET, REMOVE clauses cannot be used in SQL queries with joins, as they affect the Postgres Pro transaction system. One possible solution is to protect the query with CTEs.

```
SELECT id,
    graph_query.name = t.name as names_match,
    graph_query.age = t.age as ages_match
FROM schema_name.sql_person AS t
JOIN cypher('graph_name', $$
        MATCH (n:Person)
        RETURN n.name, n.age, id(n)
$$) as graph_query(name agtype, age agtype, id agtype)
ON t.person_id = graph_query.id;

 id | names_match | ages_match
 ---+-------------+------------
 1  | True        | True
 2  | False       | True
 3  | True        | False
(3 rows)
```

F.3.29.3. Cypher in SQL Expressions

Cypher cannot be used in an expression, the query must exists in the FROM clause of a query. However, if the Cypher query is placed in a subquery, it will behave as any SQL style query.

F.3.29.3.1. Using Cypher with =

When writing a Cypher query that is known to return one column and one row, the = comparison operator may be used.

```
SELECT t.name FROM schema_name.sql_person AS t
where t.name = (
    SELECT a
    FROM cypher('graph_name', $$
          MATCH (v)
        RETURN v.name
    $$) as (name varchar(50))
    ORDER BY name
    LIMIT 1);

   name   | age
----------+-----
 "Andres" | 36
(1 rows)
```

F.3.29.3.2. Working with Postgres Pro IN Clause

When writing a Cypher query that is known to return one column but may have multiple rows, the IN operator may be used.

```
SELECT t.name, t.age FROM schema_name.sql_person as t
where t.name in (
    SELECT *
    FROM cypher('graph_name', $$
        MATCH (v:Person)
        RETURN v.name
    $$) as (a agtype));
```

```
  name     | age
-----------+-----
 "Andres"  | 36
 "Tobias"  | 25
 "Peter"   | 35
(3 rows)
```

F.3.29.3.3. Working with Postgres Pro EXISTS Clause

When writing a Cypher query that may have more than one column and row returned, the `EXISTS` operator may be used.

```
SELECT t.name, t.age
FROM schema_name.sql_person as t
WHERE EXISTS (
    SELECT *
    FROM cypher('graph_name', $$
      MATCH (v:Person)
        RETURN v.name, v.age
    $$) as (name agtype, age agtype)
    WHERE name = t.name AND age = t.age
);

   name    | age
-----------+-----
 "Andres"  | 36
 "Tobias"  | 25
 "Peter"   | 35
(3 rows)
```

F.3.29.3.4. Querying Multiple Graphs

There is no restriction to the number of graphs an SQL statement can query. Users may query multiple graphs simultaneously.

```
SELECT graph_1.name, graph_1.age, graph_2.license_number
FROM cypher('graph_1', $$
    MATCH (v:Person)
    RETURN v.name, v.age
$$) as graph_1(col_1 agtype, col_2 agtype, col_3 agtype)
JOIN cypher('graph_2', $$
    MATCH (v:Doctor)
    RETURN v.name, v.license_number
$$) as graph_2(name agtype, license_number agtype)
ON graph_1.name = graph_2.name

   name    | age | license_number
-----------+-----+----------------
 "Andres"  | 36  | 1234567890
(1 rows)
```

F.3.29.4. Prepared Statements

Cypher can run a read query within a prepared statement. When using parameters with stored procedures, an SQL parameter must be placed in the Cypher function call. See The apache_age Query Format for details.

A Cypher parameter is in the format of a "$" followed by an identifier. Unlike Postgres Pro parameters, Cypher parameters start with a letter, followed by an alphanumeric string of arbitrary length. Example: *$parameter_name*

Preparing prepared statements in Cypher is an extension of Postgres Pro stored procedure system. Use the `PREPARE` clause to create a query with the Cypher function call in it. Do not place Postgres Pro style parameters in the Cypher query call, instead place Cypher parameters in the query and place a Postgres Pro parameter as the third argument in the Cypher function call.

```
PREPARE cypher_stored_procedure(agtype) AS
SELECT *
FROM cypher('expr', $$
    MATCH (v:Person)
    WHERE v.name = $name //Cypher parameter
    RETURN v
$$, $1) //An SQL Parameter must be placed in the Cypher function call
AS (v agtype);
```

When executing the prepared statement, place an `agtype map` with the parameter values where the Postgres Pro parameter in the Cypher function call is. The value must be an `agtype map` or an error will be thrown. Exclude the `$` for parameter names.

```
EXECUTE cypher_prepared_statement('{'name': 'Tobias'}');
```

F.3.29.5. PL/pgSQL Functions

Cypher commands can be run in PL/pgSQL functions without restriction.

```
SELECT *
FROM cypher('imdb', $$
    CREATE (toby:actor {name: 'Toby Maguire'}),
         (tom:actor {name: 'Tom Holland'}),
         (willam:actor {name: 'Willam Dafoe'}),
         (robert:actor {name: 'Robert Downey Jr'}),
         (spiderman:movie {title: 'Spiderman'}),
         (no_way_home:movie {title: 'Spiderman: No Way Home'}),
         (homecoming:movie {title: 'Spiderman: Homecoming'}),
         (ironman:movie {title: 'Ironman'}),
         (tropic_thunder:movie {title: 'Tropic Thunder'}),
         (toby)-[:acted_in {role: 'Peter Parker', alter_ego: 'Spiderman'}]->(spiderman),
         (willam)-[:acted_in {role: 'Norman Osborn', alter_ego: 'Green Goblin'}]-
>(spiderman),
         (toby)-[:acted_in {role: 'Toby Maguire'}]->(tropic_thunder),
         (robert)-[:acted_in {role: 'Kirk Lazarus'}]->(tropic_thunder),
         (robert)-[:acted_in {role: 'Tony Stark', alter_ego: 'Ironman'}]->(homecoming),
         (tom)-[:acted_in {role: 'Peter Parker', alter_ego: 'Spiderman'}]->(homecoming),
         (tom)-[:acted_in {role: 'Peter Parker', alter_ego: 'Spiderman'}]-
>(no_way_home),
         (toby)-[:acted_in {role: 'Peter Parker', alter_ego: 'Spiderman'}]-
>(no_way_home),
         (willam)-[:acted_in {role: 'Norman Osborn', alter_ego: 'Green Goblin'}]-
>(no_way_home)
$$) AS (a agtype);
```

The example of function creation is shown below.

```
CREATE OR REPLACE FUNCTION get_all_actor_names()
RETURNS TABLE(actor agtype)
LANGUAGE plpgsql
AS $BODY$
BEGIN
    LOAD 'age';
    SET search_path TO ag_catalog;
```

```
    RETURN QUERY
    SELECT *
    FROM ag_catalog.cypher('imdb', $$
        MATCH (v:actor)
        RETURN v.name
    $$) AS (a agtype);
END
$BODY$;
```

Execute the query:

```
SELECT * FROM get_all_actor_names();

       actor
--------------------
 "Toby Maguire"
 "Tom Holland"
 "Willam Dafoe"
 "Robert Downey Jr"
(4 rows)
```

> **Note**
>
> It is recommended to add the `LOAD 'age'` command and setting the `search_path` to the function declaration to ensure that the `CREATE FUNCTION` command works consistently.

F.3.29.5.1. Dynamic Cypher Example

```
CREATE OR REPLACE FUNCTION get_actors_who_played_role(role agtype)
RETURNS TABLE(actor agtype, movie agtype)
LANGUAGE plpgsql
AS $function$
DECLARE sql VARCHAR;
BEGIN
        load 'age';
        SET search_path TO ag_catalog;

        sql := format('
        SELECT *
        FROM cypher(''imdb'', $$
            MATCH (actor)-[:acted_in {role: %s}]->(movie:movie)
            RETURN actor.name, movie.title
        $$) AS (actor agtype, movie agtype);
    ', role);

        RETURN QUERY EXECUTE sql;

END
$function$;
```

```
SELECT * FROM get_actors_who_played_role('"Peter Parker"');

     actor      |          movie
----------------+-------------------------
 "Toby Maguire" | "Spiderman: No Way Home"
 "Toby Maguire" | "Spiderman"
 "Tom Holland"  | "Spiderman: Homecoming"
 "Tom Holland"  | "Spiderman: No Way Home"
```

```
(4 rows)
```

F.3.29.6. SQL in Cypher

apache_age does not support SQL being directly written in Cypher. However, with user-defined functions you can write SQL queries and call them in a Cypher command.

> **Note**
>
> This applies to void and scalar-value functions only. Set returning functions are not currently supported.

Create a function:

```
CREATE OR REPLACE FUNCTION public.get_event_year(name agtype) returns agtype AS $$
    SELECT year::agtype
    FROM history AS h
    WHERE h.event_name = name::text
    LIMIT 1;
$$ LANGUAGE sql;
```

```
SELECT * FROM cypher('graph_name', $$
    MATCH (e:event)
    WHERE e.year < public.get_event_year(e.name)
    RETURN e.name
$$) as (n agtype);

        n
--------------------
 "Apache Con 2021"
(1 row)
```

F.4. aqo

The aqo module is a Postgres Pro Enterprise extension for cost-based query optimization. Using machine learning methods, more precisely, a modification of the k-NN algorithm, aqo improves cardinality estimation, which can optimize execution plans and, consequently, speed up query execution.

The aqo module can collect statistics on all the executed queries, excluding the queries that access system relations. The collected statistics is classified by query class. If the queries differ in their constants only, they belong to the same class. For each query class, aqo stores the cardinality quality, planning time, execution time, and execution statistics for machine learning. Based on this data, aqo builds a new query plan and uses it for the next query of the same class. aqo test runs have shown significant performance improvements for complex queries.

> **Important**
>
> Query optimization using the aqo module is not supported on standby.

aqo saves all the learning data (aqo_data), queries (aqo_query_texts), query settings (aqo_queries), and query execution statistics (aqo_query_stat) to files. When aqo starts, it loads this data to shared memory. You can access aqo data through functions and views.

> **Warning**
>
> Be aware that aqo may not work correctly right after extension upgrades that change its kernel and after Postgres Pro upgrades. Therefore, after each Postgres Pro upgrade, call `aqo_reset()`

and run `DROP EXTENSION aqo`. However, after Postgres Pro minor release upgrades to versions to 13.11/14.8/15.3 or higher a call to `aqo_reset()` is not needed as aqo is reset automatically if required.

After a minor release upgrade, also run `ALTER EXTENSION aqo UPDATE` and keep in mind that aqo downgrade is impossible.

In the event of an automatic aqo reset or manually calling `aqo_reset()`, all the machine learning data gets lost, and new learning will be needed for future aqo use. Therefore, if some data, such as query texts, may help in aqo learning, back up this data in advance.

F.4.1. Installation and Setup

The aqo extension is included into Postgres Pro Enterprise. Once you have Postgres Pro Enterprise installed, complete the following steps to enable aqo:

1. Add `aqo` to the shared_preload_libraries parameter in the `postgresql.conf` file:

   ```
   shared_preload_libraries = 'aqo'
   ```

   The `aqo` library must be preloaded at the server startup, since adaptive query optimization needs to be enabled per cluster.

2. Create the aqo extension using the following query:

   ```
   CREATE EXTENSION aqo;
   ```

Once the extension is created, you can start optimizing queries.

The command

```
DROP EXTENSION aqo;
```

will only remove aqo interface at the cluster level. aqo will still be running on all the backends while it is listed in `shared_preload_libraries` and at the server restart, will continue working in the operation mode specified in `postgresql.conf`. Besides, aqo will retain its internal state after consequent execution of `DROP EXTENSION` -> `CREATE EXTENSION`.

To remove all the data from the aqo storage, including the collected statistics, call `aqo_reset()`:

```
SELECT aqo_reset();
```

To actually disable aqo at the cluster level, do the following:

```
ALTER SYSTEM SET aqo.mode = 'disabled';
SELECT pg_reload_conf();
DROP EXTENSION aqo;
```

If you do not want aqo to be loaded at the server restart, remove the line

```
shared_preload_libraries = 'aqo'
```

from the `postgresql.conf` file.

F.4.1.1. Configuration

With the default operation mode (`controlled`), aqo does not affect query performance. Depending on your database usage model, you should choose between the following modes:

- `intelligent` — this mode auto-tunes your queries based on statistics collected per query class. See the description of the `auto_tuning` flag of the aqo_queries view for more details.
- `forced` — this mode collects statistics for all queries altogether without any classification.

- `controlled` — this mode uses the default planner for all new queries, but continues using the previously specified planning settings for already known query classes, if any.
- `learn` — this mode collects statistics on all the executed queries and updates the data for query classes without auto-tuning queries.
- `frozen` — this mode reads the collected statistics for already known query classes but does not collect any new data. You can use this mode to reduce the impact of aqo on query planning and execution.
- `disabled` — this mode disables aqo for all queries, even for the known query classes. The collected statistics and aqo settings are saved and can be used in the future. You can use this mode to temporarily disable aqo without losing the collected statistics and configuration.

To dynamically change the aqo mode in your current session, run the following command:

```
ALTER SYSTEM SET aqo.mode = 'mode';
SELECT pg_reload_conf();
```

where *mode* is the name of the operation mode to use.

F.4.2. Usage

F.4.2.1. Choosing Operation Mode for Query Optimization

If you often run queries of the same class, for example, your application limits the number of possible query classes, you can use the `intelligent` mode to improve planning for these queries. In this mode, aqo analyzes each query execution and stores statistics. Statistics on queries of different classes is stored separately. If performance is not improved after 50 iterations, the aqo extension falls back to the default query planner.

> **Note**
>
> You can view the current query plan using the standard Postgres Pro `EXPLAIN` command with the `ANALYZE` option. For details, see the Section 14.1.

Since the `intelligent` mode tries to learn separately for different query classes, aqo may fail to provide performance improvements if queries in the workload are of multiple different classes or if the classes of the queries in the workload are constantly changing. For such workloads, reset the aqo extension to the `controlled` mode, or try using the `forced` mode.

In the `forced` mode, aqo does not classify the collected statistics by query classes and tries to optimize all queries together. Therefore, aqo_query_texts, aqo_queries and aqo_query_stat views do not get updated. Machine learning data collected in any other modes is inapplicable for the `forced` mode and vice versa. This mode can help you optimize workloads with multiple different query classes, and it consumes less memory than the intelligent mode. However, since the `forced` mode lacks intelligent tuning, performance may decrease for some queries. If you see performance issues in this mode, switch aqo to the `controlled` mode.

In the `controlled` mode, aqo does not collect statistics for new query classes, so they will not be optimized. For known query classes, aqo will continue collecting statistics and using optimized planning algorithms. So use the `controlled` mode only after aqo learned in the `learn` or `intelligent` mode. As there are no query classes in the `forced` mode, switching from it to the `controlled` mode actually means disabling aqo.

The `learn` mode collects statistics from all the executed queries and updates the data for query classes. This mode is similar to the `intelligent` mode, except that it does not provide intelligent tuning.

If you want to reduce the impact of aqo on query planning and execution, you can use it in the `frozen` mode. In this mode, aqo only reads the collected statistics for already known query classes but does not collect any new data.

Switching to the `disabled` mode is the only way to actually disable aqo without losing the statistics and aqo settings, which are saved and can be used in the future. Queries in this mode will be executed as though there were no aqo at all.

F.4.2.2. Fine-Tuning aqo

You must have superuser rights to access aqo views and configure advanced query settings.

When run in the `intelligent` or `learn` mode, aqo assigns a unique hash value to each query class to separate the collected statistics. If you switch to the `forced` mode, the statistics for all untracked query classes is stored in a common query class with hash 0. You can view all the processed query classes and their corresponding hash values in the `aqo_query_texts` view:

```
SELECT * FROM aqo_query_texts;
```

To find out the class, that is, hash, of a query and aqo mode, enable `aqo.show_hash` and `aqo.show_details` environment variables and execute the query. The output will contain something like this:

```
...
Planning Time: 23.538 ms
...
Execution Time: 249813.875 ms
...
Using aqo: true
...
AQO mode: LEARN
...
Query hash: -2439501042637610315
```

Each query class has an associated separate space, called *feature space*, in which the statistics for this query class is collected. Each feature space has associated *feature subspaces*, where the information about selectivity and cardinality for each query plan node is collected.

Each query class has its own optimization settings. These settings are shown in the `aqo_queries` view:

```
SELECT * FROM aqo_queries;
```

The settings available are listed in the `aqo_queries` View table.

You can manually change these settings to adjust optimization for a particular query class. For example:

```
 -- Add a new query class into the aqo_queries view:

SET aqo.mode='intelligent';
SELECT * FROM a, b WHERE a.id=b.id;
SET aqo.mode='controlled';

 -- Disable auto_tuning, enable both learn_aqo and use_aqo
 -- for this query class:

SELECT count(*) FROM (SELECT queryid FROM aqo_queries) AS q1,
  LATERAL aqo_queries_update(q1.queryid, NULL, true, true, false) AS q2
  WHERE queryid = (SELECT queryid FROM aqo_query_texts
  WHERE query_text LIKE 'SELECT * FROM a, b WHERE a.id=b.id;');

 -- Run EXPLAIN ANALYZE until the plan changes:

EXPLAIN ANALYZE SELECT * FROM a, b WHERE a.id=b.id;
EXPLAIN ANALYZE SELECT * FROM a, b WHERE a.id=b.id;
```

```
 -- Disable learning to stop statistics collection
 -- and use the optimized plan:

 SELECT count(*) FROM (SELECT queryid FROM aqo_queries) AS q1,
  LATERAL aqo_queries_update(q1.queryid, NULL, false, true, false) AS q2
  WHERE queryid = (SELECT queryid FROM aqo_query_texts
  WHERE query_text LIKE 'SELECT * FROM a, b WHERE a.id=b.id;');
```

To stop intelligent tuning for a particular query class, disable the `auto_tuning` setting:

```
SELECT count(*) FROM (SELECT queryid FROM aqo_queries) AS q1,
  LATERAL aqo_queries_update(q1.queryid, NULL, true, true, false) AS q2
  WHERE queryid = 'hash');
```

where *hash* is the hash value for this query class. As a result, aqo disables automatic change of the `learn_aqo` and `use_aqo` settings.

To disable further learning for a particular query class, use the following command:

```
SELECT count(*) FROM (SELECT queryid FROM aqo_queries) AS q1,
  LATERAL aqo_queries_update(q1.queryid, NULL, false, true, false) AS q2
  WHERE queryid = 'hash');
```

where *hash* is the hash value for this query class.

To fully disable aqo for all queries and use the default Postgres Pro query planner, run:

```
SELECT count(*) FROM (SELECT queryid FROM aqo_queries) AS q1,
  LATERAL aqo_queries_update(q1.queryid, NULL, false, false, false) AS q2
  WHERE queryid IN (SELECT queryid FROM aqo_query_texts);
```

F.4.3. Reference

F.4.3.1. Configuration Parameters

`aqo.mode` (`text`)

Defines the aqo operation mode. Possible values are listed in Section F.4.1.1.

Default: `controlled`.

`aqo.show_hash` (`boolean`)

Show a hash value that is computed from a query tree and uniquely identifies the class of queries or class of plan nodes. Starting with Postgres Pro 14, aqo uses the native query ID to identify a query class for consistency with other extensions, such as pg_stat_statements. So, the query ID can be taken from the `Query Identifier` field in `EXPLAIN ANALYZE` output of a query.

Default: `off`.

`aqo.show_details` (`boolean`)

Add some details to `EXPLAIN` output of a query, such as the prediction or feature-subspace hash, and show some additional aqo-specific on-screen information.

Default: `off`.

`aqo.join_threshold` (`integer`)

Ignore queries that contain smaller number of joins, which means that statistics for such queries will not be collected.

Default: `3`.

`aqo.statement_timeout` (`integer`)

Defines the initial value of the *smart statement timeout*, in milliseconds, which is needed to limit the execution time when manually training aqo on special queries with a poor cardinality forecast. aqo can dynamically change the value of the smart statement timeout during this training. When the cardinality estimation error on nodes exceeds 0.1, the value of `aqo.statement_timeout` is automatically incremented exponentially, but remains not greater than statement_timeout.

Default: `0`.

`aqo.force_collect_stat` (`boolean`)

Gather statistics on query executions even in the `disabled` mode. Although no predictions are made, some overhead will be added.

Default: `off`.

`aqo.dsm_size_max` (`integer`)

Defines the maximum size of dynamic shared memory, in MB, that aqo can allocate to store learning data. When this number is exceeded, an attempt to load the aqo_data view will fail with "out of memory" error.

Default: `100`.

`aqo.fs_max_items` (`integer`)

Defines the maximum number of feature spaces that aqo can operate with. When this number is exceeded, learning on new query classes will no longer occur, and they will not appear in the views accordingly.

Default: `10000`.

`aqo.fss_max_items` (`integer`)

Defines the maximum number of feature subspaces that aqo can operate with. When this number is exceeded, the selectivity and cardinality for new query plan nodes will no longer be collected, and new feature subspaces will not appear in the aqo_data view accordingly.

Default: `100000`.

`aqo.wide_search` (`boolean`)

Enables searching neighbors with the same feature subspace among different query classes.

Default: `off`.

`aqo.querytext_max_size` (`integer`)

Defines the maximum size of the query in the aqo_query_texts view.

Default: `1000`.

`aqo.min_neighbors_for_predicting` (`integer`)

Defines the minimum number of neighbors needed for the cardinality prediction. If there are fewer of them, aqo will not make any prediction.

Default: `3`.

`aqo.predict_with_few_neighbors` (`boolean`)

Enables aqo to make predictions with fewer neighbors than were found.

Default: `on`.

F.4.3.2. Views

F.4.3.2.1. aqo_query_texts

The aqo_query_texts view classifies all the query classes processed by aqo. For each query class, the view shows the text of the first analyzed query of this class.

Table F.8. aqo_query_texts View

Column Name	Description
queryid	Stores the query ID, that is, the feature-space hash, that uniquely identifies the query class.
query_text	Provides the text of the first analyzed query of the given class.

F.4.3.2.2. aqo_queries

The aqo_queries view shows optimization settings for different query classes.

Table F.9. aqo_queries View

Setting	Description
queryid	Stores the query ID that uniquely identifies the query class.
learn_aqo	Enables statistics collection for this query class.
use_aqo	Enables the aqo cardinality prediction for the next execution of this query class. If the cost estimation model is inaccurate, this may slow down query execution.
fspace_hash	Provides a unique identifier of the separate space in which the statistics for this query class is collected. By default, fspace_hash is equal to queryid. You can change this setting to a different queryid to optimize different query classes together. It may decrease the amount of memory for models and even improve query execution performance. However, changing this setting may cause unexpected aqo behavior, so make sure to use it only if you know what you are doing.
auto_tuning	Shows whether aqo can dynamically change use_aqo and learn_aqo settings for this query class. By default, auto-tuning is only enabled in the intelligent mode. In more detail, when auto_tuning is on, if for several successive executions of a query for which use_aqo is off, the cardinality error remains sufficiently small and stable, aqo turns on use_aqo . For queries with learn_aqo =true (it is so for new queries), several first executions are done both using aqo and without it. The faster the query is executed compared to the execution with the standard planner, the more likely aqo will be used for the next query execution. If after a certain number of executions the execution time with aqo appears to be worse than with the standard planner, aqo will never be used for this query

Setting	Description
	class: auto_tuning , use_aqo and learn_aqo are set to off.
smart_timeout	Shows the value of smart statement timeout for this query class.
count_increase_timeout	Shows how many times the smart statement timeout increased for this query class.

F.4.3.2.3. aqo_data

The aqo_data view shows machine learning data for cardinality estimation refinement. To forget all the collected statistics for a particular query class, you can delete all rows from aqo_data with the corresponding fs.

Table F.10. aqo_data View

Data	Description
fs	Feature-space hash.
fss	Feature-subspace hash.
nfeatures	Feature-subspace size for the query plan node.
features	Logarithm of the selectivity which the cardinality prediction is based on.
targets	Cardinality logarithm for the query plan node.
reliability	Equals: • 1 — indicates data obtained after normal execution of a query • 0.1 — indicates data obtained from a partially executed node (not needed as unreliable) • 0.9 — indicates data obtained from a finished node, but from a partially executed statement
oids	List of IDs of tables that were involved in the prediction for this node.

F.4.3.2.4. aqo_query_stat

The aqo_query_stat view shows statistics on query execution, by query class. The aqo extension uses this data when the auto_tuning option is enabled for a particular query class.

Table F.11. aqo_query_stat View

Data	Description
execution_time_with_aqo	Execution time for queries run with aqo enabled.
execution_time_without_aqo	Execution time for queries run with aqo disabled.
planning_time_with_aqo	Planning time for queries run with aqo enabled.
planning_time_without_aqo	Planning time for queries run with aqo disabled.
cardinality_error_with_aqo	Cardinality estimation error in the selected query plans with aqo enabled.
cardinality_error_without_aqo	Cardinality estimation error in the selected query plans with aqo disabled.
executions_with_aqo	Number of queries run with aqo enabled.
executions_without_aqo	Number of queries run with aqo disabled.

F.4.3.3. Functions

aqo adds several functions to Postgres Pro catalog.

F.4.3.3.1. Storage Management Functions

> **Important**
>
> Functions `aqo_queries_update`, `aqo_query_texts_update`, `aqo_query_stat_update`, and `aqo_data_update` modify data files underlying aqo views. Therefore, call these functions only if you understand the logic of adaptive query optimization.

`aqo_cleanup()` → `setof integer`

Removes data related to query classes that are linked (may be partially) with removed relations. Returns the number of removed feature spaces (classes) and feature subspaces. Insensitive to removing other objects.

`aqo_enable_class (`*`queryid`* `bigint)` → `void`

Sets `learn_aqo`, `use_aqo` and `auto_tuning` (only in the `intelligent` mode) to true for a given query class.

`aqo_disable_class (`*`queryid`* `bigint)` → `void`

Sets `learn_aqo`, `use_aqo` and `auto_tuning` (only in the `intelligent` mode) to false for a given query class.

`aqo_drop_class (`*`queryid`* `bigint)` → `integer`

Removes all data related to a given query class from the aqo storage. Returns the number of records removed from the aqo storage.

`aqo_reset()` → `bigint`

Removes data from the aqo storage: machine learning data, query texts, statistics and query class preferences. Returns the number of records removed from the aqo storage.

`aqo_queries_update (`*`queryid`* `bigint,` *`fs`* `bigint,` *`learn_aqo`* `boolean,` *`use_aqo`* `boolean,` *`auto_tuning`* `boolean)` → `boolean`

Assigns new values to the following settings in the aqo_queries view for a given query class: `fspace_hash`, `learn_aqo`, `use_aqo` and `auto_tuning`. NULL value means “leave as is”.

`aqo_query_texts_update (`*`queryid`* `bigint,` *`query_text`* `text)` → `boolean`

Updates or inserts a record in a data file underlying the aqo_query_texts view for a given *`queryid`*.

`aqo_query_stat_update (`*`queryid`* `bigint,` *`execution_time_with_aqo`* `double precision[],` *`execution_time_without_aqo`* `double precision[],` *`planning_time_with_aqo`* `double precision[],` *`planning_time_without_aqo`* `double precision[],` *`cardinality_error_with_aqo`* `double precision[],` *`cardinality_error_without_aqo`* `double precision[],` *`executions_with_aqo`* `bigint[],` *`executions_without_aqo`* `bigint[])` → `boolean`

Updates or inserts a record in a data file underlying the aqo_query_stat view for a given *`queryid`*.

`aqo_data_update (`*`fs`* `bigint,` *`fss`* `integer,` *`nfeatures`* `integer,` *`features`* `double precision[][],` *`targets`* `double precision[],` *`reliability`* `double precision[],` *`oids`* `oid[])` → `boolean`

Updates or inserts a record in a data file underlying the aqo_data view for given *`fs`* and *`fss`*.

F.4.3.3.2. Memory Management Functions

`aqo_memory_usage` () → `setof record`

Displays sizes of aqo memory contexts and hash tables.

F.4.3.3.3. Analytics Functions

`aqo_cardinality_error` (*`controlled`* `boolean`) → `setof record`

Shows the cardinality error for each query class. If *`controlled`* is true, shows the error of the last execution with aqo enabled. If *`controlled`* is false, returns the average cardinality error for all logged executions with aqo disabled.

`aqo_execution_time` (*`controlled`* `boolean`) → `setof record`

Shows the execution time for each query class. If *`controlled`* is true, shows the execution time of the last execution with aqo enabled. If *`controlled`* is false, returns the average execution time for all logged executions with aqo disabled.

F.4.4. Examples

Example F.1. Learning on a Query

Consider optimization of a query using aqo.

When the query is executed for the first time, it is missing in tables underlying aqo views. So there is no data for predicting with aqo for each plan node, and "AQO not used" lines appear in the `EXPLAIN` output:

```
postgres=# EXPLAIN (ANALYZE, SUMMARY OFF, TIMING OFF) select count(*) from score join
 course on score.cno=course.cno join student on score.sno=student.sno where degree<90
 and test_preparation = 0;
                                                 QUERY PLAN
-------------------------------------------------------------------------------------------
 Aggregate  (cost=308.28..308.29 rows=1 width=8) (actual rows=1 loops=1)
   AQO not used, fss=0
   ->  Hash Join  (cost=124.80..299.47 rows=3526 width=0) (actual rows=3649 loops=1)
         AQO not used, fss=2128507884
         Hash Cond: (score.sno = student.sno)
         ->  Hash Join  (cost=16.30..181.70 rows=3526 width=4) (actual rows=3649
 loops=1)
               AQO not used, fss=-303037802
               Hash Cond: (score.cno = course.cno)
               ->  Seq Scan on score  (cost=0.00..156.00 rows=3526 width=8) (actual
 rows=3649 loops=1)
                     AQO not used, fss=-636613046
                     Filter: ((degree < 90) AND (test_preparation = 0))
                     Rows Removed by Filter: 1351
               ->  Hash  (cost=12.80..12.80 rows=280 width=4) (actual rows=10 loops=1)
                     Buckets: 1024  Batches: 1  Memory Usage: 9kB
                     ->  Seq Scan on course  (cost=0.00..12.80 rows=280 width=4)
 (actual rows=10 loops=1)
                           AQO not used, fss=-1076069505
         ->  Hash  (cost=71.00..71.00 rows=3000 width=4) (actual rows=3000 loops=1)
               Buckets: 4096  Batches: 1  Memory Usage: 138kB
               ->  Seq Scan on student  (cost=0.00..71.00 rows=3000 width=4) (actual
 rows=3000 loops=1)
                     AQO not used, fss=-1838231581
 Using aqo: true
 AQO mode: LEARN
 Query hash: -727505571757520766
```

```
 JOINS: 2
(24 rows)
```

If there is no information on a certain node in the aqo_data view, aqo will add the appropriate record there for future learning and predictions except for nodes with `fss=0` in the `EXPLAIN` output. As each of `features` and `targets` in the `aqo_data` view is a logarithm to base `e`, to get the actual value, raise `e` to this power. For example: exp(0):

```
         fs          |     fss     | nfeatures |
 features                                      |       targets       | reliability |
     oids
---------------------+-------------+-----------
+-------------------------------------------------------------------------------------
+---------------------+-------------+---------------------
 -727505571757520766 |  2128507884 |         4 |
 {{-0.03438753143452488,-5.634789603169249,-0.3149847743198556,-8.006367567650246}} |
 {8.202208436436448} | {1}         | {16579,16555,16563}
 -727505571757520766 | -1076069505 |         0 |
                                                  | {2.302585092994046} | {1}         |
 {16555}
 -727505571757520766 | -1838231581 |         0 |
                                                  | {8.006367567650246} | {1}         |
 {16563}
 -727505571757520766 |  -303037802 |         3 |
 {{-0.03438753143452488,-5.634789603169249,-0.3149847743198556}}                      |
 {8.202208436436448} | {1}         | {16579,16555}
 -727505571757520766 |  -636613046 |         2 |
 {{-0.03438753143452488,-0.3149847743198556}}                                         |
 {8.202208436436448} | {1}         | {16579}
(6 rows)
```

When the query is executed for the second time, aqo recognizes the query and makes a prediction. Pay attention to the cardinality predicted by aqo and the value of aqo error (“error=0%”).

```
postgres=# EXPLAIN (ANALYZE, SUMMARY OFF, TIMING OFF) select count(*) from score join
 course on score.cno=course.cno join student on score.sno=student.sno where degree<90
 and test_preparation = 0;
                                                QUERY PLAN
-----------------------------------------------------------------------------------------
 Aggregate  (cost=305.86..305.87 rows=1 width=8) (actual rows=1 loops=1)
   AQO not used, fss=0
   ->  Hash Join  (cost=121.42..296.74 rows=3649 width=0) (actual rows=3649 loops=1)
         AQO: rows=3649, error=0%, fss=2128507884
         Hash Cond: (score.sno = student.sno)
         ->  Hash Join  (cost=12.93..178.65 rows=3649 width=4) (actual rows=3649
 loops=1)
               AQO: rows=3649, error=0%, fss=-303037802
               Hash Cond: (score.cno = course.cno)
               ->  Seq Scan on score  (cost=0.00..156.00 rows=3649 width=8) (actual
 rows=3649 loops=1)
                     AQO: rows=3649, error=0%, fss=-636613046
                     Filter: ((degree < 90) AND (test_preparation = 0))
                     Rows Removed by Filter: 1351
               ->  Hash  (cost=12.80..12.80 rows=10 width=4) (actual rows=10 loops=1)
                     Buckets: 1024  Batches: 1  Memory Usage: 9kB
                     ->  Seq Scan on course  (cost=0.00..12.80 rows=10 width=4) (actual
 rows=10 loops=1)
                           AQO: rows=10, error=0%, fss=-1076069505
         ->  Hash  (cost=71.00..71.00 rows=3000 width=4) (actual rows=3000 loops=1)
```

```
               Buckets: 4096  Batches: 1  Memory Usage: 138kB
               ->  Seq Scan on student  (cost=0.00..71.00 rows=3000 width=4) (actual
 rows=3000 loops=1)
                     AQO: rows=3000, error=0%, fss=-1838231581
 Using aqo: true
 AQO mode: LEARN
 Query hash: -727505571757520766
 JOINS: 2
(24 rows)
```

In case of an error, values of `features` and `targets` must change, but as there was no error above, they did not change.

```
         fs          |     fss     | nfeatures |
 features                                      |       targets       | reliability |
     oids
---------------------+-------------+-----------
+-------------------------------------------------------------------------------
+---------------------+-------------+---------------------
 -727505571757520766 |  2128507884 |         4 |
 {{-0.03438753143452488,-5.634789603169249,-0.3149847743198556,-8.006367567650246}} |
 {8.202208436436448} | {1}         | {16579,16555,16563}
 -727505571757520766 | -1076069505 |         0 |
                                                | {2.302585092994046} | {1}         |
 {16555}
 -727505571757520766 | -1838231581 |         0 |
                                                | {8.006367567650246} | {1}         |
 {16563}
 -727505571757520766 |  -303037802 |         3 |
 {{-0.03438753143452488,-5.634789603169249,-0.3149847743198556}}                     |
 {8.202208436436448} | {1}         | {16579,16555}
 -727505571757520766 |  -636613046 |         2 |
 {{-0.03438753143452488,-0.3149847743198556}}                                        |
 {8.202208436436448} | {1}         | {16579}
(6 rows)
```

Let's change a constant in the query, and you will notice that the prediction is made with an error:

```
    postgres=# EXPLAIN (ANALYZE, SUMMARY OFF, TIMING OFF) select count(*) from score
 join course on score.cno=course.cno join student on score.sno=student.sno where
 degree<80 and test_preparation = 0;
                                                    QUERY PLAN
-------------------------------------------------------------------------------------------------
 Aggregate  (cost=305.86..305.87 rows=1 width=8) (actual rows=1 loops=1)
   AQO not used, fss=0
   ->  Hash Join  (cost=121.42..296.74 rows=3649 width=0) (actual rows=3551 loops=1)
         AQO: rows=3649, error=3%, fss=2128507884
         Hash Cond: (score.sno = student.sno)
         ->  Hash Join  (cost=12.93..178.65 rows=3649 width=4) (actual rows=3551
 loops=1)
               AQO: rows=3649, error=3%, fss=-303037802
               Hash Cond: (score.cno = course.cno)
               ->  Seq Scan on score  (cost=0.00..156.00 rows=3649 width=8) (actual
 rows=3551 loops=1)
                     AQO: rows=3649, error=3%, fss=-636613046
                     Filter: ((degree < 80) AND (test_preparation = 0))
                     Rows Removed by Filter: 1449
               ->  Hash  (cost=12.80..12.80 rows=10 width=4) (actual rows=10 loops=1)
                     Buckets: 1024  Batches: 1  Memory Usage: 9kB
```

```
                      ->  Seq Scan on course  (cost=0.00..12.80 rows=10 width=4) (actual
 rows=10 loops=1)
                            AQO: rows=10, error=0%, fss=-1076069505
         ->  Hash  (cost=71.00..71.00 rows=3000 width=4) (actual rows=3000 loops=1)
               Buckets: 4096  Batches: 1  Memory Usage: 138kB
               ->  Seq Scan on student  (cost=0.00..71.00 rows=3000 width=4) (actual
 rows=3000 loops=1)
                     AQO: rows=3000, error=0%, fss=-1838231581
 Using aqo: true
 AQO mode: LEARN
 Query hash: -727505571757520766
 JOINS: 2
(24 rows)
```

However, instead of recalculating `features` and `targets`, aqo added new values of selectivity and cardinality for this query to `aqo_data`:

```
         fs           |     fss     | nfeatures |
                                          features
                                            |                targets                 |
 reliability |        oids
---------------------+-------------+-----------
+-----------------------------------------------------------------------------------------
+--------------------------------------+-------------+---------------------
 -727505571757520766 |  1141621836 |         0 |

                                         | {0}                                     | {1}
       | {16579,16555,16563}
 -727505571757520766 |  2128507884 |         4 |
 {{-0.030949078292235133,-5.634789603169249,-0.3149847743198556,-8.006367567650246},
{-0.34221288089027607,-5.634789603169249,-0.3149847743198556,-8.006367567650246}} |
 {8.202208436436448,8.174984532943087} | {1,1}       | {16579,16555,16563}
 -727505571757520766 | -1076069505 |         0 |

                                         | {2.302585092994046}                     | {1}
       | {16555}
 -727505571757520766 | -1838231581 |         0 |

                                         | {8.006367567650246}                     | {1}
       | {16563}
 -727505571757520766 |  -303037802 |         3 |
 {{-0.030949078292235133,-5.634789603169249,-0.3149847743198556},
{-0.34221288089027607,-5.634789603169249,-0.3149847743198556}}
              | {8.202208436436448,8.174984532943087} | {1,1}       | {16579,16555}
 -727505571757520766 |  -636613046 |         2 |
 {{-0.030949078292235133,-0.3149847743198556},
{-0.34221288089027607,-0.3149847743198556}}
```

Now the prediction has no error:

```
postgres=# EXPLAIN (ANALYZE, SUMMARY OFF, TIMING OFF) select count(*) from score join
 course on score.cno=course.cno join student on score.sno=student.sno where degree<80
 and test_preparation = 0;
                                                QUERY PLAN
-----------------------------------------------------------------------------------------
 Aggregate  (cost=305.10..305.11 rows=1 width=8) (actual rows=1 loops=1)
   AQO not used, fss=0
   ->  Hash Join  (cost=121.42..296.22 rows=3551 width=0) (actual rows=3551 loops=1)
```

```
        AQO: rows=3551, error=0%, fss=2128507884
        Hash Cond: (score.sno = student.sno)
        ->  Hash Join  (cost=12.93..178.39 rows=3551 width=4) (actual rows=3551
 loops=1)
              AQO: rows=3551, error=0%, fss=-303037802
              Hash Cond: (score.cno = course.cno)
              ->  Seq Scan on score  (cost=0.00..156.00 rows=3551 width=8) (actual
 rows=3551 loops=1)
                    AQO: rows=3551, error=0%, fss=-636613046
                    Filter: ((degree < 80) AND (test_preparation = 0))
                    Rows Removed by Filter: 1449
              ->  Hash  (cost=12.80..12.80 rows=10 width=4) (actual rows=10 loops=1)
                    Buckets: 1024  Batches: 1  Memory Usage: 9kB
                    ->  Seq Scan on course  (cost=0.00..12.80 rows=10 width=4) (actual
 rows=10 loops=1)
                          AQO: rows=10, error=0%, fss=-1076069505
        ->  Hash  (cost=71.00..71.00 rows=3000 width=4) (actual rows=3000 loops=1)
              Buckets: 4096  Batches: 1  Memory Usage: 138kB
              ->  Seq Scan on student  (cost=0.00..71.00 rows=3000 width=4) (actual
 rows=3000 loops=1)
                    AQO: rows=3000, error=0%, fss=-1838231581
 Using aqo: true
 AQO mode: LEARN
 Query hash: -727505571757520766
 JOINS: 2
(24 rows)
```

Example F.2. Using the aqo_query_stat View

The `aqo_query_stats` view shows statistics on the query planning time, query execution time and cardinality error. Based on this data you can make a decision whether to use aqo predictions for different query classes.

Let's query the `aqo_query_stats` view:

```
select queryid, cardinality_error_with_aqo,
 cardinality_error_without_aqo,execution_time_with_aqo, execution_time_without_aqo,
 planning_time_with_aqo, planning_time_without_aqo from aqo_query_stat \gx
-[ RECORD 1 ]-----------------
+-----------------------------------------------------------------------------------------------
queryid                        | 8041624334006338922
cardinality_error_with_aqo     |
 {0.14932737556062836,0,0.507421202801325,0.00040469447777891077}
cardinality_error_without_aqo | {0.1493979460962751,0.018403615483185476}
execution_time_with_aqo        | {0.004760108,0.008743075,0.006608304,0.012392751}
execution_time_without_aqo     | {0.005775926,0.012730316}
planning_time_with_aqo         | {0.006927997,0.004247339,0.005005022,0.004169717}
planning_time_without_aqo      | {0.001783542,0.001706121}
```

The retrieved data is for the query from Example F.1, which was executed once without aqo for each of the parameters `degree<80` and `degree<90` and twice with aqo for each of these parameters. It is clear that with aqo, the cardinality error decreases to 0.0004, while the minimum cardinality error without aqo is 0.15. Besides, the execution time with aqo is lower than without it. So the conclusion is that aqo learns well on this query, and the prediction can be used for this query class.

F.4.5. Author

Oleg Ivanov

F.5. auth_delay

auth_delay causes the server to pause briefly before reporting authentication failure, to make brute-force attacks on database passwords more difficult. Note that it does nothing to prevent denial-of-service attacks, and may even exacerbate them, since processes that are waiting before reporting authentication failure will still consume connection slots.

In order to function, this module must be loaded via shared_preload_libraries in postgresql.conf.

F.5.1. Configuration Parameters

auth_delay.milliseconds (int)

The number of milliseconds to wait before reporting an authentication failure. The default is 0.

These parameters must be set in postgresql.conf. Typical usage might be:

```
# postgresql.conf
shared_preload_libraries = 'auth_delay'

auth_delay.milliseconds = '500'
```

F.5.2. Author

KaiGai Kohei <kaigai@ak.jp.nec.com>

F.6. auto_explain

The auto_explain module provides a means for logging execution plans of slow statements automatically, without having to run EXPLAIN by hand. This is especially helpful for tracking down un-optimized queries in large applications.

The module provides no SQL-accessible functions. To use it, simply load it into the server. You can load it into an individual session:

```
LOAD 'auto_explain';
```

(You must be superuser to do that.) More typical usage is to preload it into some or all sessions by including auto_explain in session_preload_libraries or shared_preload_libraries in postgresql.conf. Then you can track unexpectedly slow queries no matter when they happen. Of course there is a price in overhead for that.

F.6.1. Configuration Parameters

There are several configuration parameters that control the behavior of auto_explain. Note that the default behavior is to do nothing, so you must set at least auto_explain.log_min_duration if you want any results.

auto_explain.log_min_duration (integer)

auto_explain.log_min_duration is the minimum statement execution time, in milliseconds, that will cause the statement's plan to be logged. Setting this to 0 logs all plans. -1 (the default) disables logging of plans. For example, if you set it to 250ms then all statements that run 250ms or longer will be logged. Only superusers can change this setting.

auto_explain.log_analyze (boolean)

auto_explain.log_analyze causes EXPLAIN ANALYZE output, rather than just EXPLAIN output, to be printed when an execution plan is logged. This parameter is off by default. Only superusers can change this setting.

> **Note**
>
> When this parameter is on, per-plan-node timing occurs for all statements executed, whether or not they run long enough to actually get logged. This can have an extremely negative impact

on performance. Turning off auto_explain.log_timing ameliorates the performance cost, at the price of obtaining less information.

auto_explain.log_buffers (boolean)

auto_explain.log_buffers controls whether buffer usage statistics are printed when an execution plan is logged; it's equivalent to the BUFFERS option of EXPLAIN. This parameter has no effect unless auto_explain.log_analyze is enabled. This parameter is off by default. Only superusers can change this setting.

auto_explain.log_wal (boolean)

auto_explain.log_wal controls whether WAL usage statistics are printed when an execution plan is logged; it's equivalent to the WAL option of EXPLAIN. This parameter has no effect unless auto_explain.log_analyze is enabled. This parameter is off by default. Only superusers can change this setting.

auto_explain.log_timing (boolean)

auto_explain.log_timing controls whether per-node timing information is printed when an execution plan is logged; it's equivalent to the TIMING option of EXPLAIN. The overhead of repeatedly reading the system clock can slow down queries significantly on some systems, so it may be useful to set this parameter to off when only actual row counts, and not exact times, are needed. This parameter has no effect unless auto_explain.log_analyze is enabled. This parameter is on by default. Only superusers can change this setting.

auto_explain.log_triggers (boolean)

auto_explain.log_triggers causes trigger execution statistics to be included when an execution plan is logged. This parameter has no effect unless auto_explain.log_analyze is enabled. This parameter is off by default. Only superusers can change this setting.

auto_explain.log_verbose (boolean)

auto_explain.log_verbose controls whether verbose details are printed when an execution plan is logged; it's equivalent to the VERBOSE option of EXPLAIN. This parameter is off by default. Only superusers can change this setting.

auto_explain.log_settings (boolean)

auto_explain.log_settings controls whether information about modified configuration options is printed when an execution plan is logged. Only options affecting query planning with value different from the built-in default value are included in the output. This parameter is off by default. Only superusers can change this setting.

auto_explain.log_format (enum)

auto_explain.log_format selects the EXPLAIN output format to be used. The allowed values are text, xml, json, and yaml. The default is text. Only superusers can change this setting.

auto_explain.log_level (enum)

auto_explain.log_level selects the log level at which auto_explain will log the query plan. Valid values are DEBUG5, DEBUG4, DEBUG3, DEBUG2, DEBUG1, INFO, NOTICE, WARNING, and LOG. The default is LOG. Only superusers can change this setting.

auto_explain.log_nested_statements (boolean)

auto_explain.log_nested_statements causes nested statements (statements executed inside a function) to be considered for logging. When it is off, only top-level query plans are logged. This parameter is off by default. Only superusers can change this setting.

`auto_explain.sample_rate` (`real`)

`auto_explain.sample_rate` causes auto_explain to only explain a fraction of the statements in each session. The default is 1, meaning explain all the queries. In case of nested statements, either all will be explained or none. Only superusers can change this setting.

In ordinary usage, these parameters are set in `postgresql.conf`, although superusers can alter them on-the-fly within their own sessions. Typical usage might be:

```
# postgresql.conf
session_preload_libraries = 'auto_explain'

auto_explain.log_min_duration = '3s'
```

F.6.2. Example

```
postgres=# LOAD 'auto_explain';
postgres=# SET auto_explain.log_min_duration = 0;
postgres=# SET auto_explain.log_analyze = true;
postgres=# SELECT count(*)
           FROM pg_class, pg_index
           WHERE oid = indrelid AND indisunique;
```

This might produce log output such as:

```
LOG:  duration: 0.196 ms planning: 0.548 ms plan:
  Query Text: SELECT count(*)
              FROM pg_class, pg_index
              WHERE oid = indrelid AND indisunique;
  Aggregate  (cost=16.79..16.80 rows=1 width=0) (actual time=3.626..3.627 rows=1
 loops=1)
    ->  Hash Join  (cost=4.17..16.55 rows=92 width=0) (actual time=3.349..3.594 rows=92
 loops=1)
          Hash Cond: (pg_class.oid = pg_index.indrelid)
          ->  Seq Scan on pg_class  (cost=0.00..9.55 rows=255 width=4) (actual
 time=0.016..0.140 rows=255 loops=1)
          ->  Hash  (cost=3.02..3.02 rows=92 width=4) (actual time=3.238..3.238 rows=92
 loops=1)
                Buckets: 1024  Batches: 1  Memory Usage: 4kB
                ->  Seq Scan on pg_index  (cost=0.00..3.02 rows=92 width=4) (actual
 time=0.008..3.187 rows=92 loops=1)
                      Filter: indisunique
```

Note that Postgres Pro added a new field to the output to show planning time.

F.6.3. Authors

Takahiro Itagaki <itagaki.takahiro@oss.ntt.co.jp>

Postgres Professional, Moscow, Russia

F.7. bloom

`bloom` provides an index access method based on *Bloom filters*.

A Bloom filter is a space-efficient data structure that is used to test whether an element is a member of a set. In the case of an index access method, it allows fast exclusion of non-matching tuples via signatures whose size is determined at index creation.

A signature is a lossy representation of the indexed attribute(s), and as such is prone to reporting false positives; that is, it may be reported that an element is in the set, when it is not. So index search results must always be rechecked using the actual attribute values from the heap entry. Larger signatures

reduce the odds of a false positive and thus reduce the number of useless heap visits, but of course also make the index larger and hence slower to scan.

This type of index is most useful when a table has many attributes and queries test arbitrary combinations of them. A traditional btree index is faster than a bloom index, but it can require many btree indexes to support all possible queries where one needs only a single bloom index. Note however that bloom indexes only support equality queries, whereas btree indexes can also perform inequality and range searches.

F.7.1. Parameters

A `bloom` index accepts the following parameters in its `WITH` clause:

`length`

Length of each signature (index entry) in bits. It is rounded up to the nearest multiple of `16`. The default is `80` bits and the maximum is `4096`.

`col1 — col32`

Number of bits generated for each index column. Each parameter's name refers to the number of the index column that it controls. The default is `2` bits and the maximum is `4095`. Parameters for index columns not actually used are ignored.

F.7.2. Examples

This is an example of creating a bloom index:

```
CREATE INDEX bloomidx ON tbloom USING bloom (i1,i2,i3)
       WITH (length=80, col1=2, col2=2, col3=4);
```

The index is created with a signature length of 80 bits, with attributes i1 and i2 mapped to 2 bits, and attribute i3 mapped to 4 bits. We could have omitted the `length`, `col1`, and `col2` specifications since those have the default values.

Here is a more complete example of bloom index definition and usage, as well as a comparison with equivalent btree indexes. The bloom index is considerably smaller than the btree index, and can perform better.

```
=# CREATE TABLE tbloom AS
   SELECT
     (random() * 1000000)::int as i1,
     (random() * 1000000)::int as i2,
     (random() * 1000000)::int as i3,
     (random() * 1000000)::int as i4,
     (random() * 1000000)::int as i5,
     (random() * 1000000)::int as i6
   FROM
  generate_series(1,10000000);
SELECT 10000000
```

A sequential scan over this large table takes a long time:

```
=# EXPLAIN ANALYZE SELECT * FROM tbloom WHERE i2 = 898732 AND i5 = 123451;
                                                 QUERY PLAN
-------------------------------------------------------------------
-----------------------------------
 Seq Scan on tbloom  (cost=0.00..213744.00 rows=250 width=24) (actual
 time=357.059..357.059 rows=0 loops=1)
   Filter: ((i2 = 898732) AND (i5 = 123451))
   Rows Removed by Filter: 10000000
 Planning Time: 0.346 ms
 Execution Time: 357.076 ms
```

```
(5 rows)
```

Even with the btree index defined the result will still be a sequential scan:

```
=# CREATE INDEX btreeidx ON tbloom (i1, i2, i3, i4, i5, i6);
CREATE INDEX
=# SELECT pg_size_pretty(pg_relation_size('btreeidx'));
 pg_size_pretty
----------------
 386 MB
(1 row)
=# EXPLAIN ANALYZE SELECT * FROM tbloom WHERE i2 = 898732 AND i5 = 123451;
                                                      QUERY PLAN
----------------------------------------------------------------------
----------------------------------
 Seq Scan on tbloom  (cost=0.00..213744.00 rows=2 width=24) (actual
 time=351.016..351.017 rows=0 loops=1)
   Filter: ((i2 = 898732) AND (i5 = 123451))
   Rows Removed by Filter: 10000000
 Planning Time: 0.138 ms
 Execution Time: 351.035 ms
(5 rows)
```

Having the bloom index defined on the table is better than btree in handling this type of search:

```
=# CREATE INDEX bloomidx ON tbloom USING bloom (i1, i2, i3, i4, i5, i6);
CREATE INDEX
=# SELECT pg_size_pretty(pg_relation_size('bloomidx'));
 pg_size_pretty
----------------
 153 MB
(1 row)
=# EXPLAIN ANALYZE SELECT * FROM tbloom WHERE i2 = 898732 AND i5 = 123451;
                                                         QUERY PLAN
----------------------------------------------------------------------
-----------------------------------------------
 Bitmap Heap Scan on tbloom  (cost=1792.00..1799.69 rows=2 width=24) (actual
 time=22.605..22.606 rows=0 loops=1)
   Recheck Cond: ((i2 = 898732) AND (i5 = 123451))
   Rows Removed by Index Recheck: 2300
   Heap Blocks: exact=2256
   ->  Bitmap Index Scan on bloomidx  (cost=0.00..178436.00 rows=1 width=0) (actual
 time=20.005..20.005 rows=2300 loops=1)
         Index Cond: ((i2 = 898732) AND (i5 = 123451))
 Planning Time: 0.099 ms
 Execution Time: 22.632 ms
(8 rows)
```

Now, the main problem with the btree search is that btree is inefficient when the search conditions do not constrain the leading index column(s). A better strategy for btree is to create a separate index on each column. Then the planner will choose something like this:

```
=# CREATE INDEX btreeidx1 ON tbloom (i1);
CREATE INDEX
=# CREATE INDEX btreeidx2 ON tbloom (i2);
CREATE INDEX
=# CREATE INDEX btreeidx3 ON tbloom (i3);
CREATE INDEX
=# CREATE INDEX btreeidx4 ON tbloom (i4);
CREATE INDEX
```

```
=# CREATE INDEX btreeidx5 ON tbloom (i5);
CREATE INDEX
=# CREATE INDEX btreeidx6 ON tbloom (i6);
CREATE INDEX
=# EXPLAIN ANALYZE SELECT * FROM tbloom WHERE i2 = 898732 AND i5 = 123451;
                                                          QUERY PLAN
------------------------------------------------------------------------------
-------------------------------------------------------
 Bitmap Heap Scan on tbloom  (cost=9.29..13.30 rows=1 width=24) (actual
 time=0.032..0.033 rows=0 loops=1)
   Recheck Cond: ((i5 = 123451) AND (i2 = 898732))
   ->  BitmapAnd  (cost=9.29..9.29 rows=1 width=0) (actual time=0.047..0.047 rows=0
 loops=1)
         ->  Bitmap Index Scan on btreeidx5  (cost=0.00..4.52 rows=11 width=0) (actual
 time=0.026..0.026 rows=7 loops=1)
               Index Cond: (i5 = 123451)
         ->  Bitmap Index Scan on btreeidx2  (cost=0.00..4.52 rows=11 width=0) (actual
 time=0.007..0.007 rows=8 loops=1)
               Index Cond: (i2 = 898732)
 Planning Time: 0.264 ms
 Execution Time: 0.047 ms
(9 rows)
```

Although this query runs much faster than with either of the single indexes, we pay a penalty in index size. Each of the single-column btree indexes occupies 88.5 MB, so the total space needed is 531 MB, over three times the space used by the bloom index.

F.7.3. Operator Class Interface

An operator class for bloom indexes requires only a hash function for the indexed data type and an equality operator for searching. This example shows the operator class definition for the `text` data type:

```
CREATE OPERATOR CLASS text_ops
DEFAULT FOR TYPE text USING bloom AS
    OPERATOR    1   =(text, text),
    FUNCTION    1   hashtext(text);
```

F.7.4. Limitations

- Only operator classes for `int4` and `text` are included with the module.
- Only the `=` operator is supported for search. But it is possible to add support for arrays with union and intersection operations in the future.
- `bloom` access method doesn't support `UNIQUE` indexes.
- `bloom` access method doesn't support searching for `NULL` values.

F.7.5. Authors

Teodor Sigaev `<teodor@postgrespro.ru>`, Postgres Professional, Moscow, Russia

Alexander Korotkov `<a.korotkov@postgrespro.ru>`, Postgres Professional, Moscow, Russia

Oleg Bartunov `<obartunov@postgrespro.ru>`, Postgres Professional, Moscow, Russia

F.8. btree_gin

`btree_gin` provides sample GIN operator classes that implement B-tree equivalent behavior for the data types `int2`, `int4`, `int8`, `float4`, `float8`, `timestamp with time zone`, `timestamp without time zone`, `time with time zone`, `time without time zone`, `date`, `interval`, `oid`, `money`, `"char"`, `varchar`, `text`, `bytea`, `bit`, `varbit`, `macaddr`, `macaddr8`, `inet`, `cidr`, `uuid`, `name`, `bool`, `bpchar`, and all `enum` types.

In general, these operator classes will not outperform the equivalent standard B-tree index methods, and they lack one major feature of the standard B-tree code: the ability to enforce uniqueness. However, they are useful for GIN testing and as a base for developing other GIN operator classes. Also, for queries that test both a GIN-indexable column and a B-tree-indexable column, it might be more efficient to create a multicolumn GIN index that uses one of these operator classes than to create two separate indexes that would have to be combined via bitmap ANDing.

This module is considered "trusted", that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.8.1. Example Usage

```
CREATE TABLE test (a int4);
-- create index
CREATE INDEX testidx ON test USING GIN (a);
-- query
SELECT * FROM test WHERE a < 10;
```

F.8.2. Authors

Teodor Sigaev (`<teodor@stack.net>`) and Oleg Bartunov (`<oleg@sai.msu.su>`). See *http://www.sai.msu.su/~megera/oddmuse/index.cgi/Gin* for additional information.

F.9. btree_gist

`btree_gist` provides GiST index operator classes that implement B-tree equivalent behavior for the data types `int2`, `int4`, `int8`, `float4`, `float8`, `numeric`, `timestamp with time zone`, `timestamp without time zone`, `time with time zone`, `time without time zone`, `date`, `interval`, `oid`, `money`, `char`, `varchar`, `text`, `bytea`, `bit`, `varbit`, `macaddr`, `macaddr8`, `inet`, `cidr`, `uuid`, and all `enum` types.

In general, these operator classes will not outperform the equivalent standard B-tree index methods, and they lack one major feature of the standard B-tree code: the ability to enforce uniqueness. However, they provide some other features that are not available with a B-tree index, as described below. Also, these operator classes are useful when a multicolumn GiST index is needed, wherein some of the columns are of data types that are only indexable with GiST but other columns are just simple data types. Lastly, these operator classes are useful for GiST testing and as a base for developing other GiST operator classes.

In addition to the typical B-tree search operators, `btree_gist` also provides index support for `<>` ("not equals"). This may be useful in combination with an exclusion constraint, as described below.

Also, for data types for which there is a natural distance metric, `btree_gist` defines a distance operator `<->`, and provides GiST index support for nearest-neighbor searches using this operator. Distance operators are provided for `int2`, `int4`, `int8`, `float4`, `float8`, `timestamp with time zone`, `timestamp without time zone`, `time without time zone`, `date`, `interval`, `oid`, and `money`.

This module is considered "trusted", that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.9.1. Example Usage

Simple example using `btree_gist` instead of `btree`:

```
CREATE TABLE test (a int4);
-- create index
CREATE INDEX testidx ON test USING GIST (a);
-- query
SELECT * FROM test WHERE a < 10;
-- nearest-neighbor search: find the ten entries closest to "42"
SELECT *, a <-> 42 AS dist FROM test ORDER BY a <-> 42 LIMIT 10;
```

Use an exclusion constraint to enforce the rule that a cage at a zoo can contain only one kind of animal:

```
=> CREATE TABLE zoo (
  cage   INTEGER,
  animal TEXT,
  EXCLUDE USING GIST (cage WITH =, animal WITH <>)
);

=> INSERT INTO zoo VALUES(123, 'zebra');
INSERT 0 1
=> INSERT INTO zoo VALUES(123, 'zebra');
INSERT 0 1
=> INSERT INTO zoo VALUES(123, 'lion');
ERROR:  conflicting key value violates exclusion constraint "zoo_cage_animal_excl"
DETAIL:  Key (cage, animal)=(123, lion) conflicts with existing key (cage,
 animal)=(123, zebra).
=> INSERT INTO zoo VALUES(124, 'lion');
INSERT 0 1
```

F.9.2. Upgrade notes for version 1.6

In version 1.6 `btree_gist` switched to using in-core distance operators, and its own implementations were removed. References to these operators in `btree_gist` opclasses will be updated automatically during the extension upgrade, but if the user has created objects referencing these operators or functions, then these objects must be dropped manually before updating the extension.

F.9.3. Authors

Teodor Sigaev (<teodor@stack.net>), Oleg Bartunov (<oleg@sai.msu.su>), Janko Richter (<janko-richter@yahoo.de>), and Paul Jungwirth (<pj@illuminatedcomputing.com>). See *http://www.sai.msu.su/~megera/postgres/gist/* for additional information.

F.10. citext

The `citext` module provides a case-insensitive character string type, `citext`. Essentially, it internally calls `lower` when comparing values. Otherwise, it behaves almost exactly like `text`.

> **Tip**
>
> Consider using *nondeterministic collations* (see Section 23.2.2.4) instead of this module. They can be used for case-insensitive comparisons, accent-insensitive comparisons, and other combinations, and they handle more Unicode special cases correctly.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.10.1. Rationale

The standard approach to doing case-insensitive matches in Postgres Pro has been to use the `lower` function when comparing values, for example

```
SELECT * FROM tab WHERE lower(col) = LOWER(?);
```

This works reasonably well, but has a number of drawbacks:

- It makes your SQL statements verbose, and you always have to remember to use `lower` on both the column and the query value.
- It won't use an index, unless you create a functional index using `lower`.

- If you declare a column as `UNIQUE` or `PRIMARY KEY`, the implicitly generated index is case-sensitive. So it's useless for case-insensitive searches, and it won't enforce uniqueness case-insensitively.

The `citext` data type allows you to eliminate calls to `lower` in SQL queries, and allows a primary key to be case-insensitive. `citext` is locale-aware, just like `text`, which means that the matching of upper case and lower case characters is dependent on the rules of the database's `LC_CTYPE` setting. Again, this behavior is identical to the use of `lower` in queries. But because it's done transparently by the data type, you don't have to remember to do anything special in your queries.

F.10.2. How to Use It

Here's a simple example of usage:

```
CREATE TABLE users (
    nick CITEXT PRIMARY KEY,
    pass TEXT   NOT NULL
);

INSERT INTO users VALUES ( 'larry',  sha256(random()::text::bytea) );
INSERT INTO users VALUES ( 'Tom',    sha256(random()::text::bytea) );
INSERT INTO users VALUES ( 'Damian', sha256(random()::text::bytea) );
INSERT INTO users VALUES ( 'NEAL',   sha256(random()::text::bytea) );
INSERT INTO users VALUES ( 'Bjørn',  sha256(random()::text::bytea) );

SELECT * FROM users WHERE nick = 'Larry';
```

The `SELECT` statement will return one tuple, even though the `nick` column was set to `larry` and the query was for `Larry`.

F.10.3. String Comparison Behavior

`citext` performs comparisons by converting each string to lower case (as though `lower` were called) and then comparing the results normally. Thus, for example, two strings are considered equal if `lower` would produce identical results for them.

In order to emulate a case-insensitive collation as closely as possible, there are `citext`-specific versions of a number of string-processing operators and functions. So, for example, the regular expression operators `~` and `~*` exhibit the same behavior when applied to `citext`: they both match case-insensitively. The same is true for `!~` and `!~*`, as well as for the `LIKE` operators `~~` and `~~*`, and `!~~` and `!~~*`. If you'd like to match case-sensitively, you can cast the operator's arguments to `text`.

Similarly, all of the following functions perform matching case-insensitively if their arguments are `citext`:

- `regexp_match()`
- `regexp_matches()`
- `regexp_replace()`
- `regexp_split_to_array()`
- `regexp_split_to_table()`
- `replace()`
- `split_part()`
- `strpos()`
- `translate()`

For the regexp functions, if you want to match case-sensitively, you can specify the “c” flag to force a case-sensitive match. Otherwise, you must cast to `text` before using one of these functions if you want case-sensitive behavior.

F.10.4. Limitations

- citext's case-folding behavior depends on the LC_CTYPE setting of your database. How it compares values is therefore determined when the database is created. It is not truly case-insensitive in the terms defined by the Unicode standard. Effectively, what this means is that, as long as you're happy with your collation, you should be happy with citext's comparisons. But if you have data in different languages stored in your database, users of one language may find their query results are not as expected if the collation is for another language.
- As of PostgreSQL 9.1, you can attach a COLLATE specification to citext columns or data values. Currently, citext operators will honor a non-default COLLATE specification while comparing case-folded strings, but the initial folding to lower case is always done according to the database's LC_CTYPE setting (that is, as though COLLATE "default" were given). This may be changed in a future release so that both steps follow the input COLLATE specification.
- citext is not as efficient as text because the operator functions and the B-tree comparison functions must make copies of the data and convert it to lower case for comparisons. Also, only text can support B-Tree deduplication. However, citext is slightly more efficient than using lower to get case-insensitive matching.
- citext doesn't help much if you need data to compare case-sensitively in some contexts and case-insensitively in other contexts. The standard answer is to use the text type and manually use the lower function when you need to compare case-insensitively; this works all right if case-insensitive comparison is needed only infrequently. If you need case-insensitive behavior most of the time and case-sensitive infrequently, consider storing the data as citext and explicitly casting the column to text when you want case-sensitive comparison. In either situation, you will need two indexes if you want both types of searches to be fast.
- The schema containing the citext operators must be in the current search_path (typically public); if it is not, the normal case-sensitive text operators will be invoked instead.
- The approach of lower-casing strings for comparison does not handle some Unicode special cases correctly, for example when one upper-case letter has two lower-case letter equivalents. Unicode distinguishes between *case mapping* and *case folding* for this reason. Use nondeterministic collations instead of citext to handle that correctly.

F.10.5. Author

David E. Wheeler <david@kineticode.com>

Inspired by the original citext module by Donald Fraser.

F.11. cube

This module implements a data type cube for representing multidimensional cubes.

This module is considered “trusted”, that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.11.1. Syntax

Table F.12 shows the valid external representations for the cube type. *x*, *y*, etc. denote floating-point numbers.

Table F.12. Cube External Representations

External Syntax	Meaning
x	A one-dimensional point (or, zero-length one-dimensional interval)
(*x*)	Same as above

External Syntax	Meaning
x1, *x2*,..., *xn*	A point in n-dimensional space, represented internally as a zero-volume cube
(*x1*, *x2*,..., *xn*)	Same as above
(*x*),(*y*)	A one-dimensional interval starting at *x* and ending at *y* or vice versa; the order does not matter
[(*x*),(*y*)]	Same as above
(*x1*,..., *xn*),(*y1*,..., *yn*)	An n-dimensional cube represented by a pair of its diagonally opposite corners
[(*x1*,..., *xn*),(*y1*,..., *yn*)]	Same as above

It does not matter which order the opposite corners of a cube are entered in. The `cube` functions automatically swap values if needed to create a uniform "lower left — upper right" internal representation. When the corners coincide, `cube` stores only one corner along with an "is point" flag to avoid wasting space.

White space is ignored on input, so `[(x),(y)]` is the same as `[ ( x ), ( y ) ]`.

F.11.2. Precision

Values are stored internally as 64-bit floating point numbers. This means that numbers with more than about 16 significant digits will be truncated.

F.11.3. Usage

Table F.13 shows the specialized operators provided for type `cube`.

Table F.13. Cube Operators

Operator Description
`cube && cube → boolean` Do the cubes overlap?
`cube @> cube → boolean` Does the first cube contain the second?
`cube <@ cube → boolean` Is the first cube contained in the second?
`cube -> integer → float8` Extracts the *n*-th coordinate of the cube (counting from 1).
`cube ~> integer → float8` Extracts the *n*-th coordinate of the cube, counting in the following way: *n* = 2 * *k* - 1 means lower bound of *k*-th dimension, *n* = 2 * *k* means upper bound of *k*-th dimension. Negative *n* denotes the inverse value of the corresponding positive coordinate. This operator is designed for KNN-GiST support.
`cube <-> cube → float8` Computes the Euclidean distance between the two cubes.
`cube <#> cube → float8` Computes the taxicab (L-1 metric) distance between the two cubes.
`cube <=> cube → float8` Computes the Chebyshev (L-inf metric) distance between the two cubes.

In addition to the above operators, the usual comparison operators shown in Table 9.1 are available for type cube. These operators first compare the first coordinates, and if those are equal, compare the second coordinates, etc. They exist mainly to support the b-tree index operator class for cube, which can be useful for example if you would like a UNIQUE constraint on a cube column. Otherwise, this ordering is not of much practical use.

The cube module also provides a GiST index operator class for cube values. A cube GiST index can be used to search for values using the =, &&, @>, and <@ operators in WHERE clauses.

In addition, a cube GiST index can be used to find nearest neighbors using the metric operators <->, <#>, and <=> in ORDER BY clauses. For example, the nearest neighbor of the 3-D point (0.5, 0.5, 0.5) could be found efficiently with:

```
SELECT c FROM test ORDER BY c <-> cube(array[0.5,0.5,0.5]) LIMIT 1;
```

The ~> operator can also be used in this way to efficiently retrieve the first few values sorted by a selected coordinate. For example, to get the first few cubes ordered by the first coordinate (lower left corner) ascending one could use the following query:

```
SELECT c FROM test ORDER BY c ~> 1 LIMIT 5;
```

And to get 2-D cubes ordered by the first coordinate of the upper right corner descending:

```
SELECT c FROM test ORDER BY c ~> 3 DESC LIMIT 5;
```

Table F.14 shows the available functions.

Table F.14. Cube Functions

Function **Description** **Example(s)**
cube (float8) → cube Makes a one dimensional cube with both coordinates the same. cube(1) → (1)
cube (float8, float8) → cube Makes a one dimensional cube. cube(1, 2) → (1),(2)
cube (float8[]) → cube Makes a zero-volume cube using the coordinates defined by the array. cube(ARRAY[1,2,3]) → (1, 2, 3)
cube (float8[], float8[]) → cube Makes a cube with upper right and lower left coordinates as defined by the two arrays, which must be of the same length. cube(ARRAY[1,2], ARRAY[3,4]) → (1, 2),(3, 4)
cube (cube, float8) → cube Makes a new cube by adding a dimension on to an existing cube, with the same values for both endpoints of the new coordinate. This is useful for building cubes piece by piece from calculated values. cube('(1,2),(3,4)'::cube, 5) → (1, 2, 5),(3, 4, 5)
cube (cube, float8, float8) → cube Makes a new cube by adding a dimension on to an existing cube. This is useful for building cubes piece by piece from calculated values. cube('(1,2),(3,4)'::cube, 5, 6) → (1, 2, 5),(3, 4, 6)
cube_dim (cube) → integer

Function Description Example(s)
Returns the number of dimensions of the cube. `cube_dim('(1,2),(3,4)')` → `2`

`cube_ll_coord` (`cube`, `integer`) → `float8`
Returns the *n*-th coordinate value for the lower left corner of the cube.
`cube_ll_coord('(1,2),(3,4)', 2)` → `2`

`cube_ur_coord` (`cube`, `integer`) → `float8`
Returns the *n*-th coordinate value for the upper right corner of the cube.
`cube_ur_coord('(1,2),(3,4)', 2)` → `4`

`cube_is_point` (`cube`) → `boolean`
Returns true if the cube is a point, that is, the two defining corners are the same.
`cube_is_point(cube(1,1))` → `t`

`cube_distance` (`cube`, `cube`) → `float8`
Returns the distance between two cubes. If both cubes are points, this is the normal distance function.
`cube_distance('(1,2)', '(3,4)')` → `2.8284271247461903`

`cube_subset` (`cube`, `integer[]`) → `cube`
Makes a new cube from an existing cube, using a list of dimension indexes from an array. Can be used to extract the endpoints of a single dimension, or to drop dimensions, or to reorder them as desired.
`cube_subset(cube('(1,3,5),(6,7,8)'), ARRAY[2])` → `(3),(7)`
`cube_subset(cube('(1,3,5),(6,7,8)'), ARRAY[3,2,1,1])` → `(5, 3, 1, 1),(8, 7, 6, 6)`

`cube_union` (`cube`, `cube`) → `cube`
Produces the union of two cubes.
`cube_union('(1,2)', '(3,4)')` → `(1, 2),(3, 4)`

`cube_inter` (`cube`, `cube`) → `cube`
Produces the intersection of two cubes.
`cube_inter('(1,2)', '(3,4)')` → `(3, 4),(1, 2)`

`cube_enlarge` (*c* `cube`, *r* `double`, *n* `integer`) → `cube`
Increases the size of the cube by the specified radius *r* in at least *n* dimensions. If the radius is negative the cube is shrunk instead. All defined dimensions are changed by the radius *r*. Lower-left coordinates are decreased by *r* and upper-right coordinates are increased by *r*. If a lower-left coordinate is increased to more than the corresponding upper-right coordinate (this can only happen when *r* < 0) than both coordinates are set to their average. If *n* is greater than the number of defined dimensions and the cube is being enlarged (*r* > 0), then extra dimensions are added to make *n* altogether; 0 is used as the initial value for the extra coordinates. This function is useful for creating bounding boxes around a point for searching for nearby points.
`cube_enlarge('(1,2),(3,4)', 0.5, 3)` → `(0.5, 1.5, -0.5),(3.5, 4.5, 0.5)`

F.11.4. Defaults

I believe this union:

```
select cube_union('(0,5,2),(2,3,1)', '0');
cube_union
```

```
-------------------
(0, 0, 0),(2, 5, 2)
(1 row)
```

does not contradict common sense, neither does the intersection

```
select cube_inter('(0,-1),(1,1)', '(-2),(2)');
cube_inter
-------------
(0, 0),(1, 0)
(1 row)
```

In all binary operations on differently-dimensioned cubes, I assume the lower-dimensional one to be a Cartesian projection, i. e., having zeroes in place of coordinates omitted in the string representation. The above examples are equivalent to:

```
cube_union('(0,5,2),(2,3,1)','(0,0,0),(0,0,0)');
cube_inter('(0,-1),(1,1)','(-2,0),(2,0)');
```

The following containment predicate uses the point syntax, while in fact the second argument is internally represented by a box. This syntax makes it unnecessary to define a separate point type and functions for (box,point) predicates.

```
select cube_contains('(0,0),(1,1)', '0.5,0.5');
cube_contains
--------------
t
(1 row)
```

F.11.5. Notes

For examples of usage, see the regression test `sql/cube.sql`.

To make it harder for people to break things, there is a limit of 100 on the number of dimensions of cubes. This is set in `cubedata.h` if you need something bigger.

F.11.6. Credits

Original author: Gene Selkov, Jr. <selkovjr@mcs.anl.gov>, Mathematics and Computer Science Division, Argonne National Laboratory.

My thanks are primarily to Prof. Joe Hellerstein (*https://dsf.berkeley.edu/jmh/*) for elucidating the gist of the GiST (*http://gist.cs.berkeley.edu/*), and to his former student Andy Dong for his example written for Illustra. I am also grateful to all Postgres developers, present and past, for enabling myself to create my own world and live undisturbed in it. And I would like to acknowledge my gratitude to Argonne Lab and to the U.S. Department of Energy for the years of faithful support of my database research.

Minor updates to this package were made by Bruno Wolff III <bruno@wolff.to> in August/September of 2002. These include changing the precision from single precision to double precision and adding some new functions.

Additional updates were made by Joshua Reich <josh@root.net> in July 2006. These include `cube(float8[], float8[])` and cleaning up the code to use the V1 call protocol instead of the deprecated V0 protocol.

F.12. daterange_inclusive

`daterange_inclusive` is an extension to the built-in `daterange` range type. By default, `daterange` excludes the upper bound of the range — `[)`, whereas `daterange_inclusive` does not — `[]`. Other than the covered range bound, there are no other differences between `daterange` and `daterange_inclusive`.

This module is considered “trusted”, that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.12.1. Rationale

At times, it is more convenient to output date ranges with inclusive upper bounds. For example, it may apply to employees' absences. If an employee is absent from January 1, 2025, to January 10, 2025, using the daterange range type will prevent the database from outputting this date range in its entirety. In such cases, you would need to manually subtract one day from the output. The daterange_inclusive extension addresses this issue.

F.12.2. Example Usage

```
CREATE EXTENSION daterange_inclusive;
SELECT daterange('[2024-01-01,2024-06-01]');
      daterange
-------------------------
[2024-01-01,2024-06-02)

SELECT daterange_inclusive('[2024-01-01,2024-06-01]');
   daterange_inclusive
-------------------------
[2024-01-01,2024-06-01]
```

F.13. dblink

dblink is a module that supports connections to other Postgres Pro databases from within a database session.

See also postgres_fdw, which provides roughly the same functionality using a more modern and standards-compliant infrastructure.

dblink_connect

dblink_connect — opens a persistent connection to a remote database

Synopsis

```
dblink_connect(text connstr) returns text
dblink_connect(text connname, text connstr) returns text
```

Description

`dblink_connect()` establishes a connection to a remote Postgres Pro database. The server and database to be contacted are identified through a standard libpq connection string. Optionally, a name can be assigned to the connection. Multiple named connections can be open at once, but only one unnamed connection is permitted at a time. The connection will persist until closed or until the database session is ended.

The connection string may also be the name of an existing foreign server. It is recommended to use the foreign-data wrapper `dblink_fdw` when defining the foreign server. See the example below, as well as CREATE SERVER and CREATE USER MAPPING.

Arguments

connname

The name to use for this connection; if omitted, an unnamed connection is opened, replacing any existing unnamed connection.

connstr

libpq-style connection info string, for example `hostaddr=127.0.0.1 port=5432 dbname=mydb user=postgres password=mypasswd options=-csearch_path=`. For details see Section 36.1.1. Alternatively, the name of a foreign server.

Return Value

Returns status, which is always `OK` (since any error causes the function to throw an error instead of returning).

Notes

If untrusted users have access to a database that has not adopted a secure schema usage pattern, begin each session by removing publicly-writable schemas from `search_path`. One could, for example, add `options=-csearch_path=` to *connstr*. This consideration is not specific to `dblink`; it applies to every interface for executing arbitrary SQL commands.

Only superusers may use `dblink_connect` to create non-password-authenticated connections. If non-superusers need this capability, use `dblink_connect_u` instead.

It is unwise to choose connection names that contain equal signs, as this opens a risk of confusion with connection info strings in other `dblink` functions.

Examples

```
SELECT dblink_connect('dbname=postgres options=-csearch_path=');
 dblink_connect
----------------
 OK
(1 row)

SELECT dblink_connect('myconn', 'dbname=postgres options=-csearch_path=');
```

```
 dblink_connect
----------------
 OK
(1 row)

-- FOREIGN DATA WRAPPER functionality
-- Note: local connection must require password authentication for this to work
 properly
--       Otherwise, you will receive the following error from dblink_connect():
--       ERROR:  password is required
--       DETAIL:  Non-superuser cannot connect if the server does not request a
 password.
--       HINT:  Target server's authentication method must be changed.

CREATE SERVER fdtest FOREIGN DATA WRAPPER dblink_fdw OPTIONS (hostaddr '127.0.0.1',
 dbname 'contrib_regression');

CREATE USER regress_dblink_user WITH PASSWORD 'secret';
CREATE USER MAPPING FOR regress_dblink_user SERVER fdtest OPTIONS (user
 'regress_dblink_user', password 'secret');
GRANT USAGE ON FOREIGN SERVER fdtest TO regress_dblink_user;
GRANT SELECT ON TABLE foo TO regress_dblink_user;

\set ORIGINAL_USER :USER
\c - regress_dblink_user
SELECT dblink_connect('myconn', 'fdtest');
 dblink_connect
----------------
 OK
(1 row)

SELECT * FROM dblink('myconn', 'SELECT * FROM foo') AS t(a int, b text, c text[]);
 a  | b |       c
----+---+---------------
  0 | a | {a0,b0,c0}
  1 | b | {a1,b1,c1}
  2 | c | {a2,b2,c2}
  3 | d | {a3,b3,c3}
  4 | e | {a4,b4,c4}
  5 | f | {a5,b5,c5}
  6 | g | {a6,b6,c6}
  7 | h | {a7,b7,c7}
  8 | i | {a8,b8,c8}
  9 | j | {a9,b9,c9}
 10 | k | {a10,b10,c10}
(11 rows)

\c - :ORIGINAL_USER
REVOKE USAGE ON FOREIGN SERVER fdtest FROM regress_dblink_user;
REVOKE SELECT ON TABLE foo FROM regress_dblink_user;
DROP USER MAPPING FOR regress_dblink_user SERVER fdtest;
DROP USER regress_dblink_user;
DROP SERVER fdtest;
```

dblink_connect_u

dblink_connect_u — opens a persistent connection to a remote database, insecurely

Synopsis

```
dblink_connect_u(text connstr) returns text
dblink_connect_u(text connname, text connstr) returns text
```

Description

`dblink_connect_u()` is identical to `dblink_connect()`, except that it will allow non-superusers to connect using any authentication method.

If the remote server selects an authentication method that does not involve a password, then impersonation and subsequent escalation of privileges can occur, because the session will appear to have originated from the user as which the local Postgres Pro server runs. Also, even if the remote server does demand a password, it is possible for the password to be supplied from the server environment, such as a `~/.pgpass` file belonging to the server's user. This opens not only a risk of impersonation, but the possibility of exposing a password to an untrustworthy remote server. Therefore, `dblink_connect_u()` is initially installed with all privileges revoked from `PUBLIC`, making it un-callable except by superusers. In some situations it may be appropriate to grant `EXECUTE` permission for `dblink_connect_u()` to specific users who are considered trustworthy, but this should be done with care. It is also recommended that any `~/.pgpass` file belonging to the server's user *not* contain any records specifying a wildcard host name.

For further details see `dblink_connect()`.

dblink_disconnect

dblink_disconnect — closes a persistent connection to a remote database

Synopsis

```
dblink_disconnect() returns text
dblink_disconnect(text connname) returns text
```

Description

`dblink_disconnect()` closes a connection previously opened by `dblink_connect()`. The form with no arguments closes an unnamed connection.

Arguments

connname

The name of a named connection to be closed.

Return Value

Returns status, which is always `OK` (since any error causes the function to throw an error instead of returning).

Examples

```
SELECT dblink_disconnect();
 dblink_disconnect
-------------------
 OK
(1 row)

SELECT dblink_disconnect('myconn');
 dblink_disconnect
-------------------
 OK
(1 row)
```

dblink

dblink — executes a query in a remote database

Synopsis

```
dblink(text connname, text sql [, bool fail_on_error]) returns setof record
dblink(text connstr, text sql [, bool fail_on_error]) returns setof record
dblink(text sql [, bool fail_on_error]) returns setof record
```

Description

`dblink` executes a query (usually a `SELECT`, but it can be any SQL statement that returns rows) in a remote database.

When two `text` arguments are given, the first one is first looked up as a persistent connection's name; if found, the command is executed on that connection. If not found, the first argument is treated as a connection info string as for `dblink_connect`, and the indicated connection is made just for the duration of this command.

Arguments

connname

Name of the connection to use; omit this parameter to use the unnamed connection.

connstr

A connection info string, as previously described for `dblink_connect`.

sql

The SQL query that you wish to execute in the remote database, for example `select * from foo`.

fail_on_error

If true (the default when omitted) then an error thrown on the remote side of the connection causes an error to also be thrown locally. If false, the remote error is locally reported as a NOTICE, and the function returns no rows.

Return Value

The function returns the row(s) produced by the query. Since `dblink` can be used with any query, it is declared to return `record`, rather than specifying any particular set of columns. This means that you must specify the expected set of columns in the calling query — otherwise Postgres Pro would not know what to expect. Here is an example:

```
SELECT *
    FROM dblink('dbname=mydb options=-csearch_path=',
                'select proname, prosrc from pg_proc')
      AS t1(proname name, prosrc text)
    WHERE proname LIKE 'bytea%';
```

The “alias” part of the `FROM` clause must specify the column names and types that the function will return. (Specifying column names in an alias is actually standard SQL syntax, but specifying column types is a Postgres Pro extension.) This allows the system to understand what `*` should expand to, and what `proname` in the `WHERE` clause refers to, in advance of trying to execute the function. At run time, an error will be thrown if the actual query result from the remote database does not have the same number of columns shown in the `FROM` clause. The column names need not match, however, and `dblink` does not insist on exact type matches either. It will succeed so long as the returned data strings are valid input for the column type declared in the `FROM` clause.

Notes

A convenient way to use `dblink` with predetermined queries is to create a view. This allows the column type information to be buried in the view, instead of having to spell it out in every query. For example,

```
CREATE VIEW myremote_pg_proc AS
  SELECT *
    FROM dblink('dbname=postgres options=-csearch_path=',
                'select proname, prosrc from pg_proc')
    AS t1(proname name, prosrc text);

SELECT * FROM myremote_pg_proc WHERE proname LIKE 'bytea%';
```

Examples

```
SELECT * FROM dblink('dbname=postgres options=-csearch_path=',
                     'select proname, prosrc from pg_proc')
  AS t1(proname name, prosrc text) WHERE proname LIKE 'bytea%';
  proname   |   prosrc
------------+------------
 byteacat   | byteacat
 byteaeq    | byteaeq
 bytealt    | bytealt
 byteale    | byteale
 byteagt    | byteagt
 byteage    | byteage
 byteane    | byteane
 byteacmp   | byteacmp
 bytealike  | bytealike
 byteanlike | byteanlike
 byteain    | byteain
 byteaout   | byteaout
(12 rows)

SELECT dblink_connect('dbname=postgres options=-csearch_path=');
 dblink_connect
----------------
 OK
(1 row)

SELECT * FROM dblink('select proname, prosrc from pg_proc')
  AS t1(proname name, prosrc text) WHERE proname LIKE 'bytea%';
  proname   |   prosrc
------------+------------
 byteacat   | byteacat
 byteaeq    | byteaeq
 bytealt    | bytealt
 byteale    | byteale
 byteagt    | byteagt
 byteage    | byteage
 byteane    | byteane
 byteacmp   | byteacmp
 bytealike  | bytealike
 byteanlike | byteanlike
 byteain    | byteain
 byteaout   | byteaout
(12 rows)

SELECT dblink_connect('myconn', 'dbname=regression options=-csearch_path=');
```

```
 dblink_connect
----------------
 OK
(1 row)

SELECT * FROM dblink('myconn', 'select proname, prosrc from pg_proc')
  AS t1(proname name, prosrc text) WHERE proname LIKE 'bytea%';
  proname   |   prosrc
------------+------------
 bytearecv  | bytearecv
 byteasend  | byteasend
 byteale    | byteale
 byteagt    | byteagt
 byteage    | byteage
 byteane    | byteane
 byteacmp   | byteacmp
 bytealike  | bytealike
 byteanlike | byteanlike
 byteacat   | byteacat
 byteaeq    | byteaeq
 bytealt    | bytealt
 byteain    | byteain
 byteaout   | byteaout
(14 rows)
```

dblink_exec

dblink_exec — executes a command in a remote database

Synopsis

```
dblink_exec(text connname, text sql [, bool fail_on_error]) returns text
dblink_exec(text connstr, text sql [, bool fail_on_error]) returns text
dblink_exec(text sql [, bool fail_on_error]) returns text
```

Description

`dblink_exec` executes a command (that is, any SQL statement that doesn't return rows) in a remote database.

When two `text` arguments are given, the first one is first looked up as a persistent connection's name; if found, the command is executed on that connection. If not found, the first argument is treated as a connection info string as for `dblink_connect`, and the indicated connection is made just for the duration of this command.

Arguments

connname

Name of the connection to use; omit this parameter to use the unnamed connection.

connstr

A connection info string, as previously described for `dblink_connect`.

sql

The SQL command that you wish to execute in the remote database, for example `insert into foo values(0, 'a', '{"a0","b0","c0"}')`.

fail_on_error

If true (the default when omitted) then an error thrown on the remote side of the connection causes an error to also be thrown locally. If false, the remote error is locally reported as a NOTICE, and the function's return value is set to `ERROR`.

Return Value

Returns status, either the command's status string or `ERROR`.

Examples

```
SELECT dblink_connect('dbname=dblink_test_standby');
 dblink_connect
----------------
 OK
(1 row)

SELECT dblink_exec('insert into foo values(21, ''z'', ''{"a0","b0","c0"}'');');
   dblink_exec
-----------------
 INSERT 943366 1
(1 row)

SELECT dblink_connect('myconn', 'dbname=regression');
 dblink_connect
```

```
----------------
 OK
(1 row)

SELECT dblink_exec('myconn', 'insert into foo values(21, ''z'',
 ''{"a0","b0","c0"}'');');
   dblink_exec
------------------
 INSERT 6432584 1
(1 row)

SELECT dblink_exec('myconn', 'insert into pg_class values (''foo'')',false);
NOTICE:  sql error
DETAIL:  ERROR:  null value in column "relnamespace" violates not-null constraint

 dblink_exec
-------------
 ERROR
(1 row)
```

dblink_open

dblink_open — opens a cursor in a remote database

Synopsis

```
dblink_open(text cursorname, text sql [, bool fail_on_error]) returns text
dblink_open(text connname, text cursorname, text sql [, bool fail_on_error]) returns
 text
```

Description

`dblink_open()` opens a cursor in a remote database. The cursor can subsequently be manipulated with `dblink_fetch()` and `dblink_close()`.

Arguments

connname

Name of the connection to use; omit this parameter to use the unnamed connection.

cursorname

The name to assign to this cursor.

sql

The `SELECT` statement that you wish to execute in the remote database, for example `select * from pg_class`.

fail_on_error

If true (the default when omitted) then an error thrown on the remote side of the connection causes an error to also be thrown locally. If false, the remote error is locally reported as a NOTICE, and the function's return value is set to `ERROR`.

Return Value

Returns status, either `OK` or `ERROR`.

Notes

Since a cursor can only persist within a transaction, `dblink_open` starts an explicit transaction block (`BEGIN`) on the remote side, if the remote side was not already within a transaction. This transaction will be closed again when the matching `dblink_close` is executed. Note that if you use `dblink_exec` to change data between `dblink_open` and `dblink_close`, and then an error occurs or you use `dblink_disconnect` before `dblink_close`, your change *will be lost* because the transaction will be aborted.

Examples

```
SELECT dblink_connect('dbname=postgres options=-csearch_path=');
 dblink_connect
----------------
 OK
(1 row)

SELECT dblink_open('foo', 'select proname, prosrc from pg_proc');
 dblink_open
-------------
 OK
(1 row)
```

dblink_fetch

dblink_fetch — returns rows from an open cursor in a remote database

Synopsis

```
dblink_fetch(text cursorname, int howmany [, bool fail_on_error]) returns setof record
dblink_fetch(text connname, text cursorname, int howmany [, bool fail_on_error])
 returns setof record
```

Description

`dblink_fetch` fetches rows from a cursor previously established by `dblink_open`.

Arguments

connname

Name of the connection to use; omit this parameter to use the unnamed connection.

cursorname

The name of the cursor to fetch from.

howmany

The maximum number of rows to retrieve. The next *howmany* rows are fetched, starting at the current cursor position, moving forward. Once the cursor has reached its end, no more rows are produced.

fail_on_error

If true (the default when omitted) then an error thrown on the remote side of the connection causes an error to also be thrown locally. If false, the remote error is locally reported as a NOTICE, and the function returns no rows.

Return Value

The function returns the row(s) fetched from the cursor. To use this function, you will need to specify the expected set of columns, as previously discussed for `dblink`.

Notes

On a mismatch between the number of return columns specified in the `FROM` clause, and the actual number of columns returned by the remote cursor, an error will be thrown. In this event, the remote cursor is still advanced by as many rows as it would have been if the error had not occurred. The same is true for any other error occurring in the local query after the remote `FETCH` has been done.

Examples

```
SELECT dblink_connect('dbname=postgres options=-csearch_path=');
 dblink_connect
----------------
 OK
(1 row)

SELECT dblink_open('foo', 'select proname, prosrc from pg_proc where proname like
 ''bytea%''');
 dblink_open
-------------
 OK
(1 row)
```

```
SELECT * FROM dblink_fetch('foo', 5) AS (funcname name, source text);
 funcname |  source
----------+----------
 byteacat | byteacat
 byteacmp | byteacmp
 byteaeq  | byteaeq
 byteage  | byteage
 byteagt  | byteagt
(5 rows)

SELECT * FROM dblink_fetch('foo', 5) AS (funcname name, source text);
 funcname  |  source
-----------+-----------
 byteain   | byteain
 byteale   | byteale
 bytealike | bytealike
 bytealt   | bytealt
 byteane   | byteane
(5 rows)

SELECT * FROM dblink_fetch('foo', 5) AS (funcname name, source text);
  funcname  |   source
------------+------------
 byteanlike | byteanlike
 byteaout   | byteaout
(2 rows)

SELECT * FROM dblink_fetch('foo', 5) AS (funcname name, source text);
 funcname | source
----------+--------
(0 rows)
```

dblink_close

dblink_close — closes a cursor in a remote database

Synopsis

```
dblink_close(text cursorname [, bool fail_on_error]) returns text
dblink_close(text connname, text cursorname [, bool fail_on_error]) returns text
```

Description

`dblink_close` closes a cursor previously opened with `dblink_open`.

Arguments

connname

Name of the connection to use; omit this parameter to use the unnamed connection.

cursorname

The name of the cursor to close.

fail_on_error

If true (the default when omitted) then an error thrown on the remote side of the connection causes an error to also be thrown locally. If false, the remote error is locally reported as a NOTICE, and the function's return value is set to `ERROR`.

Return Value

Returns status, either `OK` or `ERROR`.

Notes

If `dblink_open` started an explicit transaction block, and this is the last remaining open cursor in this connection, `dblink_close` will issue the matching `COMMIT`.

Examples

```
SELECT dblink_connect('dbname=postgres options=-csearch_path=');
 dblink_connect
----------------
 OK
(1 row)

SELECT dblink_open('foo', 'select proname, prosrc from pg_proc');
 dblink_open
-------------
 OK
(1 row)

SELECT dblink_close('foo');
 dblink_close
--------------
 OK
(1 row)
```

dblink_get_connections

dblink_get_connections — returns the names of all open named dblink connections

Synopsis

```
dblink_get_connections() returns text[]
```

Description

`dblink_get_connections` returns an array of the names of all open named `dblink` connections.

Return Value

Returns a text array of connection names, or NULL if none.

Examples

```
SELECT dblink_get_connections();
```

dblink_error_message

dblink_error_message — gets last error message on the named connection

Synopsis

```
dblink_error_message(text connname) returns text
```

Description

`dblink_error_message` fetches the most recent remote error message for a given connection.

Arguments

connname

Name of the connection to use.

Return Value

Returns last error message, or `OK` if there has been no error in this connection.

Notes

When asynchronous queries are initiated by `dblink_send_query`, the error message associated with the connection might not get updated until the server's response message is consumed. This typically means that `dblink_is_busy` or `dblink_get_result` should be called prior to `dblink_error_message`, so that any error generated by the asynchronous query will be visible.

Examples

```
SELECT dblink_error_message('dtest1');
```

dblink_send_query

dblink_send_query — sends an async query to a remote database

Synopsis

```
dblink_send_query(text connname, text sql) returns int
```

Description

`dblink_send_query` sends a query to be executed asynchronously, that is, without immediately waiting for the result. There must not be an async query already in progress on the connection.

After successfully dispatching an async query, completion status can be checked with `dblink_is_busy`, and the results are ultimately collected with `dblink_get_result`. It is also possible to attempt to cancel an active async query using `dblink_cancel_query`.

Arguments

connname

Name of the connection to use.

sql

The SQL statement that you wish to execute in the remote database, for example `select * from pg_class`.

Return Value

Returns 1 if the query was successfully dispatched, 0 otherwise.

Examples

```
SELECT dblink_send_query('dtest1', 'SELECT * FROM foo WHERE f1 < 3');
```

dblink_is_busy

dblink_is_busy — checks if connection is busy with an async query

Synopsis

```
dblink_is_busy(text connname) returns int
```

Description

`dblink_is_busy` tests whether an async query is in progress.

Arguments

connname

Name of the connection to check.

Return Value

Returns 1 if connection is busy, 0 if it is not busy. If this function returns 0, it is guaranteed that `dblink_get_result` will not block.

Examples

```
SELECT dblink_is_busy('dtest1');
```

dblink_get_notify

dblink_get_notify — retrieve async notifications on a connection

Synopsis

```
dblink_get_notify() returns setof (notify_name text, be_pid int, extra text)
dblink_get_notify(text connname) returns setof (notify_name text, be_pid int, extra
 text)
```

Description

`dblink_get_notify` retrieves notifications on either the unnamed connection, or on a named connection if specified. To receive notifications via dblink, `LISTEN` must first be issued, using `dblink_exec`. For details see LISTEN and NOTIFY.

Arguments

connname

The name of a named connection to get notifications on.

Return Value

Returns `setof (notify_name text, be_pid int, extra text)`, or an empty set if none.

Examples

```
SELECT dblink_exec('LISTEN virtual');
 dblink_exec
-------------
 LISTEN
(1 row)

SELECT * FROM dblink_get_notify();
 notify_name | be_pid | extra
-------------+--------+-------
(0 rows)

NOTIFY virtual;
NOTIFY

SELECT * FROM dblink_get_notify();
 notify_name | be_pid | extra
-------------+--------+-------
 virtual     |   1229 |
(1 row)
```

dblink_get_result

dblink_get_result — gets an async query result

Synopsis

```
dblink_get_result(text connname [, bool fail_on_error]) returns setof record
```

Description

`dblink_get_result` collects the results of an asynchronous query previously sent with `dblink_send_query`. If the query is not already completed, `dblink_get_result` will wait until it is.

Arguments

connname

Name of the connection to use.

fail_on_error

If true (the default when omitted) then an error thrown on the remote side of the connection causes an error to also be thrown locally. If false, the remote error is locally reported as a NOTICE, and the function returns no rows.

Return Value

For an async query (that is, an SQL statement returning rows), the function returns the row(s) produced by the query. To use this function, you will need to specify the expected set of columns, as previously discussed for `dblink`.

For an async command (that is, an SQL statement not returning rows), the function returns a single row with a single text column containing the command's status string. It is still necessary to specify that the result will have a single text column in the calling `FROM` clause.

Notes

This function *must* be called if `dblink_send_query` returned 1. It must be called once for each query sent, and one additional time to obtain an empty set result, before the connection can be used again.

When using `dblink_send_query` and `dblink_get_result`, dblink fetches the entire remote query result before returning any of it to the local query processor. If the query returns a large number of rows, this can result in transient memory bloat in the local session. It may be better to open such a query as a cursor with `dblink_open` and then fetch a manageable number of rows at a time. Alternatively, use plain `dblink()`, which avoids memory bloat by spooling large result sets to disk.

Examples

```
contrib_regression=# SELECT dblink_connect('dtest1', 'dbname=contrib_regression');
 dblink_connect
----------------
 OK
(1 row)

contrib_regression=# SELECT * FROM
contrib_regression-# dblink_send_query('dtest1', 'select * from foo where f1 < 3') AS
 t1;
 t1
----
  1
(1 row)
```

```
contrib_regression=# SELECT * FROM dblink_get_result('dtest1') AS t1(f1 int, f2 text,
 f3 text[]);
 f1 | f2 |     f3
----+----+------------
  0 | a  | {a0,b0,c0}
  1 | b  | {a1,b1,c1}
  2 | c  | {a2,b2,c2}
(3 rows)

contrib_regression=# SELECT * FROM dblink_get_result('dtest1') AS t1(f1 int, f2 text,
 f3 text[]);
 f1 | f2 | f3
----+----+----
(0 rows)

contrib_regression=# SELECT * FROM
contrib_regression-# dblink_send_query('dtest1', 'select * from foo where f1 < 3;
 select * from foo where f1 > 6') AS t1;
 t1
----
  1
(1 row)

contrib_regression=# SELECT * FROM dblink_get_result('dtest1') AS t1(f1 int, f2 text,
 f3 text[]);
 f1 | f2 |     f3
----+----+------------
  0 | a  | {a0,b0,c0}
  1 | b  | {a1,b1,c1}
  2 | c  | {a2,b2,c2}
(3 rows)

contrib_regression=# SELECT * FROM dblink_get_result('dtest1') AS t1(f1 int, f2 text,
 f3 text[]);
 f1 | f2 |      f3
----+----+---------------
  7 | h  | {a7,b7,c7}
  8 | i  | {a8,b8,c8}
  9 | j  | {a9,b9,c9}
 10 | k  | {a10,b10,c10}
(4 rows)

contrib_regression=# SELECT * FROM dblink_get_result('dtest1') AS t1(f1 int, f2 text,
 f3 text[]);
 f1 | f2 | f3
----+----+----
(0 rows)
```

dblink_cancel_query

dblink_cancel_query — cancels any active query on the named connection

Synopsis

```
dblink_cancel_query(text connname) returns text
```

Description

`dblink_cancel_query` attempts to cancel any query that is in progress on the named connection. Note that this is not certain to succeed (since, for example, the remote query might already have finished). A cancel request simply improves the odds that the query will fail soon. You must still complete the normal query protocol, for example by calling `dblink_get_result`.

Arguments

connname

Name of the connection to use.

Return Value

Returns `OK` if the cancel request has been sent, or the text of an error message on failure.

Examples

```
SELECT dblink_cancel_query('dtest1');
```

dblink_get_pkey

dblink_get_pkey — returns the positions and field names of a relation's primary key fields

Synopsis

```
dblink_get_pkey(text relname) returns setof dblink_pkey_results
```

Description

`dblink_get_pkey` provides information about the primary key of a relation in the local database. This is sometimes useful in generating queries to be sent to remote databases.

Arguments

relname

Name of a local relation, for example `foo` or `myschema.mytab`. Include double quotes if the name is mixed-case or contains special characters, for example `"FooBar"`; without quotes, the string will be folded to lower case.

Return Value

Returns one row for each primary key field, or no rows if the relation has no primary key. The result row type is defined as

```
CREATE TYPE dblink_pkey_results AS (position int, colname text);
```

The `position` column simply runs from 1 to *N*; it is the number of the field within the primary key, not the number within the table's columns.

Examples

```
CREATE TABLE foobar (
    f1 int,
    f2 int,
    f3 int,
    PRIMARY KEY (f1, f2, f3)
);
CREATE TABLE

SELECT * FROM dblink_get_pkey('foobar');
 position | colname
----------+---------
        1 | f1
        2 | f2
        3 | f3
(3 rows)
```

dblink_build_sql_insert

dblink_build_sql_insert — builds an INSERT statement using a local tuple, replacing the primary key field values with alternative supplied values

Synopsis

```
dblink_build_sql_insert(text relname,
                        int2vector primary_key_attnums,
                        integer num_primary_key_atts,
                        text[] src_pk_att_vals_array,
                        text[] tgt_pk_att_vals_array) returns text
```

Description

`dblink_build_sql_insert` can be useful in doing selective replication of a local table to a remote database. It selects a row from the local table based on primary key, and then builds an SQL `INSERT` command that will duplicate that row, but with the primary key values replaced by the values in the last argument. (To make an exact copy of the row, just specify the same values for the last two arguments.)

Arguments

relname

Name of a local relation, for example `foo` or `myschema.mytab`. Include double quotes if the name is mixed-case or contains special characters, for example `"FooBar"`; without quotes, the string will be folded to lower case.

primary_key_attnums

Attribute numbers (1-based) of the primary key fields, for example `1 2`.

num_primary_key_atts

The number of primary key fields.

src_pk_att_vals_array

Values of the primary key fields to be used to look up the local tuple. Each field is represented in text form. An error is thrown if there is no local row with these primary key values.

tgt_pk_att_vals_array

Values of the primary key fields to be placed in the resulting `INSERT` command. Each field is represented in text form.

Return Value

Returns the requested SQL statement as text.

Notes

As of PostgreSQL 9.0, the attribute numbers in *primary_key_attnums* are interpreted as logical column numbers, corresponding to the column's position in `SELECT * FROM relname`. Previous versions interpreted the numbers as physical column positions. There is a difference if any column(s) to the left of the indicated column have been dropped during the lifetime of the table.

Examples

```
SELECT dblink_build_sql_insert('foo', '1 2', 2, '{"1", "a"}', '{"1", "b''a"}');
             dblink_build_sql_insert
------------------------------------------------
```

```
 INSERT INTO foo(f1,f2,f3) VALUES('1','b''a','1')
(1 row)
```

dblink_build_sql_delete

dblink_build_sql_delete — builds a DELETE statement using supplied values for primary key field values

Synopsis

```
dblink_build_sql_delete(text relname,
                        int2vector primary_key_attnums,
                        integer num_primary_key_atts,
                        text[] tgt_pk_att_vals_array) returns text
```

Description

`dblink_build_sql_delete` can be useful in doing selective replication of a local table to a remote database. It builds an SQL `DELETE` command that will delete the row with the given primary key values.

Arguments

`relname`

Name of a local relation, for example `foo` or `myschema.mytab`. Include double quotes if the name is mixed-case or contains special characters, for example `"FooBar"`; without quotes, the string will be folded to lower case.

`primary_key_attnums`

Attribute numbers (1-based) of the primary key fields, for example `1 2`.

`num_primary_key_atts`

The number of primary key fields.

`tgt_pk_att_vals_array`

Values of the primary key fields to be used in the resulting `DELETE` command. Each field is represented in text form.

Return Value

Returns the requested SQL statement as text.

Notes

As of PostgreSQL 9.0, the attribute numbers in *`primary_key_attnums`* are interpreted as logical column numbers, corresponding to the column's position in `SELECT * FROM relname`. Previous versions interpreted the numbers as physical column positions. There is a difference if any column(s) to the left of the indicated column have been dropped during the lifetime of the table.

Examples

```
SELECT dblink_build_sql_delete('"MyFoo"', '1 2', 2, '{"1", "b"}');
           dblink_build_sql_delete
---------------------------------------------
 DELETE FROM "MyFoo" WHERE f1='1' AND f2='b'
(1 row)
```

dblink_build_sql_update

dblink_build_sql_update — builds an UPDATE statement using a local tuple, replacing the primary key field values with alternative supplied values

Synopsis

```
dblink_build_sql_update(text relname,
                        int2vector primary_key_attnums,
                        integer num_primary_key_atts,
                        text[] src_pk_att_vals_array,
                        text[] tgt_pk_att_vals_array) returns text
```

Description

`dblink_build_sql_update` can be useful in doing selective replication of a local table to a remote database. It selects a row from the local table based on primary key, and then builds an SQL `UPDATE` command that will duplicate that row, but with the primary key values replaced by the values in the last argument. (To make an exact copy of the row, just specify the same values for the last two arguments.) The `UPDATE` command always assigns all fields of the row — the main difference between this and `dblink_build_sql_insert` is that it's assumed that the target row already exists in the remote table.

Arguments

`relname`

Name of a local relation, for example `foo` or `myschema.mytab`. Include double quotes if the name is mixed-case or contains special characters, for example `"FooBar"`; without quotes, the string will be folded to lower case.

`primary_key_attnums`

Attribute numbers (1-based) of the primary key fields, for example `1 2`.

`num_primary_key_atts`

The number of primary key fields.

`src_pk_att_vals_array`

Values of the primary key fields to be used to look up the local tuple. Each field is represented in text form. An error is thrown if there is no local row with these primary key values.

`tgt_pk_att_vals_array`

Values of the primary key fields to be placed in the resulting `UPDATE` command. Each field is represented in text form.

Return Value

Returns the requested SQL statement as text.

Notes

As of PostgreSQL 9.0, the attribute numbers in *`primary_key_attnums`* are interpreted as logical column numbers, corresponding to the column's position in `SELECT * FROM relname`. Previous versions interpreted the numbers as physical column positions. There is a difference if any column(s) to the left of the indicated column have been dropped during the lifetime of the table.

Examples

```
SELECT dblink_build_sql_update('foo', '1 2', 2, '{"1", "a"}', '{"1", "b"}');
                  dblink_build_sql_update
------------------------------------------------------------
```

```
 UPDATE foo SET f1='1',f2='b',f3='1' WHERE f1='1' AND f2='b'
(1 row)
```

F.14. dict_int

dict_int is an example of an add-on dictionary template for full-text search. The motivation for this example dictionary is to control the indexing of integers (signed and unsigned), allowing such numbers to be indexed while preventing excessive growth in the number of unique words, which greatly affects the performance of searching.

This module is considered “trusted”, that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.14.1. Configuration

The dictionary accepts three options:

- The maxlen parameter specifies the maximum number of digits allowed in an integer word. The default value is 6.
- The rejectlong parameter specifies whether an overlength integer should be truncated or ignored. If rejectlong is false (the default), the dictionary returns the first maxlen digits of the integer. If rejectlong is true, the dictionary treats an overlength integer as a stop word, so that it will not be indexed. Note that this also means that such an integer cannot be searched for.
- The absval parameter specifies whether leading “+” or “-” signs should be removed from integer words. The default is false. When true, the sign is removed before maxlen is applied.

F.14.2. Usage

Installing the dict_int extension creates a text search template intdict_template and a dictionary intdict based on it, with the default parameters. You can alter the parameters, for example

```
mydb# ALTER TEXT SEARCH DICTIONARY intdict (MAXLEN = 4, REJECTLONG = true);
ALTER TEXT SEARCH DICTIONARY
```

or create new dictionaries based on the template.

To test the dictionary, you can try

```
mydb# select ts_lexize('intdict', '12345678');
 ts_lexize
-----------
 {123456}
```

but real-world usage will involve including it in a text search configuration as described in Chapter 12. That might look like this:

```
ALTER TEXT SEARCH CONFIGURATION english
    ALTER MAPPING FOR int, uint WITH intdict;
```

F.15. dict_xsyn

dict_xsyn (Extended Synonym Dictionary) is an example of an add-on dictionary template for full-text search. This dictionary type replaces words with groups of their synonyms, and so makes it possible to search for a word using any of its synonyms.

F.15.1. Configuration

A dict_xsyn dictionary accepts the following options:

- matchorig controls whether the original word is accepted by the dictionary. Default is true.
- matchsynonyms controls whether the synonyms are accepted by the dictionary. Default is false.
- keeporig controls whether the original word is included in the dictionary's output. Default is true.

- `keepsynonyms` controls whether the synonyms are included in the dictionary's output. Default is `true`.
- `rules` is the base name of the file containing the list of synonyms. This file must be stored in `$SHAREDIR/tsearch_data/` (where `$SHAREDIR` means the Postgres Pro installation's shared-data directory). Its name must end in `.rules` (which is not to be included in the `rules` parameter).

The rules file has the following format:

- Each line represents a group of synonyms for a single word, which is given first on the line. Synonyms are separated by whitespace, thus:

  ```
  word syn1 syn2 syn3
  ```

- The sharp (`#`) sign is a comment delimiter. It may appear at any position in a line. The rest of the line will be skipped.

Look at `xsyn_sample.rules`, which is installed in `$SHAREDIR/tsearch_data/`, for an example.

F.15.2. Usage

Installing the `dict_xsyn` extension creates a text search template `xsyn_template` and a dictionary `xsyn` based on it, with default parameters. You can alter the parameters, for example

```
mydb# ALTER TEXT SEARCH DICTIONARY xsyn (RULES='my_rules', KEEPORIG=false);
ALTER TEXT SEARCH DICTIONARY
```

or create new dictionaries based on the template.

To test the dictionary, you can try

```
mydb=# SELECT ts_lexize('xsyn', 'word');
      ts_lexize
-----------------------
 {syn1,syn2,syn3}

mydb# ALTER TEXT SEARCH DICTIONARY xsyn (RULES='my_rules', KEEPORIG=true);
ALTER TEXT SEARCH DICTIONARY

mydb=# SELECT ts_lexize('xsyn', 'word');
      ts_lexize
-----------------------
 {word,syn1,syn2,syn3}

mydb# ALTER TEXT SEARCH DICTIONARY xsyn (RULES='my_rules', KEEPORIG=false,
 MATCHSYNONYMS=true);
ALTER TEXT SEARCH DICTIONARY

mydb=# SELECT ts_lexize('xsyn', 'syn1');
      ts_lexize
-----------------------
 {syn1,syn2,syn3}

mydb# ALTER TEXT SEARCH DICTIONARY xsyn (RULES='my_rules', KEEPORIG=true,
 MATCHORIG=false, KEEPSYNONYMS=false);
ALTER TEXT SEARCH DICTIONARY

mydb=# SELECT ts_lexize('xsyn', 'syn1');
      ts_lexize
-----------------------
 {word}
```

Real-world usage will involve including it in a text search configuration as described in Chapter 12. That might look like this:

```
ALTER TEXT SEARCH CONFIGURATION english
    ALTER MAPPING FOR word, asciiword WITH xsyn, english_stem;
```

F.16. dump_stat

The dump_stat module provides functions that allow you to backup and recover the contents of the pg_statistic table. When performing a dump/restore, you can use dump_stat to migrate the original statistics to the new server instead of running the ANALYZE command for the whole database cluster, which can significantly reduce downtime for large databases. The dump_statistic function generates INSERT statements which can later be applied to a compatible database. To successfully restore statistical data, you must install the extension on both the original and the recipient servers since these statements rely on the provided dump_stat functions.

Note that the definition of the pg_statistic table might change occasionally, which means that generated dump might be incompatible with future releases of Postgres Pro.

F.16.1. Installation

The dump_stat extension is included into Postgres Pro. Once you have Postgres Pro installed, you must execute the CREATE EXTENSION command to enable dump_stat, as follows:

```
CREATE EXTENSION dump_stat;
```

F.16.2. Functions

```
anyarray_to_text(array anyarray) returns text
```

Returns the given array as text.

```
dump_statistic() returns setof text
```

dump_statistic dumps the contents of the pg_statistic system catalog. It produces an INSERT statement per each tuple of the pg_statistic, excluding the ones that contain statistical data for tables in the information_schema and pg_catalog schemas.

The INSERT statement takes form of

```
WITH upsert as (
  UPDATE pg_catalog.pg_statistic SET column_name = expression [, ...]
  WHERE starelid = t_relname::regclass
    AND to_attname(t_relname, staattnum) = t_attname
    AND to_atttype(t_relname, staattnum) = t_atttype
    AND stainherit = t_stainherit
  RETURNING *)
ins as (
  SELECT expression [, ...]
  WHERE NOT EXISTS (SELECT * FROM upsert)
    AND to_attnum(t_relname, t_attname) IS NOT NULL
    AND to_atttype(t_relname, t_attname) = t_atttype)
INSERT INTO pg_catalog.pg_statistic SELECT * FROM ins;

where expression can be one of:

array_in(array_text, type_name::regtype::oid, -1)
value::type_name
```

To save the produced statements, redirect the psql output into a file using standard psql options. For details on the available psql options, see psql. Meta-commands starting with a backslash are not supported.

For example, to save statistics for the *dbname* database into a dump_stat.sql file, run:

```
$ psql -XAtq -c "SELECT dump_statistic()" dbname > dump_stat.sql
```

`dump_statistic(schema_name text) returns setof text`

`dump_statistic` dumps the contents of the `pg_statistic` system catalog. It produces an `INSERT` statement per each tuple of the `pg_statistic` that relates to some table in the `schema_name` schema.

`dump_statistic(schema_name text, table_name text) returns setof text`

`dump_statistic` dumps the contents of the `pg_statistic` system catalog. It produces an `INSERT` statement per each tuple of the `pg_statistic` that relates to the specified `schema_name.table_name` table.

`dump_statistic(relation regclass) returns setof text`

`dump_statistic` dumps the contents of the `pg_statistic` system catalog. It produces an `INSERT` statement per each tuple of the `pg_statistic` that contains statistical data for the specified `relation`.

`to_schema_qualified_operator(opid oid) returns text`

Fetches the schema-qualified operator name by operator id `opid`. For example:

```
test=# SELECT to_schema_qualified_operator('+(int,int)'::regoperator);
          to_schema_qualified_operator
-----------------------------------------------
 pg_catalog.+(pg_catalog.int4, pg_catalog.int4)
(1 row)
```

`to_schema_qualified_type(typid oid) returns text`

Fetches the schema-qualified type name by type id `typid`.

`to_schema_qualified_relation(relid oid) returns text`

Fetches the schema-qualified relation name by relation id `relid`.

`anyarray_elemtype(arr anyarray) returns oid`

Returns the element type of the given array as `oid`. For example:

```
test=# SELECT anyarray_elemtype(array_in('{1,2,3}', 'int'::regtype, -1));
 anyarray_elemtype
-------------------
                23
(1 row)
```

`to_attname(relation regclass, colnum int2) returns text`

Given a relation name `relation` and a column number `colnum`, returns the column name as `text`.

`to_attnum(relation regclass, col text) returns int2`

Given a relation name `relation` and a column name `col`, returns the column number as `int2`.

`to_atttype(relation regclass, col text) returns text`

Given a relation name `relation` and a column name `col`, returns the schema-qualified column type as `text`.

`to_atttype(relation regclass, colnum int2) returns text`

Given a relation name `relation` and a column number `colnum`, returns the schema-qualified column type as `text`.

`to_namespace(nsp text) returns oid`

`to_namespace` duplicates the behavior of the cast to the `regnamespace` type, which is not present in the PostgreSQL 9.4 release (and prior releases). This function returns the `oid` of the given schema.

`get_namespace(relation oid) returns oid`

`get_namespace` returns the schema of the given relation as `oid`.

F.17. earthdistance

The `earthdistance` module provides two different approaches to calculating great circle distances on the surface of the Earth. The one described first depends on the `cube` module. The second one is based on the built-in `point` data type, using longitude and latitude for the coordinates.

In this module, the Earth is assumed to be perfectly spherical. (If that's too inaccurate for you, you might want to look at the *PostGIS* project.)

The `cube` module must be installed before `earthdistance` can be installed (although you can use the `CASCADE` option of `CREATE EXTENSION` to install both in one command).

> **Caution**
>
> It is strongly recommended that `earthdistance` and `cube` be installed in the same schema, and that that schema be one for which CREATE privilege has not been and will not be granted to any untrusted users. Otherwise there are installation-time security hazards if `earthdistance`'s schema contains objects defined by a hostile user. Furthermore, when using `earthdistance`'s functions after installation, the entire search path should contain only trusted schemas.

F.17.1. Cube-Based Earth Distances

Data is stored in cubes that are points (both corners are the same) using 3 coordinates representing the x, y, and z distance from the center of the Earth. A domain `earth` over `cube` is provided, which includes constraint checks that the value meets these restrictions and is reasonably close to the actual surface of the Earth.

The radius of the Earth is obtained from the `earth()` function. It is given in meters. But by changing this one function you can change the module to use some other units, or to use a different value of the radius that you feel is more appropriate.

This package has applications to astronomical databases as well. Astronomers will probably want to change `earth()` to return a radius of `180/pi()` so that distances are in degrees.

Functions are provided to support input in latitude and longitude (in degrees), to support output of latitude and longitude, to calculate the great circle distance between two points and to easily specify a bounding box usable for index searches.

The provided functions are shown in Table F.15.

Table F.15. Cube-Based Earthdistance Functions

Function Description
`earth` () → `float8` Returns the assumed radius of the Earth.
`sec_to_gc` (`float8`) → `float8` Converts the normal straight line (secant) distance between two points on the surface of the Earth to the great circle distance between them.
`gc_to_sec` (`float8`) → `float8` Converts the great circle distance between two points on the surface of the Earth to the normal straight line (secant) distance between them.
`ll_to_earth` (`float8`, `float8`) → `earth`

Function Description
Returns the location of a point on the surface of the Earth given its latitude (argument 1) and longitude (argument 2) in degrees.
`latitude` (`earth`) → `float8` Returns the latitude in degrees of a point on the surface of the Earth.
`longitude` (`earth`) → `float8` Returns the longitude in degrees of a point on the surface of the Earth.
`earth_distance` (`earth`, `earth`) → `float8` Returns the great circle distance between two points on the surface of the Earth.
`earth_box` (`earth`, `float8`) → `cube` Returns a box suitable for an indexed search using the `cube @>` operator for points within a given great circle distance of a location. Some points in this box are further than the specified great circle distance from the location, so a second check using `earth_distance` should be included in the query.

F.17.2. Point-Based Earth Distances

The second part of the module relies on representing Earth locations as values of type `point`, in which the first component is taken to represent longitude in degrees, and the second component is taken to represent latitude in degrees. Points are taken as (longitude, latitude) and not vice versa because longitude is closer to the intuitive idea of x-axis and latitude to y-axis.

A single operator is provided, shown in Table F.16.

Table F.16. Point-Based Earthdistance Operators

Operator Description
`point <@> point` → `float8` Computes the distance in statute miles between two points on the Earth's surface.

Note that unlike the `cube`-based part of the module, units are hardwired here: changing the `earth()` function will not affect the results of this operator.

One disadvantage of the longitude/latitude representation is that you need to be careful about the edge conditions near the poles and near +/- 180 degrees of longitude. The `cube`-based representation avoids these discontinuities.

F.18. fasttrun

The `fasttrun` module provides transaction unsafe function to truncate temporary tables without growing pg_class size.

This module is required for 1C Enterprise support.

Fast truncate operation is not transactional, so its results cannot be rolled back and become immediately visible in all sessions regardless of isolation level.

F.18.1. Function

There is a function call example:

```
select fasttruncate('TABLE_NAME');
```

F.18.2. Test example

For tests you can use this example:

```
create or replace function f() returns void as $$
begin
  for i in 1..1000
    loop
      PERFORM fasttruncate('tt1');
    end loop;
  end;
$$ language plpgsql;
```

F.18.3. Authors

Teodor Sigaev <teodor@sigaev.ru>

F.19. file_fdw

The file_fdw module provides the foreign-data wrapper file_fdw, which can be used to access data files in the server's file system, or to execute programs on the server and read their output. The data file or program output must be in a format that can be read by COPY FROM; see COPY for details. Access to data files is currently read-only.

A foreign table created using this wrapper can have the following options:

filename

Specifies the file to be read. Relative paths are relative to the data directory. Either filename or program must be specified, but not both.

program

Specifies the command to be executed. The standard output of this command will be read as though COPY FROM PROGRAM were used. Either program or filename must be specified, but not both.

format

Specifies the data format, the same as COPY's FORMAT option.

header

Specifies whether the data has a header line, the same as COPY's HEADER option.

delimiter

Specifies the data delimiter character, the same as COPY's DELIMITER option.

quote

Specifies the data quote character, the same as COPY's QUOTE option.

escape

Specifies the data escape character, the same as COPY's ESCAPE option.

null

Specifies the data null string, the same as COPY's NULL option.

encoding

Specifies the data encoding, the same as COPY's ENCODING option.

Note that while COPY allows options such as HEADER to be specified without a corresponding value, the foreign table option syntax requires a value to be present in all cases. To activate COPY options typically written without a value, you can pass the value TRUE, since all such options are Booleans.

A column of a foreign table created using this wrapper can have the following options:

`force_not_null`

This is a Boolean option. If true, it specifies that values of the column should not be matched against the null string (that is, the table-level `null` option). This has the same effect as listing the column in `COPY`'s `FORCE_NOT_NULL` option.

`force_null`

This is a Boolean option. If true, it specifies that values of the column which match the null string are returned as `NULL` even if the value is quoted. Without this option, only unquoted values matching the null string are returned as `NULL`. This has the same effect as listing the column in `COPY`'s `FORCE_NULL` option.

`COPY`'s `FORCE_QUOTE` option is currently not supported by `file_fdw`.

These options can only be specified for a foreign table or its columns, not in the options of the `file_fdw` foreign-data wrapper, nor in the options of a server or user mapping using the wrapper.

Changing table-level options requires being a superuser or having the privileges of the role `pg_read_server_files` (to use a filename) or the role `pg_execute_server_program` (to use a program), for security reasons: only certain users should be able to control which file is read or which program is run. In principle regular users could be allowed to change the other options, but that's not supported at present.

When specifying the `program` option, keep in mind that the option string is executed by the shell. If you need to pass any arguments to the command that come from an untrusted source, you must be careful to strip or escape any characters that might have special meaning to the shell. For security reasons, it is best to use a fixed command string, or at least avoid passing any user input in it.

For a foreign table using `file_fdw`, `EXPLAIN` shows the name of the file to be read or program to be run. For a file, unless `COSTS OFF` is specified, the file size (in bytes) is shown as well.

Example F.3. Create a Foreign Table for Postgres Pro CSV Logs

One of the obvious uses for `file_fdw` is to make the Postgres Pro activity log available as a table for querying. To do this, first you must be logging to a CSV file, which here we will call `pglog.csv`. First, install `file_fdw` as an extension:

```
CREATE EXTENSION file_fdw;
```

Then create a foreign server:

```
CREATE SERVER pglog FOREIGN DATA WRAPPER file_fdw;
```

Now you are ready to create the foreign data table. Using the `CREATE FOREIGN TABLE` command, you will need to define the columns for the table, the CSV file name, and its format:

```
CREATE FOREIGN TABLE pglog (
  log_time timestamp(3) with time zone,
  user_name text,
  database_name text,
  process_id integer,
  connection_from text,
  session_id text,
  session_line_num bigint,
  command_tag text,
  session_start_time timestamp with time zone,
  virtual_transaction_id text,
  transaction_id bigint,
  error_severity text,
  sql_state_code text,
  message text,
  detail text,
  hint text,
```

```
  internal_query text,
  internal_query_pos integer,
  context text,
  query text,
  query_pos integer,
  location text,
  application_name text,
  backend_type text,
  leader_pid integer,
  query_id bigint
) SERVER pglog
OPTIONS ( filename 'log/pglog.csv', format 'csv' );
```

That's it — now you can query your log directly. In production, of course, you would need to define some way to deal with log rotation.

F.20. fulleq

The `fulleq` module provides additional equivalence operator for compatibility with Microsoft SQL Server.

This module is required for 1C Enterprise support.

F.20.1. Overview

The Postgres Pro equivalence operator is defined to return NULL when both operands are NULLs. However, the Microsoft SQL Servers family traditionally defines other semantic for equivalence operator, where operator returns TRUE in the case of both nulled operands. This module provides such operator with MS SQL semantic.

F.20.2. Operator fulleq

The == operator is defined for the following data types:

- bool
- bytea
- char
- name
- int2
- int4
- int8
- int2vector
- text
- oid
- xid
- cid
- oidvector
- float4
- float8
- abstime
- reltime
- macaddr
- inet

- cidr
- varchar
- date
- time
- timestamp
- timestamptz
- interval
- timetz

F.20.3. Authors

Teodor Sigaev <teodor@sigaev.ru>

F.21. fuzzystrmatch

The fuzzystrmatch module provides several functions to determine similarities and distance between strings.

> **Caution**
>
> At present, the soundex, metaphone, dmetaphone, and dmetaphone_alt functions do not work well with multibyte encodings (such as UTF-8).

This module is considered “trusted”, that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.21.1. Soundex

The Soundex system is a method of matching similar-sounding names by converting them to the same code. It was initially used by the United States Census in 1880, 1900, and 1910. Note that Soundex is not very useful for non-English names.

The fuzzystrmatch module provides two functions for working with Soundex codes:

```
soundex(text) returns text
difference(text, text) returns int
```

The soundex function converts a string to its Soundex code. The difference function converts two strings to their Soundex codes and then reports the number of matching code positions. Since Soundex codes have four characters, the result ranges from zero to four, with zero being no match and four being an exact match. (Thus, the function is misnamed — similarity would have been a better name.)

Here are some usage examples:

```
SELECT soundex('hello world!');

SELECT soundex('Anne'), soundex('Ann'), difference('Anne', 'Ann');
SELECT soundex('Anne'), soundex('Andrew'), difference('Anne', 'Andrew');
SELECT soundex('Anne'), soundex('Margaret'), difference('Anne', 'Margaret');

CREATE TABLE s (nm text);

INSERT INTO s VALUES ('john');
INSERT INTO s VALUES ('joan');
INSERT INTO s VALUES ('wobbly');
```

```
INSERT INTO s VALUES ('jack');

SELECT * FROM s WHERE soundex(nm) = soundex('john');

SELECT * FROM s WHERE difference(s.nm, 'john') > 2;
```

F.21.2. Levenshtein

This function calculates the Levenshtein distance between two strings:

```
levenshtein(text source, text target, int ins_cost, int del_cost, int sub_cost) returns
 int
levenshtein(text source, text target) returns int
levenshtein_less_equal(text source, text target, int ins_cost, int del_cost, int
 sub_cost, int max_d) returns int
levenshtein_less_equal(text source, text target, int max_d) returns int
```

Both `source` and `target` can be any non-null string, with a maximum of 255 characters. The cost parameters specify how much to charge for a character insertion, deletion, or substitution, respectively. You can omit the cost parameters, as in the second version of the function; in that case they all default to 1.

`levenshtein_less_equal` is an accelerated version of the Levenshtein function for use when only small distances are of interest. If the actual distance is less than or equal to `max_d`, then `levenshtein_less_equal` returns the correct distance; otherwise it returns some value greater than `max_d`. If `max_d` is negative then the behavior is the same as `levenshtein`.

Examples:

```
test=# SELECT levenshtein('GUMBO', 'GAMBOL');
 levenshtein
-------------
           2
(1 row)

test=# SELECT levenshtein('GUMBO', 'GAMBOL', 2, 1, 1);
 levenshtein
-------------
           3
(1 row)

test=# SELECT levenshtein_less_equal('extensive', 'exhaustive', 2);
 levenshtein_less_equal
------------------------
                      3
(1 row)

test=# SELECT levenshtein_less_equal('extensive', 'exhaustive', 4);
 levenshtein_less_equal
------------------------
                      4
(1 row)
```

F.21.3. Metaphone

Metaphone, like Soundex, is based on the idea of constructing a representative code for an input string. Two strings are then deemed similar if they have the same codes.

This function calculates the metaphone code of an input string:

```
metaphone(text source, int max_output_length) returns text
```

source has to be a non-null string with a maximum of 255 characters. max_output_length sets the maximum length of the output metaphone code; if longer, the output is truncated to this length.

Example:

```
test=# SELECT metaphone('GUMBO', 4);
 metaphone
-----------
 KM
(1 row)
```

F.21.4. Double Metaphone

The Double Metaphone system computes two “sounds like” strings for a given input string — a “primary” and an “alternate”. In most cases they are the same, but for non-English names especially they can be a bit different, depending on pronunciation. These functions compute the primary and alternate codes:

```
dmetaphone(text source) returns text
dmetaphone_alt(text source) returns text
```

There is no length limit on the input strings.

Example:

```
test=# SELECT dmetaphone('gumbo');
 dmetaphone
------------
 KMP
(1 row)
```

F.22. hstore

This module implements the hstore data type for storing sets of key/value pairs within a single Postgres Pro value. This can be useful in various scenarios, such as rows with many attributes that are rarely examined, or semi-structured data. Keys and values are simply text strings.

This module is considered “trusted”, that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.22.1. hstore External Representation

The text representation of an hstore, used for input and output, includes zero or more *key* => *value* pairs separated by commas. Some examples:

```
k => v
foo => bar, baz => whatever
"1-a" => "anything at all"
```

The order of the pairs is not significant (and may not be reproduced on output). Whitespace between pairs or around the => sign is ignored. Double-quote keys and values that include whitespace, commas, =s or >s. To include a double quote or a backslash in a key or value, escape it with a backslash.

Each key in an hstore is unique. If you declare an hstore with duplicate keys, only one will be stored in the hstore and there is no guarantee as to which will be kept:

```
SELECT 'a=>1,a=>2'::hstore;
  hstore
----------
 "a"=>"1"
```

A value (but not a key) can be an SQL NULL. For example:

```
key => NULL
```

The NULL keyword is case-insensitive. Double-quote the NULL to treat it as the ordinary string “NULL”.

> **Note**
>
> Keep in mind that the `hstore` text format, when used for input, applies *before* any required quoting or escaping. If you are passing an `hstore` literal via a parameter, then no additional processing is needed. But if you're passing it as a quoted literal constant, then any single-quote characters and (depending on the setting of the `standard_conforming_strings` configuration parameter) backslash characters need to be escaped correctly. See Section 4.1.2.1 for more on the handling of string constants.

On output, double quotes always surround keys and values, even when it's not strictly necessary.

F.22.2. `hstore` Operators and Functions

The operators provided by the `hstore` module are shown in Table F.17, the functions in Table F.18.

Table F.17. `hstore` Operators

Operator Description Example(s)

`hstore -> text → text`
Returns value associated with given key, or `NULL` if not present.
`'a=>x, b=>y'::hstore -> 'a'  → x`

`hstore -> text[] → text[]`
Returns values associated with given keys, or `NULL` if not present.
`'a=>x, b=>y, c=>z'::hstore -> ARRAY['c','a']  → {"z","x"}`

`hstore || hstore → hstore`
Concatenates two `hstore`s.
`'a=>b, c=>d'::hstore || 'c=>x, d=>q'::hstore  → "a"=>"b", "c"=>"x", "d"=>"q"`

`hstore ? text → boolean`
Does `hstore` contain key?
`'a=>1'::hstore ? 'a' → t`

`hstore ?& text[] → boolean`
Does `hstore` contain all the specified keys?
`'a=>1,b=>2'::hstore ?& ARRAY['a','b']  → t`

`hstore ?| text[] → boolean`
Does `hstore` contain any of the specified keys?
`'a=>1,b=>2'::hstore ?| ARRAY['b','c']  → t`

`hstore @> hstore → boolean`
Does left operand contain right?
`'a=>b, b=>1, c=>NULL'::hstore @> 'b=>1'  → t`

`hstore <@ hstore → boolean`
Is left operand contained in right?
`'a=>c'::hstore <@ 'a=>b, b=>1, c=>NULL'  → f`

`hstore - text → hstore`
Deletes key from left operand.
`'a=>1, b=>2, c=>3'::hstore - 'b'::text  → "a"=>"1", "c"=>"3"`

`hstore - text[] → hstore` Deletes keys from left operand.

Operator Description Example(s)
`'a=>1, b=>2, c=>3'::hstore - ARRAY['a','b']` → `"c"=>"3"`

`hstore - hstore → hstore`
Deletes pairs from left operand that match pairs in the right operand.
`'a=>1, b=>2, c=>3'::hstore - 'a=>4, b=>2'::hstore` → `"a"=>"1", "c"=>"3"`

`anyelement #= hstore → anyelement`
Replaces fields in the left operand (which must be a composite type) with matching values from `hstore`.
`ROW(1,3) #= 'f1=>11'::hstore` → `(11,3)`

`%% hstore → text[]`
Converts `hstore` to an array of alternating keys and values.
`%% 'a=>foo, b=>bar'::hstore` → `{a,foo,b,bar}`

`%# hstore → text[]`
Converts `hstore` to a two-dimensional key/value array.
`%# 'a=>foo, b=>bar'::hstore` → `{{a,foo},{b,bar}}`

Table F.18. `hstore` Functions

Function Description Example(s)

`hstore ( record ) → hstore`
Constructs an `hstore` from a record or row.
`hstore(ROW(1,2))` → `"f1"=>"1", "f2"=>"2"`

`hstore ( text[] ) → hstore`
Constructs an `hstore` from an array, which may be either a key/value array, or a two-dimensional array.
`hstore(ARRAY['a','1','b','2'])` → `"a"=>"1", "b"=>"2"`
`hstore(ARRAY[['c','3'],['d','4']])` → `"c"=>"3", "d"=>"4"`

`hstore ( text[], text[] ) → hstore`
Constructs an `hstore` from separate key and value arrays.
`hstore(ARRAY['a','b'], ARRAY['1','2'])` → `"a"=>"1", "b"=>"2"`

`hstore ( text, text ) → hstore`
Makes a single-item `hstore`.
`hstore('a', 'b')` → `"a"=>"b"`

`akeys ( hstore ) → text[]`
Extracts an `hstore`'s keys as an array.
`akeys('a=>1,b=>2')` → `{a,b}`

`skeys ( hstore ) → setof text`
Extracts an `hstore`'s keys as a set.
`skeys('a=>1,b=>2')` →
`a`
`b`

`avals ( hstore ) → text[]` Extracts an `hstore`'s values as an array.

Function
Description
Example(s)

avals('a=>1,b=>2') → {1,2}

svals (hstore) → setof text
Extracts an hstore's values as a set.

```
svals('a=>1,b=>2')  →

1
2
```

hstore_to_array (hstore) → text[]
Extracts an hstore's keys and values as an array of alternating keys and values.
hstore_to_array('a=>1,b=>2') → {a,1,b,2}

hstore_to_matrix (hstore) → text[]
Extracts an hstore's keys and values as a two-dimensional array.
hstore_to_matrix('a=>1,b=>2') → {{a,1},{b,2}}

hstore_to_json (hstore) → json
Converts an hstore to a json value, converting all non-null values to JSON strings.
This function is used implicitly when an hstore value is cast to json.
hstore_to_json('"a key"=>1, b=>t, c=>null, d=>12345, e=>012345,
f=>1.234, g=>2.345e+4') → {"a key": "1", "b": "t", "c": null, "d": "12345",
"e": "012345", "f": "1.234", "g": "2.345e+4"}

hstore_to_jsonb (hstore) → jsonb
Converts an hstore to a jsonb value, converting all non-null values to JSON strings.
This function is used implicitly when an hstore value is cast to jsonb.
hstore_to_jsonb('"a key"=>1, b=>t, c=>null, d=>12345, e=>012345,
f=>1.234, g=>2.345e+4') → {"a key": "1", "b": "t", "c": null, "d": "12345",
"e": "012345", "f": "1.234", "g": "2.345e+4"}

hstore_to_json_loose (hstore) → json
Converts an hstore to a json value, but attempts to distinguish numerical and Boolean values so they are unquoted in the JSON.
hstore_to_json_loose('"a key"=>1, b=>t, c=>null, d=>12345, e=>012345,
f=>1.234, g=>2.345e+4') → {"a key": 1, "b": true, "c": null, "d": 12345,
"e": "012345", "f": 1.234, "g": 2.345e+4}

hstore_to_jsonb_loose (hstore) → jsonb
Converts an hstore to a jsonb value, but attempts to distinguish numerical and Boolean values so they are unquoted in the JSON.
hstore_to_jsonb_loose('"a key"=>1, b=>t, c=>null, d=>12345, e=>012345,
f=>1.234, g=>2.345e+4') → {"a key": 1, "b": true, "c": null, "d": 12345,
"e": "012345", "f": 1.234, "g": 2.345e+4}

slice (hstore, text[]) → hstore
Extracts a subset of an hstore containing only the specified keys.
slice('a=>1,b=>2,c=>3'::hstore, ARRAY['b','c','x']) → "b"=>"2", "c"=>"3"

each (hstore) → setof record (*key* text, *value* text)
Extracts an hstore's keys and values as a set of records.

```
select * from each('a=>1,b=>2')  →

 key | value
-----+-------
```

Function Description Example(s)
a | 1 b | 2
exist (hstore, text) → boolean Does hstore contain key? exist('a=>1', 'a') → t
defined (hstore, text) → boolean Does hstore contain a non-NULL value for key? defined('a=>NULL', 'a') → f
delete (hstore, text) → hstore Deletes pair with matching key. delete('a=>1,b=>2', 'b') → "a"=>"1"
delete (hstore, text[]) → hstore Deletes pairs with matching keys. delete('a=>1,b=>2,c=>3', ARRAY['a','b']) → "c"=>"3"
delete (hstore, hstore) → hstore Deletes pairs matching those in the second argument. delete('a=>1,b=>2', 'a=>4,b=>2'::hstore) → "a"=>"1"
populate_record (anyelement, hstore) → anyelement Replaces fields in the left operand (which must be a composite type) with matching values from hstore. populate_record(ROW(1,2), 'f1=>42'::hstore) → (42,2)

In addition to these operators and functions, values of the hstore type can be subscripted, allowing them to act like associative arrays. Only a single subscript of type text can be specified; it is interpreted as a key and the corresponding value is fetched or stored. For example,

```
CREATE TABLE mytable (h hstore);
INSERT INTO mytable VALUES ('a=>b, c=>d');
SELECT h['a'] FROM mytable;
 h
---
 b
(1 row)

UPDATE mytable SET h['c'] = 'new';
SELECT h FROM mytable;
          h
----------------------
 "a"=>"b", "c"=>"new"
(1 row)
```

A subscripted fetch returns NULL if the subscript is NULL or that key does not exist in the hstore. (Thus, a subscripted fetch is not greatly different from the -> operator.) A subscripted update fails if the subscript is NULL; otherwise, it replaces the value for that key, adding an entry to the hstore if the key does not already exist.

F.22.3. Indexes

hstore has GiST and GIN index support for the @>, ?, ?& and ?| operators. For example:

```
CREATE INDEX hidx ON testhstore USING GIST (h);
```

```
CREATE INDEX hidx ON testhstore USING GIN (h);
```

`gist_hstore_ops` GiST opclass approximates a set of key/value pairs as a bitmap signature. Its optional integer parameter `siglen` determines the signature length in bytes. The default length is 16 bytes. Valid values of signature length are between 1 and 2024 bytes. Longer signatures lead to a more precise search (scanning a smaller fraction of the index and fewer heap pages), at the cost of a larger index.

Example of creating such an index with a signature length of 32 bytes:

```
CREATE INDEX hidx ON testhstore USING GIST (h gist_hstore_ops(siglen=32));
```

`hstore` also supports `btree` or `hash` indexes for the `=` operator. This allows `hstore` columns to be declared `UNIQUE`, or to be used in `GROUP BY`, `ORDER BY` or `DISTINCT` expressions. The sort ordering for `hstore` values is not particularly useful, but these indexes may be useful for equivalence lookups. Create indexes for `=` comparisons as follows:

```
CREATE INDEX hidx ON testhstore USING BTREE (h);

CREATE INDEX hidx ON testhstore USING HASH (h);
```

F.22.4. Examples

Add a key, or update an existing key with a new value:

```
UPDATE tab SET h['c'] = '3';
```

Another way to do the same thing is:

```
UPDATE tab SET h = h || hstore('c', '3');
```

If multiple keys are to be added or changed in one operation, the concatenation approach is more efficient than subscripting:

```
UPDATE tab SET h = h || hstore(array['q', 'w'], array['11', '12']);
```

Delete a key:

```
UPDATE tab SET h = delete(h, 'k1');
```

Convert a `record` to an `hstore`:

```
CREATE TABLE test (col1 integer, col2 text, col3 text);
INSERT INTO test VALUES (123, 'foo', 'bar');

SELECT hstore(t) FROM test AS t;
                  hstore
-----------------------------------------------
 "col1"=>"123", "col2"=>"foo", "col3"=>"bar"
(1 row)
```

Convert an `hstore` to a predefined `record` type:

```
CREATE TABLE test (col1 integer, col2 text, col3 text);

SELECT * FROM populate_record(null::test,
                              '"col1"=>"456", "col2"=>"zzz"');
 col1 | col2 | col3
------+------+------
  456 | zzz  |
(1 row)
```

Modify an existing record using the values from an `hstore`:

```
CREATE TABLE test (col1 integer, col2 text, col3 text);
INSERT INTO test VALUES (123, 'foo', 'bar');
```

```
SELECT (r).* FROM (SELECT t #= '"col3"=>"baz"' AS r FROM test t) s;
 col1 | col2 | col3
------+------+------
  123 | foo  | baz
(1 row)
```

F.22.5. Statistics

The `hstore` type, because of its intrinsic liberality, could contain a lot of different keys. Checking for valid keys is the task of the application. The following examples demonstrate several techniques for checking keys and obtaining statistics.

Simple example:

```
SELECT * FROM each('aaa=>bq, b=>NULL, ""=>1');
```

Using a table:

```
CREATE TABLE stat AS SELECT (each(h)).key, (each(h)).value FROM testhstore;
```

Online statistics:

```
SELECT key, count(*) FROM
  (SELECT (each(h)).key FROM testhstore) AS stat
  GROUP BY key
  ORDER BY count DESC, key;
    key    | count
-----------+-------
 line      |   883
 query     |   207
 pos       |   203
 node      |   202
 space     |   197
 status    |   195
 public    |   194
 title     |   190
 org       |   189
.................
```

F.22.6. Compatibility

As of PostgreSQL 9.0, `hstore` uses a different internal representation than previous versions. This presents no obstacle for dump/restore upgrades since the text representation (used in the dump) is unchanged.

In the event of a binary upgrade, upward compatibility is maintained by having the new code recognize old-format data. This will entail a slight performance penalty when processing data that has not yet been modified by the new code. It is possible to force an upgrade of all values in a table column by doing an `UPDATE` statement as follows:

```
UPDATE tablename SET hstorecol = hstorecol || '';
```

Another way to do it is:

```
ALTER TABLE tablename ALTER hstorecol TYPE hstore USING hstorecol || '';
```

The `ALTER TABLE` method requires an `ACCESS EXCLUSIVE` lock on the table, but does not result in bloating the table with old row versions.

F.22.7. Transforms

Additional extensions are available that implement transforms for the `hstore` type for the languages PL/Perl and PL/Python. The extensions for PL/Perl are called `hstore_plperl` and `hstore_plperlu`, for

trusted and untrusted PL/Perl. If you install these transforms and specify them when creating a function, `hstore` values are mapped to Perl hashes. The extensions for PL/Python are called `hstore_plpythonu`, `hstore_plpython2u`, and `hstore_plpython3u` (see Section 48.1 for the PL/Python naming convention). If you use them, `hstore` values are mapped to Python dictionaries.

> **Caution**
>
> It is strongly recommended that the transform extensions be installed in the same schema as `hstore`. Otherwise there are installation-time security hazards if a transform extension's schema contains objects defined by a hostile user.

F.22.8. Authors

Oleg Bartunov <oleg@sai.msu.su>, Moscow, Moscow University, Russia

Teodor Sigaev <teodor@sigaev.ru>, Moscow, Delta-Soft Ltd., Russia

Additional enhancements by Andrew Gierth <andrew@tao11.riddles.org.uk>, United Kingdom

F.23. Hunspell Dictionaries Modules

These modules provide Hunspell dictionaries for various languages. Upon installation of the module into database using `CREATE EXTENSION` command, text search dictionary and configuration objects in the public schema appear.

Table F.19. Modules

Language	Extension name	Dictionary name	Configuration name
American English	hunspell_en_us	english_hunspell	english_hunspell
Dutch	hunspell_nl_nl	dutch_hunspell	dutch_hunspell
French	hunspell_fr	french_hunspell	french_hunspell
Russian	hunspell_ru_ru	russian_hunspell	russian_hunspell

F.23.1. Examples

Text search objects will be created after installation of a dictionary module. We can test created configuration:

```
SELECT * FROM ts_debug('english_hunspell', 'abilities');
   alias   |   description   |   token   |          dictionaries           |
 dictionary    |  lexemes
-----------+-----------------+-----------+---------------------------------
+-----------------+-----------
 asciiword | Word, all ASCII | abilities | {english_hunspell,english_stem} |
 english_hunspell | {ability}
(1 row)
```

Or you can create your own text search configuration. For example, with the created dictionaries and with the `Snowball` dictionary you can create mixed russian-english configuration:

```
CREATE TEXT SEARCH CONFIGURATION russian_en (
  COPY = simple
);

ALTER TEXT SEARCH CONFIGURATION russian_en
  ALTER MAPPING FOR asciiword, asciihword, hword_asciipart
  WITH english_hunspell, english_stem;
```

```
ALTER TEXT SEARCH CONFIGURATION russian_en
  ALTER MAPPING FOR word, hword, hword_part
  WITH russian_hunspell, russian_stem;
```

You can create mixed dictionaries only for languages with different alphabets. If languages have similar alphabets then Postgres Pro can not decide which dictionary should be used.

A text search configuration which is created with a dictionary module is ready to use. For example, in this text you can search some words:

```
SELECT to_tsvector('english_hunspell', 'The blue whale is the largest animal');
               to_tsvector
-----------------------------------------
 'animal':7 'blue':2 'large':6 'whale':3
(1 row)
```

Search query might looks like this:

```
SELECT to_tsvector('english_hunspell', 'The blue whale is the largest animal')
  @@ to_tsquery('english_hunspell', 'large & whale');
 ?column?
----------
 t
(1 row)
```

With this configurations you can search a text using GIN or GIST indexes. For example, there is a table with GIN index:

```
CREATE TABLE table1 (t varchar);
INSERT INTO table1 VALUES ('The blue whale is the largest animal');
CREATE INDEX t_idx ON table1 USING GIN (to_tsvector('english_hunspell', "t"));
```

For this table you can execute the following query:

```
SELECT * FROM table1 where to_tsvector('english_hunspell', t)
  @@ to_tsquery('english_hunspell', 'blue & animal');
                   t
-------------------------------------
 The blue whale is the largest animal
(1 row)
```

F.24. in_memory

The `in_memory` extension enables you to store data in Postgres Pro shared memory using in-memory tables implemented via foreign data wrappers (FDW).

> **Note**
>
> This extension cannot be used together with prepared transactions or while built-in connection pooling is enabled.

In-memory tables are *index-organized* — table rows are stored in leaf pages of the B-tree index defined on the primary key for the table. This solution offers the following benefits:

- Fast random access on the primary key. This can result in significant performance benefits when working with data that requires a very high read and write access rate, especially on multi-core systems.
- Effective space usage. There is no primary key duplication as all data is stored directly in the index.

In-memory tables support transactions, including savepoints. However, the data in such tables is stored only while the server is running. Once the server is shut down, all in-memory data gets truncated. When using in-memory tables, you should also take into account the following restrictions:

- Persistence, WAL, and data replication are currently not supported for in-memory tables.
- Secondary indexes are not supported.
- Isolation levels are supported up to `REPEATABLE READ`. `SERIALIZABLE` isolation level is not supported. `REPEATABLE READ` level is used instead.
- In-memory tables do not support TOAST or any other mechanism for storing big tuples. Since the in-memory page size is 1 kB, and the B-tree index requires at least three tuples in a page, the maximum row length is limited to 304 bytes.
- When a row is deleted from an in-memory table, the corresponding data page is not freed. See Section F.24.2.3 for details.

F.24.1. Installation and Setup

To enable in-memory tables for your cluster:

1. Make sure that the postgres_fdw module is enabled.
2. Add the `in_memory` value to the `shared_preload_libraries` variable in the `postgresql.conf` file:

   ```
   shared_preload_libraries = 'in_memory'
   ```

3. Create the `in_memory` extension using the following statement:

   ```
   CREATE EXTENSION in_memory;
   ```

As a result, the `in_memory` foreign server is created, and a separate shared memory pool is allocated for in-memory tables, with pre-created pages for storing in-memory data. For in-memory tables, smaller locality is required for effective memory access, as compared to hard drives or SSD, so in-memory page size is 1 kB only. Once the extension is created, you can start using in-memory tables as explained in Section F.24.2.

> **Tip**
>
> If required, you can increase the memory size allocated for in-memory tables. For details, see Section F.24.2.6.

F.24.2. Usage

F.24.2.1. Creating In-Memory Tables

To add an in-memory table to your database, create a foreign table on the `in_memory` server, using the regular CREATE FOREIGN TABLE syntax. By default, a unique B-tree index is built upon the first column, in the ascending order. If required, you can use the `INDICES` option in the `OPTIONS` clause to define a different B-tree index structure, as follows:

```
OPTIONS ( INDICES '[ UNIQUE ] {column [ COLLATE collation ] [ASC | DESC] } [, ... ]' )
```

where *`column`* is the column to include into the B-tree index, and *`collation`* is the name of the collation to use for this column. You can specify up to eight arbitrary columns separated by commas, with sorting options defined for each of these columns (`COLLATE`, `ASC`/`DESC`). The `UNIQUE` declares the created index unique, reiterating the default behavior.

All columns to be used in the B-tree index must be of a type for which the default B-tree operator class is available. For details on operator classes, see Section 11.10.

Examples

Create an in-memory table `blog_views` to store statistics on blog views based on blog post IDs, with the unique B-tree index built upon the first column, in the ascending order:

```
CREATE FOREIGN TABLE blog_views
(
    id int8 NOT NULL,
```

```
    author text,
    views bigint NOT NULL
) SERVER in_memory
OPTIONS (INDICES 'UNIQUE (id)');
```

Define the B-tree index on the `id` and `author` columns, with the `author` values sorted in the ascending order using `"ru_RU"` collation:

```
CREATE FOREIGN TABLE blog_views
(
    id int8 NOT NULL,
    author text,
    views bigint NOT NULL
) SERVER in_memory
OPTIONS (INDICES '(id, author COLLATE "ru_RU" ASC)');
```

F.24.2.2. Running Queries on In-Memory Tables

Once an in-memory table is created, you can run all the main DML operations on this table: `SELECT`, `INSERT`, `UPDATE`, `DELETE`.

If you use the primary key as the scan qualifier when running queries, a key lookup or range scan is performed. Otherwise, a full index scan is required.

Examples

Fill the `blog_views` table with initial zero values for initial ten blog posts:

```
postgres=# INSERT INTO blog_views (SELECT id, 0 FROM generate_series(1, 10) AS id);
```

Increment the view count for a couple of posts and display the result:

```
postgres=# UPDATE blog_views SET views = views + 1 WHERE id = 1;
UPDATE 1
postgres=# UPDATE blog_views SET views = views + 1 WHERE id = 1;
UPDATE 2
postgres=# UPDATE blog_views SET views = views + 1 WHERE id = 2;
UPDATE 1
postgres=# SELECT * FROM blog_views WHERE id = 1 OR id = 2;
 id | views
----+-------
  1 |  2
  2 |  1
(2 rows)
```

Check planning and execution costs for a query that only requires a primary key lookup:

```
postgres=# EXPLAIN ANALYZE SELECT * FROM blog_views WHERE id = 1;
                        QUERY PLAN
-----------------------------------------------------------------------
Foreign Scan on blog_views  (cost=0.02..0.03 rows=1 width=16)
(actual time=0.013..0.014 rows=1 loops=1)
  Pk conds: (id = 1)
Planning time: 0.060 ms
Execution time: 0.035 ms
(4 rows)
```

Check the costs of calculating the sum of all views, which requires a full index scan:

```
postgres=# EXPLAIN ANALYZE SELECT SUM(views) FROM blog_views;
                          QUERY PLAN
-----------------------------------------------------------------------
```

```
Aggregate  (cost=1.62..1.63 rows=1 width=32)
(actual time=0.323..0.323 rows=1 loops=1)
Foreign Scan on blog_views  (cost=0.02..1.30 rows=128 width=8)
(actual time=0.005..0.168 rows=1000 loops=1)
Planning time: 0.113 ms
Execution time: 0.353 ms
(4 rows)
```

F.24.2.3. Deleting In-Memory Data

When a row is deleted from an in-memory table, data pages are not freed. To free the pages occupied by in-memory tables, you can:

- Delete the table using the `DROP FOREIGN TABLE` command.
- Truncate the table using the `TRUNCATE` command.

`RESTART IDENTITY`, `CONTINUE IDENTITY`, `CASCADE`, and `RESTRICT` options of the `TRUNCATE` command are not supported by in-memory tables.

F.24.2.4. Writing Data to In-Memory Tables on Hot Standby

In some cases, it can be useful to perform write operations on hot standby servers. For example, suppose you need to collect statistics on queries run on hot standby. Since in-memory tables are writable, you can use them for such purposes.

To set up in-memory tables for write queries on standby, create the required in-memory tables on the primary server as explained in Section F.24.2.1. Once the replication is complete, you can start writing data to these tables on hot standby.

> **Important**
>
> If the hot standby server is restarted, all the data stored in its in-memory tables gets truncated. You can continue writing data to the same in-memory tables, but all the previously stored data will be lost.

F.24.2.5. Getting Statistics on In-Memory Tables

To get statistics on in-memory pages available in your cluster, run the in_memory_page_stats function, which returns the number of all used and free in-memory pages, as well as the total number of pages allocated for in-memory tables. For example:

```
postgres=# SELECT * FROM in_memory.in_memory_page_stats();
 busy_pages | free_pages | all_pages
------------+------------+-----------
        576 |       7616 |      8192
(1 row)
```

F.24.2.6. Fine-Tuning Memory Settings

F.24.2.6.1. Increasing Shared Memory Pool for In-Memory Tables

In-memory tables are stored in a separate shared memory segment. Its size is defined by the `in_memory.shared_pool_size` parameter. By default, this memory segment is limited to 8 MB.

If the data to be stored in in-memory tables exceeds the size of the allocated memory segment, the following error occurs:

```
ERROR: failed to get a new page: shared pool size is exceeded
```

To avoid such issues, you can increase the `in_memory.shared_pool_size` value, or limit the size of the stored data. Changing the shared pool size requires a server restart.

F.24.2.6.2. Managing the Undo Log

To enable multi-version concurrency control (MVCC), the `in_memory` module uses the *undo log* — a shared-memory ring buffer that stores the previous versions of data entries and pages. The size of the undo log is defined by the `in_memory.undo_size` parameter and is limited to 1 MB by default. If a buffer overflow occurs before a transaction is complete, the following error is returned:

```
ERROR: failed to add undo record: undo size is exceeded
```

To avoid this issue, you can increase the `in_memory.undo_size` value, or split the transactions into smaller ones.

If the required version of the entry or page has already been overwritten in the undo log when it is accessed for read, the following error occurs:

```
ERROR: snapshot is outdated
```

In this case, you can:

- Increase the `in_memory.undo_size` value. Changing this parameter requires a server restart.
- Ensure that the undo log is not truncated while the snapshot is in use. To achieve this, you can use the `READ COMMITTED` isolation level, or split a complex query into several smaller ones.

F.24.3. Reference

F.24.3.1. Configuration Variables

`in_memory.shared_pool_size` (`integer`)

Defines the size of the shared memory segment allocated for in-memory tables.

Default: 8MB

`in_memory.undo_size` (`integer`)

Defines the size of the undo log.

Default: 1MB

F.24.3.2. Functions

`in_memory.in_memory_page_stats()`

Displays statistics on pages of in-memory tables:

- `busy_pages` — in-memory pages containing any data.
- `free_pages` — empty in-memory pages. This number includes all the initially allocated pages to which no data has been written yet, as well as the pages from which all data has been deleted.
- `all_pages` — the total number of in-memory pages allocated on this server.

F.24.4. Authors

Postgres Professional, Moscow, Russia

F.25. intagg

The `intagg` module provides an integer aggregator and an enumerator. `intagg` is now obsolete, because there are built-in functions that provide a superset of its capabilities. However, the module is still provided as a compatibility wrapper around the built-in functions.

F.25.1. Functions

The aggregator is an aggregate function `int_array_aggregate(integer)` that produces an integer array containing exactly the integers it is fed. This is a wrapper around `array_agg`, which does the same thing for any array type.

The enumerator is a function `int_array_enum(integer[])` that returns `setof integer`. It is essentially the reverse operation of the aggregator: given an array of integers, expand it into a set of rows. This is a wrapper around `unnest`, which does the same thing for any array type.

F.25.2. Sample Uses

Many database systems have the notion of a one to many table. Such a table usually sits between two indexed tables, for example:

```
CREATE TABLE left (id INT PRIMARY KEY, ...);
CREATE TABLE right (id INT PRIMARY KEY, ...);
CREATE TABLE one_to_many(left INT REFERENCES left, right INT REFERENCES right);
```

It is typically used like this:

```
SELECT right.* from right JOIN one_to_many ON (right.id = one_to_many.right)
  WHERE one_to_many.left = item;
```

This will return all the items in the right hand table for an entry in the left hand table. This is a very common construct in SQL.

Now, this methodology can be cumbersome with a very large number of entries in the `one_to_many` table. Often, a join like this would result in an index scan and a fetch for each right hand entry in the table for a particular left hand entry. If you have a very dynamic system, there is not much you can do. However, if you have some data which is fairly static, you can create a summary table with the aggregator.

```
CREATE TABLE summary AS
  SELECT left, int_array_aggregate(right) AS right
  FROM one_to_many
  GROUP BY left;
```

This will create a table with one row per left item, and an array of right items. Now this is pretty useless without some way of using the array; that's why there is an array enumerator. You can do

```
SELECT left, int_array_enum(right) FROM summary WHERE left = item;
```

The above query using `int_array_enum` produces the same results as

```
SELECT left, right FROM one_to_many WHERE left = item;
```

The difference is that the query against the summary table has to get only one row from the table, whereas the direct query against `one_to_many` must index scan and fetch a row for each entry.

On one system, an `EXPLAIN` showed a query with a cost of 8488 was reduced to a cost of 329. The original query was a join involving the `one_to_many` table, which was replaced by:

```
SELECT right, count(right) FROM
  ( SELECT left, int_array_enum(right) AS right
    FROM summary JOIN (SELECT left FROM left_table WHERE left = item) AS lefts
         ON (summary.left = lefts.left)
  ) AS list
  GROUP BY right
  ORDER BY count DESC;
```

F.26. intarray

The `intarray` module provides a number of useful functions and operators for manipulating null-free arrays of integers. There is also support for indexed searches using some of the operators.

All of these operations will throw an error if a supplied array contains any NULL elements.

Many of these operations are only sensible for one-dimensional arrays. Although they will accept input arrays of more dimensions, the data is treated as though it were a linear array in storage order.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.26.1. `intarray` Functions and Operators

The functions provided by the `intarray` module are shown in Table F.20, the operators in Table F.21.

Table F.20. `intarray` Functions

Function Description Example(s)

`icount ( integer[] ) → integer`
Returns the number of elements in the array.
`icount('{1,2,3}'::integer[])` → `3`

`sort ( integer[], dir text ) → integer[]`
Sorts the array in either ascending or descending order. *dir* must be `asc` or `desc`.
`sort('{1,3,2}'::integer[], 'desc')` → `{3,2,1}`

`sort ( integer[] ) → integer[]`
`sort_asc ( integer[] ) → integer[]`
Sorts in ascending order.
`sort(array[11,77,44])` → `{11,44,77}`

`sort_desc ( integer[] ) → integer[]`
Sorts in descending order.
`sort_desc(array[11,77,44])` → `{77,44,11}`

`uniq ( integer[] ) → integer[]`
Removes adjacent duplicates. Often used with `sort` to remove all duplicates.
`uniq('{1,2,2,3,1,1}'::integer[])` → `{1,2,3,1}`
`uniq(sort('{1,2,3,2,1}'::integer[]))` → `{1,2,3}`

`idx ( integer[], item integer ) → integer`
Returns index of the first array element matching *item*, or 0 if no match.
`idx(array[11,22,33,22,11], 22)` → `2`

`subarray ( integer[], start integer, len integer ) → integer[]`
Extracts the portion of the array starting at position *start*, with *len* elements.
`subarray('{1,2,3,2,1}'::integer[], 2, 3)` → `{2,3,2}`

`subarray ( integer[], start integer ) → integer[]`
Extracts the portion of the array starting at position *start*.
`subarray('{1,2,3,2,1}'::integer[], 2)` → `{2,3,2,1}`

`intset ( integer ) → integer[]`
Makes a single-element array.
`intset(42)` → `{42}`

Table F.21. `intarray` Operators

Operator Description
`integer[] && integer[] → boolean` Do arrays overlap (have at least one element in common)?
`integer[] @> integer[] → boolean` Does left array contain right array?
`integer[] <@ integer[] → boolean` Is left array contained in right array?

Operator Description
`# integer[]` → `integer` Returns the number of elements in the array.
`integer[] # integer` → `integer` Returns index of the first array element matching the right argument, or 0 if no match. (Same as `idx` function.)
`integer[] + integer` → `integer[]` Adds element to end of array.
`integer[] + integer[]` → `integer[]` Concatenates the arrays.
`integer[] - integer` → `integer[]` Removes entries matching the right argument from the array.
`integer[] - integer[]` → `integer[]` Removes elements of the right array from the left array.
`integer[] | integer` → `integer[]` Computes the union of the arguments.
`integer[] | integer[]` → `integer[]` Computes the union of the arguments.
`integer[] & integer[]` → `integer[]` Computes the intersection of the arguments.
`integer[] @@ query_int` → `boolean` Does array satisfy query? (see below)
`query_int ~~ integer[]` → `boolean` Does array satisfy query? (commutator of `@@`)

The operators `&&`, `@>` and `<@` are equivalent to Postgres Pro's built-in operators of the same names, except that they work only on integer arrays that do not contain nulls, while the built-in operators work for any array type. This restriction makes them faster than the built-in operators in many cases.

The `@@` and `~~` operators test whether an array satisfies a *query*, which is expressed as a value of a specialized data type `query_int`. A *query* consists of integer values that are checked against the elements of the array, possibly combined using the operators `&` (AND), `|` (OR), and `!` (NOT). Parentheses can be used as needed. For example, the query `1&(2|3)` matches arrays that contain 1 and also contain either 2 or 3.

F.26.2. Index Support

`intarray` provides index support for the `&&`, `@>`, and `@@` operators, as well as regular array equality.

Two parameterized GiST index operator classes are provided: `gist__int_ops` (used by default) is suitable for small- to medium-size data sets, while `gist__intbig_ops` uses a larger signature and is more suitable for indexing large data sets (i.e., columns containing a large number of distinct array values). The implementation uses an RD-tree data structure with built-in lossy compression.

`gist__int_ops` approximates an integer set as an array of integer ranges. Its optional integer parameter `numranges` determines the maximum number of ranges in one index key. The default value of `numranges` is 100. Valid values are between 1 and 253. Using larger arrays as GiST index keys leads to a more precise search (scanning a smaller fraction of the index and fewer heap pages), at the cost of a larger index.

`gist__intbig_ops` approximates an integer set as a bitmap signature. Its optional integer parameter `siglen` determines the signature length in bytes. The default signature length is 16 bytes. Valid values

of signature length are between 1 and 2024 bytes. Longer signatures lead to a more precise search (scanning a smaller fraction of the index and fewer heap pages), at the cost of a larger index.

There is also a non-default GIN operator class `gin__int_ops`, which supports these operators as well as `<@`.

The choice between GiST and GIN indexing depends on the relative performance characteristics of GiST and GIN, which are discussed elsewhere.

F.26.3. Example

```
-- a message can be in one or more “sections”
CREATE TABLE message (mid INT PRIMARY KEY, sections INT[], ...);

-- create specialized index with signature length of 32 bytes
CREATE INDEX message_rdtree_idx ON message USING GIST (sections gist__intbig_ops
 (siglen = 32));

-- select messages in section 1 OR 2 - OVERLAP operator
SELECT message.mid FROM message WHERE message.sections && '{1,2}';

-- select messages in sections 1 AND 2 - CONTAINS operator
SELECT message.mid FROM message WHERE message.sections @> '{1,2}';

-- the same, using QUERY operator
SELECT message.mid FROM message WHERE message.sections @@ '1&2'::query_int;
```

F.26.4. Authors

All work was done by Teodor Sigaev (<teodor@sigaev.ru>) and Oleg Bartunov (<oleg@sai.msu.su>). See *http://www.sai.msu.su/~megera/postgres/gist/* for additional information. Andrey Oktyabrski did a great work on adding new functions and operations.

F.27. isn

The `isn` module provides data types for the following international product numbering standards: EAN13, UPC, ISBN (books), ISMN (music), and ISSN (serials). Numbers are validated on input according to a hard-coded list of prefixes; this list of prefixes is also used to hyphenate numbers on output. Since new prefixes are assigned from time to time, the list of prefixes may be out of date. It is hoped that a future version of this module will obtain the prefix list from one or more tables that can be easily updated by users as needed; however, at present, the list can only be updated by modifying the source code and recompiling. Alternatively, prefix validation and hyphenation support may be dropped from a future version of this module.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.27.1. Data Types

Table F.22 shows the data types provided by the `isn` module.

Table F.22. `isn` Data Types

Data Type	Description
`EAN13`	European Article Numbers, always displayed in the EAN13 display format
`ISBN13`	International Standard Book Numbers to be displayed in the new EAN13 display format

Data Type	Description
ISMN13	International Standard Music Numbers to be displayed in the new EAN13 display format
ISSN13	International Standard Serial Numbers to be displayed in the new EAN13 display format
ISBN	International Standard Book Numbers to be displayed in the old short display format
ISMN	International Standard Music Numbers to be displayed in the old short display format
ISSN	International Standard Serial Numbers to be displayed in the old short display format
UPC	Universal Product Codes

Some notes:

1. ISBN13, ISMN13, ISSN13 numbers are all EAN13 numbers.
2. EAN13 numbers aren't always ISBN13, ISMN13 or ISSN13 (some are).
3. Some ISBN13 numbers can be displayed as ISBN.
4. Some ISMN13 numbers can be displayed as ISMN.
5. Some ISSN13 numbers can be displayed as ISSN.
6. UPC numbers are a subset of the EAN13 numbers (they are basically EAN13 without the first 0 digit).
7. All UPC, ISBN, ISMN and ISSN numbers can be represented as EAN13 numbers.

Internally, all these types use the same representation (a 64-bit integer), and all are interchangeable. Multiple types are provided to control display formatting and to permit tighter validity checking of input that is supposed to denote one particular type of number.

The ISBN, ISMN, and ISSN types will display the short version of the number (ISxN 10) whenever it's possible, and will show ISxN 13 format for numbers that do not fit in the short version. The EAN13, ISBN13, ISMN13 and ISSN13 types will always display the long version of the ISxN (EAN13).

F.27.2. Casts

The isn module provides the following pairs of type casts:

- ISBN13 <=> EAN13
- ISMN13 <=> EAN13
- ISSN13 <=> EAN13
- ISBN <=> EAN13
- ISMN <=> EAN13
- ISSN <=> EAN13
- UPC <=> EAN13
- ISBN <=> ISBN13
- ISMN <=> ISMN13
- ISSN <=> ISSN13

When casting from EAN13 to another type, there is a run-time check that the value is within the domain of the other type, and an error is thrown if not. The other casts are simply relabelings that will always succeed.

F.27.3. Functions and Operators

The `isn` module provides the standard comparison operators, plus B-tree and hash indexing support for all these data types. In addition there are several specialized functions; shown in Table F.23. In this table, `isn` means any one of the module's data types.

Table F.23. `isn` Functions

Function Description
`isn_weak ( boolean ) → boolean` Sets the weak input mode, and returns new setting.
`isn_weak () → boolean` Returns the current status of the weak mode.
`make_valid ( isn ) → isn` Validates an invalid number (clears the invalid flag).
`is_valid ( isn ) → boolean` Checks for the presence of the invalid flag.

Weak mode is used to be able to insert invalid data into a table. Invalid means the check digit is wrong, not that there are missing numbers.

Why would you want to use the weak mode? Well, it could be that you have a huge collection of ISBN numbers, and that there are so many of them that for weird reasons some have the wrong check digit (perhaps the numbers were scanned from a printed list and the OCR got the numbers wrong, perhaps the numbers were manually captured... who knows). Anyway, the point is you might want to clean the mess up, but you still want to be able to have all the numbers in your database and maybe use an external tool to locate the invalid numbers in the database so you can verify the information and validate it more easily; so for example you'd want to select all the invalid numbers in the table.

When you insert invalid numbers in a table using the weak mode, the number will be inserted with the corrected check digit, but it will be displayed with an exclamation mark (`!`) at the end, for example `0-11-000322-5!`. This invalid marker can be checked with the `is_valid` function and cleared with the `make_valid` function.

You can also force the insertion of invalid numbers even when not in the weak mode, by appending the `!` character at the end of the number.

Another special feature is that during input, you can write `?` in place of the check digit, and the correct check digit will be inserted automatically.

F.27.4. Examples

```
--Using the types directly:
SELECT isbn('978-0-393-04002-9');
SELECT isbn13('0901690546');
SELECT issn('1436-4522');

--Casting types:
-- note that you can only cast from ean13 to another type when the
-- number would be valid in the realm of the target type;
-- thus, the following will NOT work: select isbn(ean13('0220356483481'));
-- but these will:
SELECT upc(ean13('0220356483481'));
SELECT ean13(upc('220356483481'));

--Create a table with a single column to hold ISBN numbers:
```

```
CREATE TABLE test (id isbn);
INSERT INTO test VALUES('9780393040029');

--Automatically calculate check digits (observe the '?'):
INSERT INTO test VALUES('220500896?');
INSERT INTO test VALUES('978055215372?');

SELECT issn('3251231?');
SELECT ismn('979047213542?');

--Using the weak mode:
SELECT isn_weak(true);
INSERT INTO test VALUES('978-0-11-000533-4');
INSERT INTO test VALUES('9780141219307');
INSERT INTO test VALUES('2-205-00876-X');
SELECT isn_weak(false);

SELECT id FROM test WHERE NOT is_valid(id);
UPDATE test SET id = make_valid(id) WHERE id = '2-205-00876-X!';

SELECT * FROM test;

SELECT isbn13(id) FROM test;
```

F.27.5. Bibliography

The information to implement this module was collected from several sites, including:

- *https://www.isbn-international.org/*
- *https://www.issn.org/*
- *https://www.ismn-international.org/*
- *https://www.wikipedia.org/*

The prefixes used for hyphenation were also compiled from:

- *https://www.gs1.org/standards/id-keys*
- *https://en.wikipedia.org/wiki/List_of_ISBN_identifier_groups*
- *https://www.isbn-international.org/content/isbn-users-manual/29*
- *https://en.wikipedia.org/wiki/International_Standard_Music_Number*
- *https://www.ismn-international.org/ranges/tools*

Care was taken during the creation of the algorithms and they were meticulously verified against the suggested algorithms in the official ISBN, ISMN, ISSN User Manuals.

F.27.6. Author

Germán Méndez Bravo (Kronuz), 2004–2006

This module was inspired by Garrett A. Wollman's `isbn_issn` code.

F.28. jsquery

JsQuery is a language to query `jsonb` data type. Its primary goal is to provide an additional functionality for `jsonb`, such as a simple and effective way for search in nested objects and arrays, as well as additional comparison operators with index support.

JsQuery is implemented by means of a `jsquery` data type (similar to `tsquery`) and the `@@` match operator for `jsonb`.

F.28.1. Installation

Postgres Pro Enterprise distribution includes jsquery as a contrib module. Once you complete Postgres Pro Enterprise installation, create the jsquery extension, as follows:

```
CREATE EXTENSION jsquery;
```

F.28.2. JSON query language

JsQuery extension contains `jsquery` datatype which represents whole JSON query as a single value (like `tsquery` does for fulltext search). The query is an expression on JSON-document values.

Simple expression is specified as *`path binary_operator value`* or *`path unary_operator`*. See the following examples.

- `x = "abc"` - value of key "x" is equal to "abc";
- `$ @> [4, 5, "zzz"]` - the JSON document is an array containing values 4, 5 and "zzz";
- `"abc xyz" >= 10` - value of key "abc xyz" is greater than or equal to 10;
- `volume IS NUMERIC` - type of key "volume" is numeric.
- `$ = true` - the whole JSON document is just a true.
- `similar_ids.@# > 5` - `similar_ids` is an array or object of length greater than 5;
- `similar_product_ids.# = "0684824396"` - array `similar_product_ids` contains string "0684824396".
- `*.color = "red"` - there is object somewhere which key "color" has value "red".
- `foo = *` - key "foo" exists in object.

Path selects set of JSON values to be checked using given operators. In the simplest case, path is just a key name. In general, path is key names and placeholders combined by dot signs. Path can use the following placeholders:

- `#` - any index of array;
- `#N` - Nth index of array;
- `%` - any key of object;
- `*` - any sequence of array indexes and object keys;
- `@#` - length of array or object, could be only used as last component of path;
- `$` - the whole JSON document as single value, could be only the whole path.

Expression is true when operator is true against at least one value selected by path.

Key names could be given either with or without double quotes. Key names without double quotes shouldn't contain spaces, start with number, or concur with jsquery keyword.

The supported binary operators are:

- Equality operator: `=`;
- Numeric comparison operators: `>`, `>=`, `<`, `<=`;
- Search in the list of scalar values using `IN` operator;
- Array comparison operators: `&&` (overlap), `@>` (contains), `<@` (contained in).
- Filtering operator: `~~`. Taking `jsonb` data as the left operand and a `jsquery` expression as the right operand, this operator checks that `jsonb` data contains any entries that satisfy the condition provided in a `jsquery` expression and returns an array of such entries, if any.

The supported unary operators are:

- Check for existence operator: `= *`;
- Check for type operators: `IS ARRAY`, `IS NUMERIC`, `IS OBJECT`, `IS STRING` and `IS BOOLEAN`.

Expressions could be complex. Complex expression is a set of expressions combined by logical operators (`AND`, `OR`, `NOT`) and grouped using parentheses.

Examples of complex expressions are given below.

- `a = 1 AND (b = 2 OR c = 3) AND NOT d = 1`
- `x.% = true OR x.# = true`

Prefix expressions are expressions given in the form path (subexpression). In this case path selects JSON values to be checked using given subexpression. Check results are aggregated in the same way as in simple expressions.

- `#(a = 1 AND b = 2)` - an array contains an element where the `a` key is 2 and the `b` key is 2
- `%($ >= 10 AND $ <= 20)` - an object contains a key with a value between 10 and 20

Path also could contain the following special placeholders with "every" semantics:

- `#:` - every index of array;
- `%:` - every key of object;
- `*:` - every sequence of array indexes and object keys.

Consider the following example.

```
%.#:($ >= 0 AND $ <= 1)
```

This example could be read as follows: there is at least one key for which the value is an array of numerics between 0 and 1.

We can rewrite this example in the following form with extra parentheses.

```
%(#:($ >= 0 AND $ <= 1))
```

The first placeholder `%` checks that expression in parentheses is true for at least one value in object. The second placeholder `#:` checks that the value is an array and all its elements satisfy expressions in parentheses.

We can rewrite this example without `#:` placeholder as follows.

```
%(NOT #(NOT ($ >= 0 AND $ <= 1)) AND $ IS ARRAY)
```

In this example we transform assertion that every element of array satisfies some condition to assertion that there is no one element which doesn't satisfy the same condition.

Some examples of using paths are given below.

- `numbers.#: IS NUMERIC` - every element of "numbers" array is numeric.
- `*:($ IS OBJECT OR $ IS BOOLEAN)` - JSON is a structure of nested objects with booleans as leaf values.
- `#:.%:($ >= 0 AND $ <= 1)` - each element of array is object containing only numeric values between 0 and 1.
- `documents.#:.% = *` - "documents" is an array of objects containing at least one key.
- `%.#: ($ IS STRING)` - JSON object contains at least one array of strings.
- `#.% = true` - at least one array element is an object that contains at least one "true" value.

Usage of path operators and parentheses needs some explanation. When same path operators are used multiple times they may refer to different values while you can refer to the same value multiple times by using parentheses and `$` operator. See the following examples.

- `# < 10 AND # > 20` - there is an element less than 10 and another element greater than 20.
- `#($ < 10 AND $ > 20)` - there is an element that is both less than 10 and greater than 20 (impossible).
- `#($ >= 10 AND $ <= 20)` - there is an element between 10 and 20.
- `# >= 10 AND # <= 20` - there is an element greater than or equal to 10 and another element less than or equal to 20. The query can be satisfied by an array with no elements between 10 and 20, for instance [0,30].

Same rules apply when you search inside objects and branchy structures.

Type checking operators and "every" placeholders are useful for document schema validation. JsQuery matching operator `@@` is immutable and can be used in CHECK constraint. See the following example.

```
CREATE TABLE js (
    id serial,
    data jsonb,
    CHECK (data @@ '
        name IS STRING AND
        similar_ids.#: IS NUMERIC AND
        points.#:(x IS NUMERIC AND y IS NUMERIC)'::jsquery));
```

In this example check constraint validates that in "data" jsonb column: value of "name" key is string, value of "similar_ids" key is array of numerics, value of "points" key is array of objects which contain numeric values in "x" and "y" keys.

See our *pgconf.eu presentation* for more examples.

F.28.3. GIN indexes

JsQuery extension contains two operator classes (opclasses) for GIN which provide different kinds of query optimization.

- jsonb_path_value_ops
- jsonb_value_path_ops

In each of two GIN opclasses jsonb documents are decomposed into entries. Each entry is associated with a particular value and its path. Difference between opclasses is in the entry representation, comparison, and usage for search optimization.

For example, jsonb document `{"a": [{"b": "xyz", "c": true}, 10], "d": {"e": [7, false]}}` would be decomposed into the following entries:

- `"a".#."b"."xyz"`
- `"a".#."c".true`
- `"a".#.10`
- `"d"."e".#.7`
- `"d"."e".#.false`

Since JsQuery doesn't support search in a particular array index, we consider all array elements to be equivalent. Thus, each array element is marked with the same `#` sign in the path.

Major problem in the entries representation is its size. In the given example key "a" is presented three times. In the large branchy documents with long keys size of naive entries representation becomes unreasonable. Both opclasses address this issue but in a slightly different way.

F.28.3.1. jsonb_path_value_ops

jsonb_path_value_ops represents entry as pair of path hash and value. The following pseudocode illustrates it.

```
(hash(path_item_1.path_item_2. ... .path_item_n); value)
```

In comparison of entries path hash is the higher part of entry and value is its lower part. This determines the features of this opclass. Since path is hashed and it is higher part of entry we need to know the full path to the value in order to use it for search. However, once path is specified we can use both exact and range searches very efficiently.

F.28.3.2. jsonb_value_path_ops

jsonb_value_path_ops represents entry as pair of value and bloom filter of path.

```
(value; bloom(path_item_1) | bloom(path_item_2) | ... | bloom(path_item_n))
```

In comparison of entries value is the higher part of entry and bloom filter of path is its lower part. This determines the features of this opclass. Since value is the higher part of entry we can perform only exact value search efficiently. Range value search is possible as well but we would have to filter all

the different paths where matching values occur. Bloom filter over path items allows index usage for conditions containing `%` and `*` in their paths.

F.28.3.3. Query optimization

JsQuery opclasses perform complex query optimization. Thus it's valuable for developer or administrator to see the result of such optimization. Unfortunately, opclasses aren't allowed to do any custom output to the EXPLAIN. That's why JsQuery provides the following functions which allows to see how particular opclass optimizes given query.

- gin_debug_query_path_value(jsquery) - for jsonb_path_value_ops
- gin_debug_query_value_path(jsquery) - for jsonb_value_path_ops

Result of these functions is a textual representation of query tree which leaves are GIN search entries. The following examples show different results of query optimization by different opclasses.

```
# SELECT gin_debug_query_path_value('x = 1 AND (*.y = 1 OR y = 2)');
 gin_debug_query_path_value
----------------------------
 x = 1 , entry 0           +

# SELECT gin_debug_query_value_path('x = 1 AND (*.y = 1 OR y = 2)');
 gin_debug_query_value_path
----------------------------
 AND                       +
   x = 1 , entry 0         +
   OR                      +
     *.y = 1 , entry 1     +
     y = 2 , entry 2       +
```

Unfortunately, jsonb has no statistics yet. That's why JsQuery optimizer has to do imperative decision while selecting conditions to be evaluated using index. This decision is made by assumption that some condition types are less selective than others. Optimizer divides conditions into the following selectivity class (listed by descending of selectivity).

1. Equality (x = c)
2. Range (c1 < x < c2)
3. Inequality (x > c)
4. Is (x is type)
5. Any (x = *)

Optimizer evades index evaluation of less selective conditions when possible. For example, in the `x = 1 AND y > 0` query `x = 1` is assumed to be more selective than `y > 0`. That's why index isn't used for evaluation of `y > 0`.

```
# SELECT gin_debug_query_path_value('x = 1 AND y > 0');
 gin_debug_query_path_value
----------------------------
 x = 1 , entry 0           +
```

With lack of statistics decisions made by optimizer can be inaccurate. That's why JsQuery supports hints. Comments `/*-- index */` and `/*-- noindex */` placed in the conditions force optimizer to use and not to use index correspondingly.

```
SELECT gin_debug_query_path_value('x = 1 AND y /*-- index */ > 0');
 gin_debug_query_path_value
----------------------------
 AND                       +
   x = 1 , entry 0         +
   y > 0 , entry 1         +

SELECT gin_debug_query_path_value('x /*-- noindex */ = 1 AND y > 0');
```

```
gin_debug_query_path_value
---------------------------
 y > 0 , entry 0           +
```

F.28.4. Authors

- Teodor Sigaev <teodor@sigaev.ru>, Postgres Professional, Moscow, Russia
- Alexander Korotkov <aekorotkov@gmail.com>, Postgres Professional, Moscow, Russia
- Oleg Bartunov <oleg@sai.msu.su>, Postgres Professional, Moscow, Russia

F.28.5. Credits

Development is sponsored by *Wargaming.net*.

F.29. lo

The `lo` module provides support for managing Large Objects (also called LOs or BLOBs). This includes a data type `lo` and a trigger `lo_manage`.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.29.1. Rationale

One of the problems with the JDBC driver (and this affects the ODBC driver also), is that the specification assumes that references to BLOBs (Binary Large OBjects) are stored within a table, and if that entry is changed, the associated BLOB is deleted from the database.

As Postgres Pro stands, this doesn't occur. Large objects are treated as objects in their own right; a table entry can reference a large object by OID, but there can be multiple table entries referencing the same large object OID, so the system doesn't delete the large object just because you change or remove one such entry.

Now this is fine for Postgres Pro-specific applications, but standard code using JDBC or ODBC won't delete the objects, resulting in orphan objects — objects that are not referenced by anything, and simply occupy disk space.

The `lo` module allows fixing this by attaching a trigger to tables that contain LO reference columns. The trigger essentially just does a `lo_unlink` whenever you delete or modify a value referencing a large object. When you use this trigger, you are assuming that there is only one database reference to any large object that is referenced in a trigger-controlled column!

The module also provides a data type `lo`, which is really just a domain of the `oid` type. This is useful for differentiating database columns that hold large object references from those that are OIDs of other things. You don't have to use the `lo` type to use the trigger, but it may be convenient to use it to keep track of which columns in your database represent large objects that you are managing with the trigger. It is also rumored that the ODBC driver gets confused if you don't use `lo` for BLOB columns.

F.29.2. How to Use It

Here's a simple example of usage:

```
CREATE TABLE image (title text, raster lo);

CREATE TRIGGER t_raster BEFORE UPDATE OR DELETE ON image
    FOR EACH ROW EXECUTE FUNCTION lo_manage(raster);
```

For each column that will contain unique references to large objects, create a `BEFORE UPDATE OR DELETE` trigger, and give the column name as the sole trigger argument. You can also restrict the trigger to only execute on updates to the column by using `BEFORE UPDATE OF` *`column_name`*. If you need multiple `lo` columns in the same table, create a separate trigger for each one, remembering to give a different name to each trigger on the same table.

F.29.3. Limitations

- Dropping a table will still orphan any objects it contains, as the trigger is not executed. You can avoid this by preceding the `DROP TABLE` with `DELETE FROM *table*`.

  `TRUNCATE` has the same hazard.

  If you already have, or suspect you have, orphaned large objects, see the vacuumlo module to help you clean them up. It's a good idea to run vacuumlo occasionally as a back-stop to the `lo_manage` trigger.

- Some frontends may create their own tables, and will not create the associated trigger(s). Also, users may not remember (or know) to create the triggers.

F.29.4. Author

Peter Mount `<peter@retep.org.uk>`

F.30. ltree

This module implements a data type `ltree` for representing labels of data stored in a hierarchical tree-like structure. Extensive facilities for searching through label trees are provided.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.30.1. Definitions

A *label* is a sequence of alphanumeric characters and underscores (for example, in C locale the characters `A-Za-z0-9_` are allowed). Labels must be less than 256 characters long.

Examples: `42`, `Personal_Services`

A *label path* is a sequence of zero or more labels separated by dots, for example `L1.L2.L3`, representing a path from the root of a hierarchical tree to a particular node. The length of a label path cannot exceed 65535 labels.

Example: `Top.Countries.Europe.Russia`

The `ltree` module provides several data types:

- `ltree` stores a label path.
- `lquery` represents a regular-expression-like pattern for matching `ltree` values. A simple word matches that label within a path. A star symbol (`*`) matches zero or more labels. These can be joined with dots to form a pattern that must match the whole label path. For example:

  ```
  foo         Match the exact label path foo
  *.foo.*     Match any label path containing the label foo
  *.foo       Match any label path whose last label is foo
  ```

  Both star symbols and simple words can be quantified to restrict how many labels they can match:

  ```
  *{n}        Match exactly n labels
  *{n,}       Match at least n labels
  *{n,m}      Match at least n but not more than m labels
  *{,m}       Match at most m labels — same as *{0,m}
  foo{n,m}    Match at least n but not more than m occurrences of foo
  foo{,}      Match any number of occurrences of foo, including zero
  ```

  In the absence of any explicit quantifier, the default for a star symbol is to match any number of labels (that is, `{,}`) while the default for a non-star item is to match exactly once (that is, `{1}`).

There are several modifiers that can be put at the end of a non-star `lquery` item to make it match more than just the exact match:

```
@           Match case-insensitively, for example a@ matches A
*           Match any label with this prefix, for example foo* matches foobar
%           Match initial underscore-separated words
```

The behavior of `%` is a bit complicated. It tries to match words rather than the entire label. For example `foo_bar%` matches `foo_bar_baz` but not `foo_barbaz`. If combined with `*`, prefix matching applies to each word separately, for example `foo_bar%*` matches `foo1_bar2_baz` but not `foo1_br2_baz`.

Also, you can write several possibly-modified non-star items separated with `|` (OR) to match any of those items, and you can put `!` (NOT) at the start of a non-star group to match any label that doesn't match any of the alternatives. A quantifier, if any, goes at the end of the group; it means some number of matches for the group as a whole (that is, some number of labels matching or not matching any of the alternatives).

Here's an annotated example of `lquery`:

```
Top.*{0,2}.sport*@.!football|tennis{1,}.Russ*|Spain
a.  b.     c.      d.                   e.
```

This query will match any label path that:

a. begins with the label `Top`

b. and next has zero to two labels before

c. a label beginning with the case-insensitive prefix `sport`

d. then has one or more labels, none of which match `football` nor `tennis`

e. and then ends with a label beginning with `Russ` or exactly matching `Spain`.

- `ltxtquery` represents a full-text-search-like pattern for matching `ltree` values. An `ltxtquery` value contains words, possibly with the modifiers `@`, `*`, `%` at the end; the modifiers have the same meanings as in `lquery`. Words can be combined with `&` (AND), `|` (OR), `!` (NOT), and parentheses. The key difference from `lquery` is that `ltxtquery` matches words without regard to their position in the label path.

  Here's an example `ltxtquery`:

  ```
  Europe & Russia*@ & !Transportation
  ```

  This will match paths that contain the label `Europe` and any label beginning with `Russia` (case-insensitive), but not paths containing the label `Transportation`. The location of these words within the path is not important. Also, when `%` is used, the word can be matched to any underscore-separated word within a label, regardless of position.

Note: `ltxtquery` allows whitespace between symbols, but `ltree` and `lquery` do not.

F.30.2. Operators and Functions

Type `ltree` has the usual comparison operators `=`, `<>`, `<`, `>`, `<=`, `>=`. Comparison sorts in the order of a tree traversal, with the children of a node sorted by label text. In addition, the specialized operators shown in Table F.24 are available.

Table F.24. `ltree` Operators

Operator Description
`ltree @> ltree` → `boolean`

Operator Description
Is left argument an ancestor of right (or equal)?
`ltree <@ ltree → boolean` Is left argument a descendant of right (or equal)?

`ltree ~ lquery → boolean`
`lquery ~ ltree → boolean`
Does `ltree` match `lquery`?

`ltree ? lquery[] → boolean`
`lquery[] ? ltree → boolean`
Does `ltree` match any `lquery` in array?

`ltree @ ltxtquery → boolean`
`ltxtquery @ ltree → boolean`
Does `ltree` match `ltxtquery`?

`ltree || ltree → ltree` Concatenates `ltree` paths.

`ltree || text → ltree`
`text || ltree → ltree`
Converts text to `ltree` and concatenates.

`ltree[] @> ltree → boolean`
`ltree <@ ltree[] → boolean`
Does array contain an ancestor of `ltree`?

`ltree[] <@ ltree → boolean`
`ltree @> ltree[] → boolean`
Does array contain a descendant of `ltree`?

`ltree[] ~ lquery → boolean`
`lquery ~ ltree[] → boolean`
Does array contain any path matching `lquery`?

`ltree[] ? lquery[] → boolean`
`lquery[] ? ltree[] → boolean`
Does `ltree` array contain any path matching any `lquery`?

`ltree[] @ ltxtquery → boolean`
`ltxtquery @ ltree[] → boolean`
Does array contain any path matching `ltxtquery`?

`ltree[] ?@> ltree → ltree` Returns first array entry that is an ancestor of `ltree`, or `NULL` if none.
`ltree[] ?<@ ltree → ltree` Returns first array entry that is a descendant of `ltree`, or `NULL` if none.
`ltree[] ?~ lquery → ltree` Returns first array entry that matches `lquery`, or `NULL` if none.
`ltree[] ?@ ltxtquery → ltree` Returns first array entry that matches `ltxtquery`, or `NULL` if none.

The operators `<@`, `@>`, `@` and `~` have analogues `^<@`, `^@>`, `^@`, `^~`, which are the same except they do not use indexes. These are useful only for testing purposes.

The available functions are shown in Table F.25.

Table F.25. `ltree` Functions

Function Description Example(s)

`subltree ( ltree, start integer, end integer ) → ltree`
Returns subpath of `ltree` from position `start` to position `end`-1 (counting from 0).
`subltree('Top.Child1.Child2', 1, 2)` → `Child1`

`subpath ( ltree, offset integer, len integer ) → ltree`
Returns subpath of `ltree` starting at position `offset`, with length `len`. If `offset` is negative, subpath starts that far from the end of the path. If `len` is negative, leaves that many labels off the end of the path.
`subpath('Top.Child1.Child2', 0, 2)` → `Top.Child1`

`subpath ( ltree, offset integer ) → ltree`
Returns subpath of `ltree` starting at position `offset`, extending to end of path. If `offset` is negative, subpath starts that far from the end of the path.
`subpath('Top.Child1.Child2', 1)` → `Child1.Child2`

`nlevel ( ltree ) → integer`
Returns number of labels in path.
`nlevel('Top.Child1.Child2')` → `3`

`index ( a ltree, b ltree ) → integer`
Returns position of first occurrence of `b` in `a`, or -1 if not found.
`index('0.1.2.3.5.4.5.6.8.5.6.8', '5.6')` → `6`

`index ( a ltree, b ltree, offset integer ) → integer`
Returns position of first occurrence of `b` in `a`, or -1 if not found. The search starts at position `offset`; negative `offset` means start `-offset` labels from the end of the path.
`index('0.1.2.3.5.4.5.6.8.5.6.8', '5.6', -4)` → `9`

`text2ltree ( text ) → ltree` Casts `text` to `ltree`.
`ltree2text ( ltree ) → text` Casts `ltree` to `text`.

`lca ( ltree [, ltree [, ... ]] ) → ltree`
Computes longest common ancestor of paths (up to 8 arguments are supported).
`lca('1.2.3', '1.2.3.4.5.6')` → `1.2`

`lca ( ltree[] ) → ltree`
Computes longest common ancestor of paths in array.
`lca(array['1.2.3'::ltree,'1.2.3.4'])` → `1.2`

F.30.3. Indexes

`ltree` supports several types of indexes that can speed up the indicated operators:

- B-tree index over `ltree`: `<`, `<=`, `=`, `>=`, `>`
- GiST index over `ltree` (`gist_ltree_ops` opclass): `<`, `<=`, `=`, `>=`, `>`, `@>`, `<@`, `@`, `~`, `?`

  `gist_ltree_ops` GiST opclass approximates a set of path labels as a bitmap signature. Its optional integer parameter `siglen` determines the signature length in bytes. The default signature length is 8 bytes. The length must be a positive multiple of `int` alignment (4 bytes on most machines)) up to

2024. Longer signatures lead to a more precise search (scanning a smaller fraction of the index and fewer heap pages), at the cost of a larger index.

Example of creating such an index with the default signature length of 8 bytes:

```
CREATE INDEX path_gist_idx ON test USING GIST (path);
```

Example of creating such an index with a signature length of 100 bytes:

```
CREATE INDEX path_gist_idx ON test USING GIST (path gist_ltree_ops(siglen=100));
```

- GiST index over `ltree[]` (`gist__ltree_ops` opclass): `ltree[] <@ ltree`, `ltree @> ltree[]`, `@`, `~`, `?`

  `gist__ltree_ops` GiST opclass works similarly to `gist_ltree_ops` and also takes signature length as a parameter. The default value of `siglen` in `gist__ltree_ops` is 28 bytes.

  Example of creating such an index with the default signature length of 28 bytes:

  ```
  CREATE INDEX path_gist_idx ON test USING GIST (array_path);
  ```

  Example of creating such an index with a signature length of 100 bytes:

  ```
  CREATE INDEX path_gist_idx ON test USING GIST (array_path
   gist__ltree_ops(siglen=100));
  ```

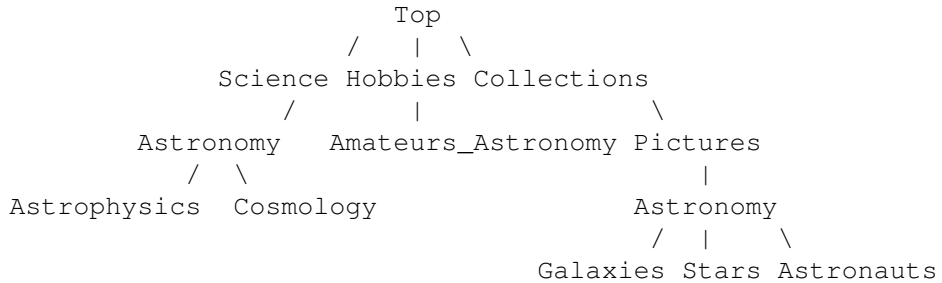
  Note: This index type is lossy.

F.30.4. Example

This example uses the following data (also available in file `contrib/ltree/ltreetest.sql` in the source distribution):

```
CREATE TABLE test (path ltree);
INSERT INTO test VALUES ('Top');
INSERT INTO test VALUES ('Top.Science');
INSERT INTO test VALUES ('Top.Science.Astronomy');
INSERT INTO test VALUES ('Top.Science.Astronomy.Astrophysics');
INSERT INTO test VALUES ('Top.Science.Astronomy.Cosmology');
INSERT INTO test VALUES ('Top.Hobbies');
INSERT INTO test VALUES ('Top.Hobbies.Amateurs_Astronomy');
INSERT INTO test VALUES ('Top.Collections');
INSERT INTO test VALUES ('Top.Collections.Pictures');
INSERT INTO test VALUES ('Top.Collections.Pictures.Astronomy');
INSERT INTO test VALUES ('Top.Collections.Pictures.Astronomy.Stars');
INSERT INTO test VALUES ('Top.Collections.Pictures.Astronomy.Galaxies');
INSERT INTO test VALUES ('Top.Collections.Pictures.Astronomy.Astronauts');
CREATE INDEX path_gist_idx ON test USING GIST (path);
CREATE INDEX path_idx ON test USING BTREE (path);
```

Now, we have a table `test` populated with data describing the hierarchy shown below:



We can do inheritance:

```
ltreetest=> SELECT path FROM test WHERE path <@ 'Top.Science';
                path
-----------------------------------
 Top.Science
 Top.Science.Astronomy
 Top.Science.Astronomy.Astrophysics
 Top.Science.Astronomy.Cosmology
(4 rows)
```

Here are some examples of path matching:

```
ltreetest=> SELECT path FROM test WHERE path ~ '*.Astronomy.*';
                     path
-----------------------------------------------
 Top.Science.Astronomy
 Top.Science.Astronomy.Astrophysics
 Top.Science.Astronomy.Cosmology
 Top.Collections.Pictures.Astronomy
 Top.Collections.Pictures.Astronomy.Stars
 Top.Collections.Pictures.Astronomy.Galaxies
 Top.Collections.Pictures.Astronomy.Astronauts
(7 rows)

ltreetest=> SELECT path FROM test WHERE path ~ '*.!pictures@.Astronomy.*';
                path
-----------------------------------
 Top.Science.Astronomy
 Top.Science.Astronomy.Astrophysics
 Top.Science.Astronomy.Cosmology
(3 rows)
```

Here are some examples of full text search:

```
ltreetest=> SELECT path FROM test WHERE path @ 'Astro*% & !pictures@';
                path
-----------------------------------
 Top.Science.Astronomy
 Top.Science.Astronomy.Astrophysics
 Top.Science.Astronomy.Cosmology
 Top.Hobbies.Amateurs_Astronomy
(4 rows)

ltreetest=> SELECT path FROM test WHERE path @ 'Astro* & !pictures@';
                path
-----------------------------------
 Top.Science.Astronomy
 Top.Science.Astronomy.Astrophysics
 Top.Science.Astronomy.Cosmology
(3 rows)
```

Path construction using functions:

```
ltreetest=> SELECT subpath(path,0,2)||'Space'||subpath(path,2) FROM test WHERE path <@
 'Top.Science.Astronomy';
                 ?column?
-----------------------------------------
 Top.Science.Space.Astronomy
 Top.Science.Space.Astronomy.Astrophysics
 Top.Science.Space.Astronomy.Cosmology
(3 rows)
```

We could simplify this by creating an SQL function that inserts a label at a specified position in a path:

```
CREATE FUNCTION ins_label(ltree, int, text) RETURNS ltree
    AS 'select subpath($1,0,$2) || $3 || subpath($1,$2);'
    LANGUAGE SQL IMMUTABLE;

ltreetest=> SELECT ins_label(path,2,'Space') FROM test WHERE path <@
 'Top.Science.Astronomy';
                ins_label
-----------------------------------------
 Top.Science.Space.Astronomy
 Top.Science.Space.Astronomy.Astrophysics
 Top.Science.Space.Astronomy.Cosmology
(3 rows)
```

F.30.5. Transforms

Additional extensions are available that implement transforms for the `ltree` type for PL/Python. The extensions are called `ltree_plpythonu`, `ltree_plpython2u`, and `ltree_plpython3u` (see Section 48.1 for the PL/Python naming convention). If you install these transforms and specify them when creating a function, `ltree` values are mapped to Python lists. (The reverse is currently not supported, however.)

> **Caution**
>
> It is strongly recommended that the transform extensions be installed in the same schema as `ltree`. Otherwise there are installation-time security hazards if a transform extension's schema contains objects defined by a hostile user.

F.30.6. Authors

All work was done by Teodor Sigaev (<teodor@stack.net>) and Oleg Bartunov (<oleg@sai.msu.su>). See *http://www.sai.msu.su/~megera/postgres/gist/* for additional information. Authors would like to thank Eugeny Rodichev for helpful discussions. Comments and bug reports are welcome.

F.31. mchar

The `mchar` module provides additional data types for compatibility with Microsoft SQL Server (MS SQL).

F.31.1. Overview

This module has been designed to improve 1C Enterprise support, most popular Russian CRM and ERP system.

It implements types MCHAR and MVARCHAR, which are bug-to-bug compatible with MS SQL CHAR and VARCHAR respectively. Additionally, these types use the ICU library for comparison and case conversion, so their behavior is identical across different operating systems.

Postgres Pro also includes citext extension which provides types similar to MCHAR. But this extension doesn't emulate MS-SQL behavior concerning end-of-value whitespace.

Differences from Postgres Pro standard CHAR and VARCHAR are:

- Case insensitive comparison
- Handling of the whitespace at the end of string
- These types are always stored as two-byte unicode value regardless of database encoding.

F.31.2. Additional types

- `mchar` — analog of the MS SQL char type

- mvarchar — analog of the MS SQL varchar type

F.31.3. MCHAR and MVARCHAR features

- Defines length(str) function
- Defines substr(str, pos[, length]) function
- Defines || operator, which would be applied to concatenate any (mchar and mvarchar) arguments
- Defines set of operators: <, <=, =, >=, > for case-insensitive comparison (ICU)
- Defines set of operators: &<, &<=, &=, &>=, &> to case-sensitive comparison (ICU)
- Implicit cast between mchar and mvarchar types
- B-tree and Hash-index support
- The LIKE [ESCAPE] operator support
- The SIMILAR TO [ESCAPE] operator support
- The ~ operator (POSIX regexp) support
- Index support for the *LIKE* operator

F.31.4. Authors

Oleg Bartunov <oleg@sai.msu.ru>
Teodor Sigaev <teodor@sigaev.ru>

F.32. multimaster

multimaster is a Postgres Pro Enterprise extension with a set of patches that turns Postgres Pro Enterprise into a synchronous shared-nothing cluster to provide Online Transaction Processing (OLTP) scalability for read transactions and high availability with automatic disaster recovery.

As compared to a standard PostgreSQL primary-standby cluster, a cluster configured with the multimaster extension offers the following benefits:

- Fault tolerance and automatic node recovery
- Synchronous logical replication and DDL replication
- Read scalability
- Working with temporary tables on each cluster node (with limitations)
- Upgrading minor releases of Postgres Pro Enterprise seamlessly for multimaster cluster clients

> **Important**
>
> Before deploying multimaster on production systems, make sure to take its replication restrictions into account. For details, see Section F.32.1.

The multimaster extension replicates your database to all nodes of the cluster and allows write transactions on each node. Write transactions are synchronously replicated to all nodes, which increases commit latency. Read-only transactions and queries are executed locally, without any measurable overhead.

To ensure high availability and fault tolerance of the cluster, multimaster determines each transaction outcome through Paxos consensus algorithm, uses custom recovery protocol and heartbeats for failure discovery. A multi-master cluster of *N* nodes can continue working while the majority of the nodes are alive and reachable by other nodes. To be configured with multimaster, the cluster must include at least three nodes. Since the data on all cluster nodes is the same, you do not typically need more than five cluster nodes. There is also a special 2+1 (referee) mode in which 2 nodes hold data and an additional

one called *referee* only participates in voting. Compared to traditional three nodes setup, this is cheaper (referee resources demands are low) but availability is decreased. For details, see Section F.32.3.3.

When a failed node is reconnected to the cluster, `multimaster` automatically fast-forwards the node to the actual state based on the Write-Ahead Log (WAL) data in the corresponding replication slot. If a node was excluded from the cluster, you can add it back using pg_basebackup.

To learn more about the `multimaster` internals, see Section F.32.2.

F.32.1. Limitations

The `multimaster` extension takes care of the database replication in a fully automated way. You can perform write transactions on any node and work with temporary tables on each cluster node simultaneously. However, make sure to take the following replication restrictions into account:

- Microsoft Windows operating system is not supported.
- 1C solutions are not supported.
- `multimaster` can replicate only one database in a cluster. If it is required to replicate the contents of several databases, you can either transfer all data into different schemas within a single database or create a separate cluster for each database and set up `multimaster` for each cluster.
- Large objects are not supported. Although creating large objects is allowed, multimaster cannot replicate such objects, and their OIDs may conflict on different nodes, so their use is not recommended.
- Since `multimaster` is based on logical replication and Paxos over three-phase commit protocol, its operation is highly affected by network latency. It is not recommended to set up a `multimaster` cluster with geographically distributed nodes.
- Using tables without primary keys can have negative impact on performance. In some cases, it can even lead to inability to restore a cluster node, so you should avoid replicating such tables with `multimaster`.
- Unlike in vanilla PostgreSQL, `read committed` isolation level can cause serialization failures on a multi-master cluster (with an SQLSTATE code '40001') if there are conflicting transactions from different nodes, so the application must be ready to retry transactions. *`Serializable`* isolation level works only with respect to local transactions on the current node.
- Sequence generation. To avoid conflicts between unique identifiers on different nodes, `multimaster` modifies the default behavior of sequence generators. By default, ID generation on each node is started with this node number and is incremented by the number of nodes. For example, in a three-node cluster, 1, 4, and 7 IDs are allocated to the objects written onto the first node, while 2, 5, and 8 IDs are reserved for the second node. If you change the number of nodes in the cluster, the incrementation interval for new IDs is adjusted accordingly. Thus, the generated sequence values are not monotonic. If it is critical to get a monotonically increasing sequence cluster-wide, you can set the `multimaster.monotonic_sequences` to `true`.
- Commit latency. In the current implementation of logical replication, `multimaster` sends data to subscriber nodes only after the local commit, so you have to wait for transaction processing twice: first on the local node, and then on all the other nodes simultaneously. In the case of a heavy-write transaction, this may result in a noticeable delay.
- Logical replication does not guarantee that a system object OID is the same on all cluster nodes, so OIDs for the same object may differ between `multimaster` cluster nodes. If your driver or application relies on OIDs, make sure that their use is restricted to connections to one and the same node to avoid errors. For example, the `Npgsql` driver may not work correctly with `multimaster` if the `NpgsqlConnection.GlobalTypeMapper` method tries using OIDs in connections to different cluster nodes.
- A `multimaster` cluster node cannot function as a logical replication subscriber. While a `multimaster` node can function as a publisher, the subscription cannot automatically switch to another node if the node fails.

- Replicated non-conflicting transactions are applied on the receiving nodes in parallel, so such transactions may become visible on different nodes in different order.
- `CREATE INDEX CONCURRENTLY`, `REINDEX CONCURRENTLY`, `CREATE TABLESPACE`, and `DROP TABLESPACE` are not supported.
- `COMMIT AND CHAIN` feature is not supported.
- `CREATE [TEMP] TABLE AS` is not supported with queries that contain explicit use of variables or arguments of functions or procedures (if the command is executed in the context of a function or procedure), and other context-sensitive objects. It is not recommended to use `CREATE TABLE AS` with the `WITH DATA` clause (data copy) in a query that uses temporary tables as it may cause the new table data synchronization issues across cluster nodes.

F.32.2. Architecture

F.32.2.1. Replication

Since each server in a multi-master cluster can accept writes, any server can abort a transaction because of a concurrent update — in the same way as it happens on a single server between different backends. To ensure high availability and data consistency on all cluster nodes, `multimaster` uses logical replication and the three-phase commit protocol with transaction outcome determined by Paxos consensus algorithm.

When Postgres Pro Enterprise loads the `multimaster` shared library, `multimaster` sets up a logical replication producer and consumer for each node, and hooks into the transaction commit pipeline. The typical data replication workflow consists of the following phases:

1. `PREPARE` phase. `multimaster` captures and implicitly transforms each `COMMIT` statement to a `PREPARE` statement. All the nodes that get the transaction via the replication protocol (*the cohort nodes*) send their vote for approving or declining the transaction to the backend process on the initiating node. This ensures that all the cohort can accept the transaction, and no write conflicts occur. For details on `PREPARE` transactions support in PostgreSQL, see the PREPARE TRANSACTION topic.
2. `PRECOMMIT` phase. If all the cohort nodes approve the transaction, the backend process sends a `PRECOMMIT` message to all the cohort nodes to express an intention to commit the transaction. The cohort nodes respond to the backend with the `PRECOMMITTED` message. In case of a failure, all the nodes can use this information to complete the transaction using a quorum-based voting procedure.
3. `COMMIT` phase. If `PRECOMMIT` is successful, the transaction is committed to all nodes.

If a node crashes or gets disconnected from the cluster between the `PREPARE` and `COMMIT` phases, the `PRECOMMIT` phase ensures that the survived nodes have enough information to complete the prepared transaction. The `PRECOMMITTED` messages help avoid the situation when the crashed node has already committed or aborted the transaction, but has not notified other nodes about the transaction status. In a two-phase commit (2PC), such a transaction would block resources (hold locks) until the recovery of the crashed node. Otherwise, data inconsistencies can appear in the database when the failed node is recovered, for example, if the failed node committed the transaction, but the survived node aborted it.

To complete the transaction, the backend must receive a response from the majority of the nodes. For example, for a cluster of $2N+1$ nodes, at least $N+1$ responses are required. Thus, `multimaster` ensures that your cluster is available for reads and writes while the majority of the nodes are connected, and no data inconsistencies occur in case of a node or connection failure.

F.32.2.2. Failure Detection and Recovery

Since `multimaster` allows writes to each node, it has to wait for responses about transaction acknowledgment from all the other nodes. Without special actions in case of a node failure, each commit would have to wait until the failed node recovery. To deal with such situations, `multimaster` periodically sends heartbeats to check the node state and the connectivity between nodes. When several heartbeats to the node are lost in a row, this node is kicked out of the cluster to allow writes to the remaining alive

nodes. You can configure the heartbeat frequency and the response timeout in the `multimaster.heartbeat_send_timeout` and `multimaster.heartbeat_recv_timeout` parameters, respectively.

For example, suppose a five-node multi-master cluster experienced a network failure that split the network into two isolated subnets, with two and three cluster nodes. Based on heartbeats propagation information, `multimaster` will continue accepting writes at each node in the bigger partition, and deny all writes in the smaller one. Thus, a cluster consisting of $2N+1$ nodes can tolerate N node failures and stay alive if any $N+1$ nodes are alive and connected to each other. You can also set up a two nodes cluster plus a lightweight referee node that does not hold the data, but acts as a tie-breaker during symmetric node partitioning. For details, see Section F.32.3.3.

In case of a partial network split when different nodes have different connectivity, `multimaster` finds a fully connected subset of nodes and disconnects nodes outside of this subset. For example, in a three-node cluster, if node A can access both B and C, but node B cannot access node C, `multimaster` isolates node C to ensure that both A and B can work.

To preserve order of transactions on different nodes and thus data integrity, the decision to exclude or add back node(s) must be taken coherently. Generations which represent a subset of currently supposedly live nodes serve this purpose. Technically, generation is a pair `<n, members>` where *n* is unique number and *members* is subset of configured nodes. A node always lives in some generation and switches to the one with higher number as soon as it learns about its existence; generation numbers act as logical clocks/terms/epochs here. Each transaction is stamped during commit with current generation of the node it is being executed on. The transaction can be proposed to be committed only after it has been PREPAREd on all its generation members. This allows to design the recovery protocol so that order of conflicting committed transactions is the same on all nodes. Node resides in generation in one of three states (can be shown with `mtm.status()`):

1. `ONLINE`: node is member of the generation and making transactions normally;
2. `RECOVERY`: node is member of the generation, but it must apply in recovery mode transactions from previous generations to become `ONLINE`;
3. `DEAD`: node will never be `ONLINE` in this generation;

For alive nodes, there is no way to distinguish between a failed node that stopped serving requests and a network-partitioned node that can be accessed by database users, but is unreachable for other nodes. If during commit of writing transaction some of current generation members are disconnected, transaction is rolled back according to generation rules. To avoid futile work, connectivity is also checked during transaction start; if you try to access an isolated node, `multimaster` returns an error message indicating the current status of the node. Thus, to prevent stale reads read-only queries are also forbidden. If you would like to continue using a disconnected node outside of the cluster in the standalone mode, you have to uninstall the `multimaster` extension on this node, as explained in Section F.32.4.5.

Each node maintains a data structure that keeps the information about the state of all nodes in relation to this node. You can get this data by calling the `mtm.status()` and the `mtm.nodes()` functions.

When a failed node connects back to the cluster, `multimaster` starts automatic recovery:

1. The reconnected node selects a cluster node, which is `ONLINE` in the highest generation, referred to as the *donor* node, and starts catching up with the current state of the cluster based on the Write-Ahead Log (WAL).
2. When the node is caught up, it ballots for including itself in the next generation. Once generation is elected, commit of new transactions will start waiting for apply on the joining node.
3. When the rest of transactions till the switch to the new generation is applied, the reconnected node is promoted to the `online` state and included into the replication scheme.

The correctness of recovery protocol was verified with TLA+ model checker. You can find the model (and more detailed description) at *doc/specs* directory of the source code.

Automatic recovery requires presence of all WAL files generated after node failure. If a node is down for a long time and storing more WALs is unacceptable, you may have to exclude this node from the

cluster and manually restore it from one of the working nodes using pg_basebackup. For details, see Section F.32.4.3.

F.32.2.3. Multimaster Background Workers

mtm-monitor

Starts all other workers for a database managed with multimaster. This is the first worker loaded during multimaster boot. Each multimaster node has a single `mtm-monitor` worker. When a new node is added, `mtm-monitor` starts `mtm-logrep-receiver` and `mtm-dmq-receiver` workers to enable replication to this node. If a node is dropped, `mtm-monitor` stops `mtm-logrep-receiver` and `mtm-dmq-receiver` workers that have been serving the dropped node. Each `mtm-monitor` controls workers on its own node only.

mtm-logrep-receiver

Receives logical replication stream from a given peer node. During normal operation, `mtm-logrep-receiver` sends replicated transactions to the pool of dynamic workers (see mtm-logrep-receiver-dynworker). During catchup, depending on the value of the multimaster.catchup_algorithm configuration parameter, `mtm-logrep-receiver` applies replicated transactions on the reconnected node or sends them to the pool of dynamic workers. The number of `mtm-logrep-receiver` workers on each node corresponds to the number of peer nodes available.

mtm-dmq-receiver

Receives acknowledgment for transactions sent to peers and checks for heartbeat timeouts. The number of `mtm-logrep-receiver` workers on each node corresponds to the number of peer nodes available.

mtm-dmq-sender

Collects acknowledgment for transactions applied on the current node and sends them to the corresponding mtm-dmq-receiver on the peer node. There is a single worker per Postgres Pro Enterprise instance.

mtm-logrep-receiver-dynworker

Dynamic pool worker for a given mtm-logrep-receiver. Applies replicated transactions received during normal operation or catchup. You can use the multimaster.max_workers configuration parameter to specify the maximum number of dynamic workers.

mtm-resolver

Performs Paxos to resolve unfinished transactions. This worker is only active during recovery or when connection with other nodes was lost. There is a single worker per Postgres Pro Enterprise instance.

mtm-campaigner

Ballots for new generations to exclude some node(s) or add myself. There is a single worker per Postgres Pro Enterprise instance.

mtm-replier

Responds to requests of mtm-campaigner and mtm-resolver.

F.32.3. Installation and Setup

To use `multimaster`, you need to install Postgres Pro or Postgres Pro Enterprise on all nodes of your cluster. Postgres Pro includes all the required dependencies and extensions. For PostgreSQL follow build and install instructions at *readme.md*.

F.32.3.1. Setting up a Multi-Master Cluster

Suppose you are setting up a cluster of three nodes, with `node1`, `node2`, and `node3` host names. After installing Postgres Pro Enterprise on all nodes, you need to initialize data directory on each node, as

explained in Section 18.2. If you would like to set up a multi-master cluster for an already existing mydb database, you can load data from mydb to one of the nodes once the cluster is initialized, or you can load data to all new nodes before cluster initialization using any convenient mechanism, such as pg_basebackup or pg_dump.

Once the data directory is set up, complete the following steps on each cluster node:

1. Modify the postgresql.conf configuration file, as follows:

   - Add multimaster to the shared_preload_libraries variable:

     ```
     shared_preload_libraries = 'multimaster'
     ```

     Tip

     If the shared_preload_libraries variable is already defined in postgresql.auto.conf, you will need to modify its value using the ALTER SYSTEM command. For details, see Section 19.1.2. Note that in a multi-master cluster, the ALTER SYSTEM command only affects the configuration of the node from which it was run.

   - Set up Postgres Pro Enterprise parameters related to replication:

     ```
     wal_level = logical
     max_connections = 100
     max_prepared_transactions = 300 # max_connections * N
     max_wal_senders = 10            # at least N
     max_replication_slots = 10      # at least 2N
     wal_sender_timeout = 0
     ```

     where *N* is the number of nodes in your cluster.

     You must change the replication level to logical as multimaster relies on logical replication. For a cluster of *N* nodes, enable at least *N* WAL sender processes and replication slots. Since multimaster implicitly adds a PREPARE phase to each COMMIT transaction, make sure to set the number of prepared transactions to *N* * max_connections. wal_sender_timeout should be disabled as multimaster uses its custom logic for failure detection.

   - Make sure you have enough background workers allocated for each node:

     ```
     max_worker_processes = 250 # (N - 1) * (multimaster.max_workers + 1) + 5
     ```

     For example, for a three-node cluster with multimaster.max_workers = 100, multimaster may need up to 207 background workers at peak times: five always-on workers (monitor, resolver, dmq-sender, campaigner, replier), one walreceiver per each peer node and up to 200 replication dynamic workers. When setting this parameter, remember that other modules may also use background workers at the same time.

   - Depending on your network environment and usage patterns, you may want to tune other multimaster parameters. For details, see Section F.32.3.2.

2. Start Postgres Pro Enterprise on all nodes.

3. Create database mydb and user mtmuser on each node:

   ```
   CREATE USER mtmuser WITH SUPERUSER PASSWORD 'mtmuserpassword';
   CREATE DATABASE mydb OWNER mtmuser;
   ```

   If you are using password-based authentication, you may want to create a password file.

   You can omit this step if you already have a database you are going to replicate, but you are recommended to create a separate superuser for multi-master replication. The examples below assume that you are going to replicate the mydb database on behalf of mtmuser.

4. Allow replication of the `mydb` database to each cluster node on behalf of `mtmuser`, as explained in Section 20.1. Make sure to use the authentication method that satisfies your security requirements. For example, `pg_hba.conf` might have the following lines on `node1`:

   ```
   host replication mtmuser node2 md5
   host mydb mtmuser node2 md5
   host replication mtmuser node3 md5
   host mydb mtmuser node3 md5
   ```

5. Connect to any node on behalf of the `mtmuser` database user, create the `multimaster` extension in the `mydb` database and run `mtm.init_cluster()`, specifying the connection string to the current node as the first argument and an array of connection strings to the other nodes as the second argument.

   For example, if you would like to connect to `node1`, run:

   ```
   CREATE EXTENSION multimaster;
   SELECT mtm.init_cluster('dbname=mydb user=mtmuser host=node1',
   '{"dbname=mydb user=mtmuser host=node2", "dbname=mydb user=mtmuser host=node3"}');
   ```

6. To ensure that `multimaster` is enabled, you can run the `mtm.status()` and `mtm.nodes()` functions:

   ```
   SELECT * FROM mtm.status();
   SELECT * FROM mtm.nodes();
   ```

   If `status` is equal to `online` and all nodes are present in the `mtm.nodes` output, your cluster is successfully configured and ready to use.

> **Tip**
>
> If you have any data that must be present on one of the nodes only, you can exclude a particular table from replication, as follows:
>
> ```
> SELECT mtm.make_table_local('table_name')
> ```

F.32.3.2. Tuning Configuration Parameters

While you can use `multimaster` in the default configuration, you may want to tune several parameters for faster failure detection or more reliable automatic recovery.

F.32.3.2.1. Setting Timeout for Failure Detection

To check availability of the peer nodes, `multimaster` periodically sends heartbeat packets to all nodes. You can define the timeout for failure detection with the following variables:

- The `multimaster.heartbeat_send_timeout` variable defines the time interval between the heartbeats. By default, this variable is set to 200ms.
- The `multimaster.heartbeat_recv_timeout` variable sets the timeout for the response. If no heartbeats are received during this time, the node is assumed to be disconnected and is excluded from the cluster. By default, this variable is set to 2000ms.

It's a good idea to set `multimaster.heartbeat_send_timeout` based on typical ping latencies between the nodes. Small recv/send ratio decreases the time of failure detection, but increases the probability of false-positive failure detection. When setting this parameter, take into account the typical packet loss ratio between your cluster nodes.

F.32.3.3. 2+1 Mode: Setting up a Standalone Referee Node

By default, `multimaster` uses a majority-based algorithm to determine whether the cluster nodes have a quorum: a cluster can only continue working if the majority of its nodes are alive and can access each other. Majority-based approach is pointless for two nodes cluster: if one of them fails, another one becomes inaccessible. There is a special 2+1 or referee mode which trades less hardware resources by

decreasing availability: two nodes hold full copy of data, and separate referee node participates only in voting, acting as a tie-breaker.

If one node goes down, another one requests referee grant (elects referee-approved generation with single node). Once the grant is received, it continues to work normally. If offline node gets up, it recovers and elects full generation containing both nodes, essentially removing the grant - this allows the node to get it in its turn later. While the grant is issued, it can't be given to another node until full generation is elected and excluded node recovers. This ensures data loss doesn't happen by the price of availability: in this setup two nodes (one normal and one referee) can be alive but cluster might be still unavailable if the referee winner is down, which is impossible with classic three nodes configuration.

The referee node does not store any cluster data, so it is not resource-intensive and can be configured on virtually any system with Postgres Pro Enterprise installed.

To avoid split-brain problems, you must have only a single referee in your cluster.

To set up a referee for your cluster:

1. Install Postgres Pro Enterprise on the node you are going to make a referee and create the `referee` extension:

   ```
   CREATE EXTENSION referee;
   ```

2. Make sure the `pg_hba.conf` file allows access to the referee node.
3. Set up the nodes that will hold cluster data following the instructions in Section F.32.3.1.
4. On all data nodes, specify the referee connection string in the `postgresql.conf` file:

   ```
   multimaster.referee_connstring = connstring
   ```

   where *`connstring`* holds libpq options required to access the referee.

The first subset of nodes that gets connected to the referee wins the voting and starts working. The other nodes have to go through the recovery process to catch up with them and join the cluster. Under heavy load, the recovery can take unpredictably long, so it is recommended to wait for all data nodes going online before switching on the load when setting up a new cluster. Once all the nodes get online, the referee discards the voting result, and all data nodes start operating together.

In case of any failure, the voting mechanism is triggered again. At this time, all nodes appear to be offline for a short period of time to allow the referee to choose a new winner, so you can see the following error message when trying to access the cluster: `[multimaster] node is not online: current status is "disabled"`.

F.32.4. Multi-Master Cluster Administration

- Monitoring the Cluster Status
- Accessing Disabled Nodes
- Adding New Nodes to the Cluster
- Removing Nodes from the Cluster
- Checking Data Consistency Across Cluster Nodes
- Delayed Transaction Commits

F.32.4.1. Monitoring Cluster Status

`multimaster` provides several functions to check the current cluster state.

To check node-specific information, use `mtm.status()`:

```
SELECT * FROM mtm.status();
```

To get the list of all nodes in the cluster together with their status, use `mtm.nodes()`:

```
SELECT * FROM mtm.nodes();
```

For details on all the returned information, see Section F.32.5.2.

F.32.4.2. Accessing Disabled Nodes

If a cluster node is disabled, any attempt to read or write data on this node raises an error by default. If you need to access the data on a disabled node, you can override this behavior at connection time by setting the application_name parameter to `mtm_admin`. In this case, you can run read and write queries on this node without multimaster supervision.

F.32.4.3. Adding New Nodes to the Cluster

> **Note**
>
> You must add nodes one by one. Avoid adding several nodes in parallel as this could cause errors.

With the `multimaster` extension, you can add or drop cluster nodes. Before adding node, stop the load and ensure (with `mtm.status()`) that all nodes are `online`. When adding a new node, you need to load all the data to this node using pg_basebackup from any cluster node, and then start this node.

Suppose we have a working cluster of three nodes, with `node1`, `node2`, and `node3` host names. To add `node4`, follow these steps:

1. Figure out the required connection string to access the new node. For example, for the database `mydb`, user `mtmuser`, and the new node `node4`, the connection string can be `"dbname=mydb user=mtmuser host=node4"`.
2. In `psql` connected to any alive node, run:

   ```
   SELECT mtm.add_node('dbname=mydb user=mtmuser host=node4');
   ```

   This command changes the cluster configuration on all nodes and creates replication slots for the new node. It also returns `node_id` of the new node, which will be required to complete the setup.
3. Go to the new node and clone all the data from one of the alive nodes to this node:

   ```
   pg_basebackup -D datadir -h node1 -U mtmuser -c fast -v
   ```

   pg_basebackup copies the entire data directory from `node1`, together with configuration settings, and prints the last LSN replayed from WAL, such as `'0/12D357F0'`. This value will be required to complete the setup.
4. Configure the new node to boot with `recovery_target=immediate` to prevent redo past the point where replication will begin. Add to `postgresql.conf`:

   ```
   restore_command = 'false'
   recovery_target = 'immediate'
   recovery_target_action = 'promote'
   ```

   And create `recovery.signal` file in the data directory.
5. Start Postgres Pro Enterprise on the new node.
6. In `psql` connected to the node used to take the base backup, run:

   ```
   SELECT mtm.join_node(4, '0/12D357F0');
   ```

   where `4` is the `node_id` returned by the `mtm.add_node()` function call and `'0/12D357F0'` is the LSN value returned by pg_basebackup.

F.32.4.4. Removing Nodes from the Cluster

Before removing node, stop the load and ensure (with `mtm.status()`) that all nodes (except the ones to be dropped) are `online`. Shut down the nodes you are going to remove. To remove the node from the cluster:

1. Run the `mtm.nodes()` function to learn the ID of the node to be removed:

   ```
   SELECT * FROM mtm.nodes();
   ```

2. Run the `mtm.drop_node()` function with this node ID as a parameter:

   ```
   SELECT mtm.drop_node(3);
   ```

   This will delete replication slots for node 3 on all cluster nodes and stop replication to this node.

If you would like to return the node to the cluster later, you will have to add it as a new node, as explained in Section F.32.4.3.

F.32.4.5. Uninstalling the multimaster Extension

If you would like to continue using the node that has been removed from the cluster in the standalone mode, you have to drop the `multimaster` extension on this node and clean up all `multimaster`-related subscriptions and uncommitted transactions to ensure that the node is no longer associated with the cluster.

1. Remove `multimaster` from shared_preload_libraries and restart Postgres Pro Enterprise.
2. Delete the `multimaster` extension and publication:

   ```
   DROP EXTENSION multimaster;
   DROP PUBLICATION multimaster;
   ```

3. Review the list of existing subscriptions using the `\dRs` command and delete each subscription that starts with the `mtm_sub_` prefix:

   ```
   \dRs
   DROP SUBSCRIPTION mtm_sub_subscription_name;
   ```

4. Review the list of existing replication slots and delete each slot that starts with the `mtm_` prefix:

   ```
   SELECT * FROM pg_replication_slots;
   SELECT pg_drop_replication_slot('mtm_slot_name');
   ```

5. Review the list of existing replication origins and delete each origin that starts with the `mtm_` prefix:

   ```
   SELECT * FROM pg_replication_origin;
   SELECT pg_replication_origin_drop('mtm_origin_name');
   ```

6. Review the list of prepared transaction left, if any:

   ```
   SELECT * FROM pg_prepared_xacts;
   ```

   You have to commit or abort these transactions by running `ABORT PREPARED transaction_id` or `COMMIT PREPARED transaction_id`, respectively.

Once all these steps are complete, you can start using the node in the standalone mode, if required.

F.32.4.6. Checking Data Consistency Across Cluster Nodes

You can check that the data is the same on all cluster nodes using the mtm.check_query(query_text) function.

As a parameter, this function takes the text of a query you would like to run for data comparison. When you call this function, it takes a consistent snapshot of data on each cluster node and runs this query against the captured snapshots. The query results are compared between pairs of nodes. If there are no differences, this function returns `true`. Otherwise, it reports the first detected difference in a warning and returns `false`.

To avoid false-positive results, always use the `ORDER BY` clause in your test query. For example, suppose you would like to check that the data in a `my_table` is the same on all cluster nodes. Compare the results of the following queries:

```
postgres=# SELECT mtm.check_query('SELECT * FROM my_table ORDER BY id');
 check_query
-------------
 t
(1 row)

postgres=# SELECT mtm.check_query('SELECT * FROM my_table');
WARNING: mismatch in column 'b' of row 0: 256 on node0, 255 on node1
 check_query
-------------
 f
(1 row)
```

Even though the data is the same, the second query reports an issue because the order of the returned data differs between cluster nodes.

F.32.4.7. Delayed Transaction Commits

When a lagging node is catching up to the donor node and cannot apply changes as quickly, you can slow down transaction execution on the donor node using the `multimaster.tx_delay_on_slow_catchup` configuration parameter. To do this, set this parameter to `on` in the `postgresql.conf` configuration file on the donor node, but not on the lagging peer node. If you edit the file on a running server, you will need to signal the postmaster to make it re-read the file (see Chapter 19 for details). If necessary, you can also specify the maximum possible delay for transaction execution in the optional `multimaster.max_tx_delay_on_slow_catchup` parameter (in milliseconds). A value of `0` means that no maximum delay is set. Currently, delays can range from 1 ms to approximately 4 seconds. Values outside the allowed range will be truncated towards the nearest valid value.

By default, this feature is disabled.

F.32.5. Reference

F.32.5.1. Configuration Parameters

`multimaster.heartbeat_recv_timeout`

Timeout, in milliseconds. If no heartbeat message is received from the node within this timeframe, the node is excluded from the cluster.

Default: 2000 ms

`multimaster.heartbeat_send_timeout`

Time interval between heartbeat messages, in milliseconds. An arbiter process broadcasts heartbeat messages to all nodes to detect connection problems.

Default: 200 ms

`multimaster.max_workers`

The maximum number of `walreceiver` workers per peer node.

> **Important**
>
> This parameter should be used with caution. If the number of simultaneous transactions in the whole cluster is bigger than the provided value, it can lead to undetected deadlocks.

Default: 100

`multimaster.monotonic_sequences`

Defines the sequence generation mode for unique identifiers. This variable can take the following values:

- `false` (default) — ID generation on each node is started with this node number and is incremented by the number of nodes. For example, in a three-node cluster, 1, 4, and 7 IDs are allocated to the objects written onto the first node, while 2, 5, and 8 IDs are reserved for the second node. If you change the number of nodes in the cluster, the incrementation interval for new IDs is adjusted accordingly.
- `true` — the generated sequence increases monotonically cluster-wide. ID generation on each node is started with this node number and is incremented by the number of nodes, but the values are omitted if they are smaller than the already generated IDs on another node. For example, in a three-node cluster, if 1, 4 and 7 IDs are already allocated to the objects on the first node, 2 and 5 IDs will be omitted on the second node. In this case, the first ID on the second node is 8. Thus, the next generated ID is always higher than the previous one, regardless of the cluster node.

Default: `false`

`multimaster.referee_connstring`

Connection string to access the referee node. You must set this parameter on all cluster nodes if the referee is set up.

`multimaster.remote_functions`

Provides a comma-separated list of function names that should be executed remotely on all multimaster nodes instead of replicating the result of their work.

`multimaster.trans_spill_threshold`

The maximal size of transaction, in kB. When this threshold is reached, the transaction is written to the disk.

Default: 100MB

`multimaster.break_connection`

Break connection with clients connected to the node if this node disconnects from the cluster. If this variable is set to `false`, the client stays connected to the node but receives an error that the node is disabled.

Default: `false`

`multimaster.connect_timeout`

Maximum time to wait while connecting, in seconds. Zero, negative, or not specified means wait indefinitely. The minimum allowed timeout is 2 seconds, therefore a value of `1` is interpreted as `2`.

Default: `0`

`multimaster.ignore_tables_without_pk`

Do not replicate tables without primary key. When `false`, such tables are replicated.

Default: `false`

`multimaster.syncpoint_interval`

Amount of WAL generated between synchronization points.

Default: `10 MB`

`multimaster.binary_basetypes`

Send data of built-in types in binary format.

Default: `true`

`multimaster.wait_peer_commits`

Wait until all peers commit the transaction before the command returns a success indication to the client.

Default: `true`

`multimaster.deadlock_prevention`

Manage prevention of transaction deadlocks that can occur when the same tuple is updated or deleted on different nodes simultaneously. If set to `off`, deadlock prevention is disabled.

If set to `simple`, the conflicting transactions are rejected. This setting may be used in any setup.

If set to `smart`, a specific algorithm is used to provide best resource availability by selectively committing or rejecting transactions. This is recommended for a setup of two nodes and a referee. In three node setups, deadlocks are still possible. If there are more than four nodes, all conflicting transactions are rejected, just as with `simple`.

Default: `off`

`multimaster.tx_delay_on_slow_catchup`

Enable delay of transaction commits on the donor node when peer nodes are catching up to this node. This parameter should only be set on the donor node.

Default: `off`

`multimaster.max_tx_delay_on_slow_catchup`

If `multimaster.tx_delay_on_slow_catchup` is enabled, this parameter specifies maximum transaction execution delay, in milliseconds. Possible values are integers greater than `0`, but it allows values only up to 4 seconds.

Default: 0

`multimaster.enable_async_3pc_on_catchup`

Enables asynchronous commit operations (`PREPARE`, `PRECOMMIT`, and `COMMIT PREPARED`) on a lagging node syncing with the donor node. This significantly accelerates the catchup process. Data integrity is maintained using the synchronization point mechanism: during catchup, the system periodically creates synchronization points when all preceding transactions are safely written to disk. This way, even if the lagging node is restarted, no transaction data is lost.

Default: true

`multimaster.catchup_algorithm`

Catchup mode for reconnected nodes. It determines how replicated transactions are applied on the reconnected node that is catching up. This configuration parameter can take one of the following values:

- `sequential` — `mtm-logrep-receiver` applies replicated transactions sequentially in the order they are received.
- `parallel` — `mtm-logrep-receiver` sends replicated transactions to the pool of dynamic workers (see mtm-logrep-receiver-dynworker). Dynamic workers apply non-conflicting transactions in parallel and conflicting transactions sequentially in the receiving order, similar to the `sequential` catchup mode. You can use the multimaster.parallel_catchup_workers configuration

parameter to specify the maximum number of dynamic workers that can apply replicated transactions in this catchup mode.

Default: `sequential`

`multimaster.parallel_catchup_workers`

The maximum number of dynamic workers that can apply replicated transactions on the reconnected node in the `parallel` catchup mode. The value of this configuration parameter cannot be greater than that of the multimaster.max_workers configuration parameter. You can use the multimaster.catchup_algorithm configuration parameter to specify the catchup mode for reconnected nodes.

Default: `8`

F.32.5.2. Functions

`mtm.init_cluster(`*`my_conninfo`* `text, `*`peers_conninfo`* `text[])`

Initializes cluster configuration on all nodes. It connects the current node to all nodes listed in *`peers_conninfo`* and creates the multimaster extension, replications slots, and replication origins on each node. Run this function once all the nodes are running and can accept connections.

Arguments:

- *`my_conninfo`* — connection string to the node on which you are running this function. Peer nodes use this string to connect back to this node.
- *`peers_conninfo`* — an array of connection strings to all the other nodes to be added to the cluster.

`mtm.add_node(`*`connstr`* `text)`

Adds a new node to the cluster. This function should be called before loading data to this node using pg_basebackup. `mtm.add_node` creates the required replication slots for a new node, so you can add a node while the cluster is under load.

Arguments:

- *`connstr`* — connection string for the new node. For example, for the database `mydb`, user `mtmuser`, and the new node `node4`, the connection string is `"dbname=mydb user=mtmuser host=node4"`.

`mtm.join_node(`*`node_id`* `int, `*`backup_end_lsn`* `pg_lsn)`

Completes the cluster setup after adding a new node. This function should be called after the added node has been started.

Arguments:

- *`node_id`* — ID of the node to add to the cluster. It corresponds to the value in the `id` column returned by `mtm.nodes()`.

  `backup_end_lsn` — the last LSN of the base backup copied to the new node. This LSN will be used as the starting point for data replication once the node joins the cluster.

`mtm.drop_node(`*`node_id`* `integer)`

Excludes a node from the cluster.

If you would like to continue using this node outside of the cluster in the standalone mode, you have to uninstall the `multimaster` extension from this node, as explained in Section F.32.4.5.

Arguments:

- *node_id* — ID of the node being dropped. It corresponds to the value in the `id` column returned by `mtm.nodes()`.

`mtm.alter_sequences()`

Fixes unique identifiers on all cluster nodes. This may be required after restoring all nodes from a single base backup.

`mtm.status()`

Shows the status of the `multimaster` extension on the current node. Returns a tuple of the following values:

- *my_node_id*, `int` — ID of this node.
- *status*, `text` — status of the node. Possible values are: `online`, `recovery`, `catchup`, `disabled` (need to recover, but not yet clear from whom), `isolated` (online in current generation, but some members are disconnected).
- *connected*, `int[]` — array of peer IDs connected to this node.
- *gen_num*, `int8` — current generation number.
- *gen_members*, `int[]` — array of current generation members node IDs.
- *gen_members_online*, `int[]` — array of current generation members node IDs which are `online` in it.
- *gen_configured*, `int[]` — array of node IDs configured in current generation.

`mtm.nodes()`

Shows the information on all nodes in the cluster. Returns a tuple of the following values:

- *id*, `integer` — node ID.
- *conninfo*, `text` — connection string to this node.
- *is_self*, `boolean` — is it me?
- *enabled*, `boolean` — is this node online in current generation?
- *connected*, `boolean` — shows whether the node is connected to our node.
- *sender_pid*, `integer` — WAL sender process ID.
- *receiver_pid*, `integer` — WAL receiver process ID.
- *n_workers*, `text` — number of started dynamic apply workers from this node.
- *receiver_mode*, `text` — in which mode receiver from this node works. Possible values are: `disabled`, `recovery`, `normal`.

`mtm.make_table_local(`*relation* `regclass)`

Stops replication for the specified table.

Arguments:

- *relation* — the table you would like to exclude from the replication scheme.

`mtm.check_query(`*query_text* `text)`

Checks data consistency across cluster nodes. This function takes a snapshot of the current state of each node, runs the specified query against these snapshots, and compares the results. If the results

are different between any two nodes, displays a warning with the first found issue and returns `false`. Otherwise, returns `true`.

Arguments:

- *`query_text`* — the query you would like to run on all nodes for data comparison. To avoid false-positive results, always use the `ORDER BY` clause in the test query.

`mtm.get_snapshots()`

Takes a snapshot of data on each cluster node and returns the snapshot ID. The snapshots remain available until the `mtm.free_snapshots()` is called, or the current session is terminated. This function is used by the mtm.check_query(query_text), there is no need to call it manually.

`mtm.free_snapshots()`

Removes data snapshots taken by the `mtm.get_snapshots()` function. This function is used by the mtm.check_query(query_text), there is no need to call it manually.

F.32.6. Compatibility

F.32.6.1. Local and Global DDL Statements

By default, any DDL statement is executed on all cluster nodes, except the following statements that can only act locally on a given node:

- `ALTER SYSTEM`
- `CREATE DATABASE`
- `DROP DATABASE`
- `REINDEX`
- `CHECKPOINT`
- `CLUSTER`
- `LOAD`
- `LISTEN`
- `CHECKPOINT`
- `NOTIFY`

F.32.7. Authors

Postgres Professional, Moscow, Russia.

F.32.7.1. Credits

The replication mechanism is based on logical decoding and an earlier version of the `pglogical` extension provided for community by the 2ndQuadrant team.

The Paxos consensus algorithm is described at:

- Leslie Lamport. *The Part-Time Parliament*

Parallel replication and recovery mechanism is similar to the one described in:

- Odorico M. Mendizabal, et al. *Checkpointing in Parallel State-Machine Replication*.

F.33. online_analyze

The `online_analyze` module provides a set of features that immediately update statistics after `INSERT`, `UPDATE`, `DELETE`, or `SELECT INTO` operations for the affected tables.

> **Note**
>
> This extension cannot be used together with autonomous transactions or while built-in connection pooling is enabled.

F.33.1. Module Loading

To use `online_analyze` module, load the shared library:

```
LOAD 'online_analyze';
```

F.33.2. Module Configuration

You can configure `online_analyze` using the following custom variables (default values are shown):

- online_analyze.enable = on

  Enables `online_analyze`.

- online_analyze.verbose = on

  Executes `ANALYZE VERBOSE`.

  > **Note**
  >
  > Since `verbose` is a reserved SQL key word, this parameter has to be double-quoted when used in SQL queries. For example:
  >
  > ```
  > ALTER SYSTEM SET "online_analyze.verbose" = 'off';
  > ```

- online_analyze.scale_factor = 0.1

  Fraction of table size to start online analysis (similar to autovacuum_analyze_scale_factor).

- online_analyze.threshold = 50

  Minimum number of row updates before starting online analysis (similar to autovacuum_analyze_threshold).

- online_analyze.min_interval = 10000

  Minimum time interval between `ANALYZE` calls per table, in milliseconds.

- online_analyze.table_type = "all"

  Type(s) of tables for online analysis. Possible values are: `all`, `persistent`, `temporary`, `none`.

- online_analyze.exclude_tables = ""

  List of tables to exclude from online analysis.

- online_analyze.include_tables = ""

  List of tables to include in online analysis (`online_analyze.include_tables` overrides `online_analyze.exclude_tables`).

- online_analyze.local_tracking = off

  Enables per-backend tracking for temporary tables by `online_analyze`. When this variable is set to `off`, `online_analyze` uses the default system statistics for temporary tables.

- online_analyze.lower_limit = 0

Minimum number of rows in a table required to trigger `online_analyze`.

- online_analyze.capacity_threshold = 100000

  Maximum number of temporary tables to store in local cache.

F.33.3. Authors

Teodor Sigaev `<teodor@sigaev.ru>`

F.34. old_snapshot

The `old_snapshot` module allows inspection of the server state that is used to implement old_snapshot_threshold.

F.34.1. Functions

`pg_old_snapshot_time_mapping(array_offset OUT int4, end_timestamp OUT timestamptz, newest_xmin OUT xid) returns setof record`

Returns all of the entries in the server's timestamp to XID mapping. Each entry represents the newest xmin of any snapshot taken in the corresponding minute.

F.35. pageinspect

The `pageinspect` module provides functions that allow you to inspect the contents of database pages at a low level, which is useful for debugging purposes. All of these functions may be used only by superusers.

F.35.1. General Functions

`get_raw_page(relname text, fork text, blkno bigint) returns bytea`

`get_raw_page` reads the specified block of the named relation and returns a copy as a `bytea` value. This allows a single time-consistent copy of the block to be obtained. *`fork`* should be `'main'` for the main data fork, `'fsm'` for the free space map, `'vm'` for the visibility map, or `'init'` for the initialization fork.

`get_raw_page(relname text, blkno bigint) returns bytea`

A shorthand version of `get_raw_page`, for reading from the main fork. Equivalent to `get_raw_page(relname, 'main', blkno)`

`page_header(page bytea) returns record`

`page_header` shows fields that are common to all Postgres Pro heap and index pages.

A page image obtained with `get_raw_page` should be passed as argument. For example:

```
test=# SELECT * FROM page_header(get_raw_page('pg_class', 0));
    lsn    | checksum | flags  | lower | upper | special | pagesize | version |
 xid_base | multi_base | prune_xid
-----------+----------+--------+-------+-------+---------+----------+---------
+----------+------------+----------
 0/24A1B50 |        0 |      1 |   232 |   368 |    8192 |     8192 |       4 |
   0 |          0 |        0
```

The returned columns correspond to the fields in the `PageHeaderData` struct.

The `checksum` field is the checksum stored in the page, which might be incorrect if the page is somehow corrupted. If data checksums are not enabled for this instance, then the value stored is meaningless.

`page_checksum(page bytea, blkno bigint) returns smallint`

`page_checksum` computes the checksum for the page, as if it was located at the given block.

A page image obtained with `get_raw_page` should be passed as argument. For example:

```
test=# SELECT page_checksum(get_raw_page('pg_class', 0), 0);
 page_checksum
---------------
         13443
```

Note that the checksum depends on the block number, so matching block numbers should be passed (except when doing esoteric debugging).

The checksum computed with this function can be compared with the `checksum` result field of the function `page_header`. If data checksums are enabled for this instance, then the two values should be equal.

`fsm_page_contents(page bytea) returns text`

`fsm_page_contents` shows the internal node structure of an FSM page. For example:

```
test=# SELECT fsm_page_contents(get_raw_page('pg_class', 'fsm', 0));
```

The output is a multiline string, with one line per node in the binary tree within the page. Only those nodes that are not zero are printed. The so-called "next" pointer, which points to the next slot to be returned from the page, is also printed.

F.35.2. Heap Functions

`heap_page_items(page bytea) returns setof record`

`heap_page_items` shows all line pointers on a heap page. For those line pointers that are in use, tuple headers as well as tuple raw data are also shown. All tuples are shown, whether or not the tuples were visible to an MVCC snapshot at the time the raw page was copied.

A heap page image obtained with `get_raw_page` should be passed as argument. For example:

```
test=# SELECT * FROM heap_page_items(get_raw_page('pg_class', 0));
```

The `heap_tuple_infomask_flags` function can be used to unpack the flag bits of `t_infomask` and `t_infomask2` for heap tuples.

`tuple_data_split(rel_oid oid, t_data bytea, t_infomask integer, t_infomask2 integer, t_bits text [, do_detoast bool]) returns bytea[]`

`tuple_data_split` splits tuple data into attributes in the same way as backend internals.

```
test=# SELECT tuple_data_split('pg_class'::regclass, t_data, t_infomask,
 t_infomask2, t_bits) FROM heap_page_items(get_raw_page('pg_class', 0));
```

This function should be called with the same arguments as the return attributes of `heap_page_items`.

If *`do_detoast`* is `true`, attributes will be detoasted as needed. Default value is `false`.

`heap_page_item_attrs(page bytea, rel_oid regclass [, do_detoast bool]) returns setof record`

`heap_page_item_attrs` is equivalent to `heap_page_items` except that it returns tuple raw data as an array of attributes that can optionally be detoasted by *`do_detoast`* which is `false` by default.

A heap page image obtained with `get_raw_page` should be passed as argument. For example:

```
test=# SELECT * FROM heap_page_item_attrs(get_raw_page('pg_class', 0),
 'pg_class'::regclass);
```

```
heap_tuple_infomask_flags(t_infomask integer, t_infomask2 integer) returns record
```

`heap_tuple_infomask_flags` decodes the `t_infomask` and `t_infomask2` returned by `heap_page_items` into a human-readable set of arrays made of flag names, with one column for all the flags and one column for combined flags. For example:

```
test=# SELECT t_ctid, raw_flags, combined_flags
         FROM heap_page_items(get_raw_page('pg_class', 0)),
           LATERAL heap_tuple_infomask_flags(t_infomask, t_infomask2)
         WHERE t_infomask IS NOT NULL OR t_infomask2 IS NOT NULL;
```

This function should be called with the same arguments as the return attributes of `heap_page_items`.

Combined flags are displayed for source-level macros that take into account the value of more than one raw bit, such as `HEAP_XMIN_FROZEN`.

F.35.3. B-Tree Functions

```
bt_metap(relname text) returns record
```

`bt_metap` returns information about a B-tree index's metapage. For example:

```
test=# SELECT * FROM bt_metap('pg_cast_oid_index');
-[ RECORD 1 ]-------------+-------
magic                     | 340322
version                   | 4
root                      | 1
level                     | 0
fastroot                  | 1
fastlevel                 | 0
last_cleanup_num_delpages | 0
last_cleanup_num_tuples   | 230
allequalimage             | f
```

```
bt_page_stats(relname text, blkno bigint) returns record
```

`bt_page_stats` returns summary information about single pages of B-tree indexes. For example:

```
test=# SELECT * FROM bt_page_stats('pg_cast_oid_index', 1);
-[ RECORD 1 ]-+-----
blkno         | 1
type          | l
live_items    | 224
dead_items    | 0
avg_item_size | 16
page_size     | 8192
free_size     | 3668
btpo_prev     | 0
btpo_next     | 0
btpo_level    | 0
btpo_flags    | 3
```

```
bt_page_items(relname text, blkno bigint) returns setof record
```

`bt_page_items` returns detailed information about all of the items on a B-tree index page. For example:

```
test=# SELECT itemoffset, ctid, itemlen, nulls, vars, data, dead, htid, tids[0:2] AS
 some_tids
        FROM bt_page_items('tenk2_hundred', 5);
 itemoffset |   ctid    | itemlen | nulls | vars |          data           | dead |
 htid  |      some_tids
------------+-----------+---------+-------+------+-------------------------+------
+--------+--------------------
```

```
               1 | (16,1)     |      16 | f      | f     | 30 00 00 00 00 00 00 00 |       |
        |
               2 | (16,8292)  |     616 | f      | f     | 24 00 00 00 00 00 00 00 | f     |
  (1,6)   | {"(1,6)","(10,22)"}
               3 | (16,8292)  |     616 | f      | f     | 25 00 00 00 00 00 00 00 | f     |
  (1,18)  | {"(1,18)","(4,22)"}
               4 | (16,8292)  |     616 | f      | f     | 26 00 00 00 00 00 00 00 | f     |
  (4,18)  | {"(4,18)","(6,17)"}
               5 | (16,8292)  |     616 | f      | f     | 27 00 00 00 00 00 00 00 | f     |
  (1,2)   | {"(1,2)","(1,19)"}
               6 | (16,8292)  |     616 | f      | f     | 28 00 00 00 00 00 00 00 | f     |
  (2,24)  | {"(2,24)","(4,11)"}
               7 | (16,8292)  |     616 | f      | f     | 29 00 00 00 00 00 00 00 | f     |
  (2,17)  | {"(2,17)","(11,2)"}
               8 | (16,8292)  |     616 | f      | f     | 2a 00 00 00 00 00 00 00 | f     |
  (0,25)  | {"(0,25)","(3,20)"}
               9 | (16,8292)  |     616 | f      | f     | 2b 00 00 00 00 00 00 00 | f     |
  (0,10)  | {"(0,10)","(0,14)"}
              10 | (16,8292)  |     616 | f      | f     | 2c 00 00 00 00 00 00 00 | f     |
  (1,3)   | {"(1,3)","(3,9)"}
              11 | (16,8292)  |     616 | f      | f     | 2d 00 00 00 00 00 00 00 | f     |
  (6,28)  | {"(6,28)","(11,1)"}
              12 | (16,8292)  |     616 | f      | f     | 2e 00 00 00 00 00 00 00 | f     |
  (0,27)  | {"(0,27)","(1,13)"}
              13 | (16,8292)  |     616 | f      | f     | 2f 00 00 00 00 00 00 00 | f     |
  (4,17)  | {"(4,17)","(4,21)"}
 (13 rows)
```

This is a B-tree leaf page. All tuples that point to the table happen to be posting list tuples (all of which store a total of 100 6 byte TIDs). There is also a “high key” tuple at `itemoffset` number 1. `ctid` is used to store encoded information about each tuple in this example, though leaf page tuples often store a heap TID directly in the `ctid` field instead. `tids` is the list of TIDs stored as a posting list.

In an internal page (not shown), the block number part of `ctid` is a “downlink”, which is a block number of another page in the index itself. The offset part (the second number) of `ctid` stores encoded information about the tuple, such as the number of columns present (suffix truncation may have removed unneeded suffix columns). Truncated columns are treated as having the value “minus infinity”.

`htid` shows a heap TID for the tuple, regardless of the underlying tuple representation. This value may match `ctid`, or may be decoded from the alternative representations used by posting list tuples and tuples from internal pages. Tuples in internal pages usually have the implementation level heap TID column truncated away, which is represented as a NULL `htid` value.

Note that the first item on any non-rightmost page (any page with a non-zero value in the `btpo_next` field) is the page's “high key”, meaning its `data` serves as an upper bound on all items appearing on the page, while its `ctid` field does not point to another block. Also, on internal pages, the first real data item (the first item that is not a high key) reliably has every column truncated away, leaving no actual value in its `data` field. Such an item does have a valid downlink in its `ctid` field, however.

For more details about the structure of B-tree indexes, see Section 64.4.1. For more details about deduplication and posting lists, see Section 64.4.3.

`bt_page_items(page bytea) returns setof record`

It is also possible to pass a page to `bt_page_items` as a `bytea` value. A page image obtained with `get_raw_page` should be passed as argument. So the last example could also be rewritten like this:

```
test=# SELECT itemoffset, ctid, itemlen, nulls, vars, data, dead, htid, tids[0:2] AS
 some_tids
```

```
        FROM bt_page_items(get_raw_page('tenk2_hundred', 5));
 itemoffset |   ctid    | itemlen | nulls | vars |          data           | dead |
 htid  |      some_tids
------------+-----------+---------+-------+------+-------------------------+------
+--------+--------------------
          1 | (16,1)    |      16 | f     | f    | 30 00 00 00 00 00 00 00 |      |
       |
          2 | (16,8292) |     616 | f     | f    | 24 00 00 00 00 00 00 00 | f    |
 (1,6)  | {"(1,6)","(10,22)"}
          3 | (16,8292) |     616 | f     | f    | 25 00 00 00 00 00 00 00 | f    |
 (1,18) | {"(1,18)","(4,22)"}
          4 | (16,8292) |     616 | f     | f    | 26 00 00 00 00 00 00 00 | f    |
 (4,18) | {"(4,18)","(6,17)"}
          5 | (16,8292) |     616 | f     | f    | 27 00 00 00 00 00 00 00 | f    |
 (1,2)  | {"(1,2)","(1,19)"}
          6 | (16,8292) |     616 | f     | f    | 28 00 00 00 00 00 00 00 | f    |
 (2,24) | {"(2,24)","(4,11)"}
          7 | (16,8292) |     616 | f     | f    | 29 00 00 00 00 00 00 00 | f    |
 (2,17) | {"(2,17)","(11,2)"}
          8 | (16,8292) |     616 | f     | f    | 2a 00 00 00 00 00 00 00 | f    |
 (0,25) | {"(0,25)","(3,20)"}
          9 | (16,8292) |     616 | f     | f    | 2b 00 00 00 00 00 00 00 | f    |
 (0,10) | {"(0,10)","(0,14)"}
         10 | (16,8292) |     616 | f     | f    | 2c 00 00 00 00 00 00 00 | f    |
 (1,3)  | {"(1,3)","(3,9)"}
         11 | (16,8292) |     616 | f     | f    | 2d 00 00 00 00 00 00 00 | f    |
 (6,28) | {"(6,28)","(11,1)"}
         12 | (16,8292) |     616 | f     | f    | 2e 00 00 00 00 00 00 00 | f    |
 (0,27) | {"(0,27)","(1,13)"}
         13 | (16,8292) |     616 | f     | f    | 2f 00 00 00 00 00 00 00 | f    |
 (4,17) | {"(4,17)","(4,21)"}
(13 rows)
```

All the other details are the same as explained in the previous item.

F.35.4. BRIN Functions

`brin_page_type(page bytea) returns text`

`brin_page_type` returns the page type of the given BRIN index page, or throws an error if the page is not a valid BRIN page. For example:

```
test=# SELECT brin_page_type(get_raw_page('brinidx', 0));
 brin_page_type
----------------
 meta
```

`brin_metapage_info(page bytea) returns record`

`brin_metapage_info` returns assorted information about a BRIN index metapage. For example:

```
test=# SELECT * FROM brin_metapage_info(get_raw_page('brinidx', 0));
   magic    | version | pagesperrange | lastrevmappage
------------+---------+---------------+----------------
 0xA8109CFA |       1 |             4 |              2
```

`brin_revmap_data(page bytea) returns setof tid`

`brin_revmap_data` returns the list of tuple identifiers in a BRIN index range map page. For example:

```
test=# SELECT * FROM brin_revmap_data(get_raw_page('brinidx', 2)) LIMIT 5;
  pages
```

```
---------
 (6,137)
 (6,138)
 (6,139)
 (6,140)
 (6,141)
```

`brin_page_items(page bytea, index oid) returns setof record`

`brin_page_items` returns the data stored in the BRIN data page. For example:

```
test=# SELECT * FROM brin_page_items(get_raw_page('brinidx', 5),
                                     'brinidx')
       ORDER BY blknum, attnum LIMIT 6;
 itemoffset | blknum | attnum | allnulls | hasnulls | placeholder |    value
------------+--------+--------+----------+----------+-------------+--------------
        137 |      0 |      1 | t        | f        | f           |
        137 |      0 |      2 | f        | f        | f           | {1 .. 88}
        138 |      4 |      1 | t        | f        | f           |
        138 |      4 |      2 | f        | f        | f           | {89 .. 176}
        139 |      8 |      1 | t        | f        | f           |
        139 |      8 |      2 | f        | f        | f           | {177 .. 264}
```

The returned columns correspond to the fields in the `BrinMemTuple` and `BrinValues` structs.

F.35.5. GIN Functions

`gin_metapage_info(page bytea) returns record`

`gin_metapage_info` returns information about a GIN index metapage. For example:

```
test=# SELECT * FROM gin_metapage_info(get_raw_page('gin_index', 0));
-[ RECORD 1 ]----+-----------
pending_head     | 4294967295
pending_tail     | 4294967295
tail_free_size   | 0
n_pending_pages  | 0
n_pending_tuples | 0
n_total_pages    | 7
n_entry_pages    | 6
n_data_pages     | 0
n_entries        | 693
version          | 2
```

`gin_page_opaque_info(page bytea) returns record`

`gin_page_opaque_info` returns information about a GIN index opaque area, like the page type. For example:

```
test=# SELECT * FROM gin_page_opaque_info(get_raw_page('gin_index', 2));
 rightlink | maxoff |         flags
-----------+--------+-----------------------
         5 |      0 | {data,leaf,compressed}
(1 row)
```

`gin_leafpage_items(page bytea) returns setof record`

`gin_leafpage_items` returns information about the data stored in a GIN leaf page. For example:

```
test=# SELECT first_tid, nbytes, tids[0:5] AS some_tids
       FROM gin_leafpage_items(get_raw_page('gin_test_idx', 2));
 first_tid | nbytes |                        some_tids
-----------+--------+-----------------------------------------------------------
```

```
 (8,41)    |    244 | {"(8,41)","(8,43)","(8,44)","(8,45)","(8,46)"}
 (10,45)   |    248 | {"(10,45)","(10,46)","(10,47)","(10,48)","(10,49)"}
 (12,52)   |    248 | {"(12,52)","(12,53)","(12,54)","(12,55)","(12,56)"}
 (14,59)   |    320 | {"(14,59)","(14,60)","(14,61)","(14,62)","(14,63)"}
 (167,16)  |    376 | {"(167,16)","(167,17)","(167,18)","(167,19)","(167,20)"}
 (170,30)  |    376 | {"(170,30)","(170,31)","(170,32)","(170,33)","(170,34)"}
 (173,44)  |    197 | {"(173,44)","(173,45)","(173,46)","(173,47)","(173,48)"}
(7 rows)
```

F.35.6. GiST Functions

`gist_page_opaque_info(page bytea) returns record`

`gist_page_opaque_info` returns information from a GiST index page's opaque area, such as the NSN, rightlink and page type. For example:

```
test=# SELECT * FROM gist_page_opaque_info(get_raw_page('test_gist_idx', 2));
 lsn | nsn | rightlink | flags
-----+-----+-----------+--------
 0/1 | 0/0 |         1 | {leaf}
(1 row)
```

`gist_page_items(page bytea, index_oid regclass) returns setof record`

`gist_page_items` returns information about the data stored in a page of a GiST index. For example:

```
test=# SELECT * FROM gist_page_items(get_raw_page('test_gist_idx', 0),
 'test_gist_idx');
 itemoffset |   ctid    | itemlen | dead |             keys
------------+-----------+---------+------+-------------------------------
          1 | (1,65535) |      40 | f    | (p)=("(166,166),(1,1)")
          2 | (2,65535) |      40 | f    | (p)=("(332,332),(167,167)")
          3 | (3,65535) |      40 | f    | (p)=("(498,498),(333,333)")
          4 | (4,65535) |      40 | f    | (p)=("(664,664),(499,499)")
          5 | (5,65535) |      40 | f    | (p)=("(830,830),(665,665)")
          6 | (6,65535) |      40 | f    | (p)=("(996,996),(831,831)")
          7 | (7,65535) |      40 | f    | (p)=("(1000,1000),(997,997)")
(7 rows)
```

`gist_page_items_bytea(page bytea) returns setof record`

Same as `gist_page_items`, but returns the key data as a raw `bytea` blob. Since it does not attempt to decode the key, it does not need to know which index is involved. For example:

```
test=# SELECT * FROM gist_page_items_bytea(get_raw_page('test_gist_idx', 0));
 itemoffset |   ctid    | itemlen | dead |
 key_data
------------+-----------+---------+------+----------------------------------------
----------------------------------------
          1 | (1,65535) |      40 | f    |
 \x00000100ffff28000000000000c064400000000000c064400000000000f03f000000000000f03f
          2 | (2,65535) |      40 | f    |
 \x00000200ffff28000000000000c074400000000000c074400000000000e064400000000000e06440
          3 | (3,65535) |      40 | f    |
 \x00000300ffff28000000000000207f400000000000207f400000000000d074400000000000d07440
          4 | (4,65535) |      40 | f    |
 \x00000400ffff28000000000000c084400000000000c084400000000000307f400000000000307f40
          5 | (5,65535) |      40 | f    |
 \x00000500ffff28000000000000f089400000000000f089400000000000c884400000000000c88440
          6 | (6,65535) |      40 | f    |
 \x00000600ffff28000000000000208f400000000000208f400000000000f889400000000000f88940
```

```
           7 | (7,65535) |      40 | f    |
 \x00000700ffff28000000000000408f400000000000408f400000000000288f400000000000288f40
(7 rows)
```

F.35.7. Hash Functions

`hash_page_type(page bytea) returns text`

`hash_page_type` returns page type of the given HASH index page. For example:

```
test=# SELECT hash_page_type(get_raw_page('con_hash_index', 0));
 hash_page_type
----------------
 metapage
```

`hash_page_stats(page bytea) returns setof record`

`hash_page_stats` returns information about a bucket or overflow page of a HASH index. For example:

```
test=# SELECT * FROM hash_page_stats(get_raw_page('con_hash_index', 1));
-[ RECORD 1 ]---+-----------
live_items      | 407
dead_items      | 0
page_size       | 8192
free_size       | 8
hasho_prevblkno | 4096
hasho_nextblkno | 8474
hasho_bucket    | 0
hasho_flag      | 66
hasho_page_id   | 65408
```

`hash_page_items(page bytea) returns setof record`

`hash_page_items` returns information about the data stored in a bucket or overflow page of a HASH index page. For example:

```
test=# SELECT * FROM hash_page_items(get_raw_page('con_hash_index', 1)) LIMIT 5;
 itemoffset |   ctid    |    data
------------+-----------+------------
          1 | (899,77)  | 1053474816
          2 | (897,29)  | 1053474816
          3 | (894,207) | 1053474816
          4 | (892,159) | 1053474816
          5 | (890,111) | 1053474816
```

`hash_bitmap_info(index oid, blkno bigint) returns record`

`hash_bitmap_info` shows the status of a bit in the bitmap page for a particular overflow page of HASH index. For example:

```
test=# SELECT * FROM hash_bitmap_info('con_hash_index', 2052);
 bitmapblkno | bitmapbit | bitstatus
-------------+-----------+-----------
          65 |         3 | t
```

`hash_metapage_info(page bytea) returns record`

`hash_metapage_info` returns information stored in the meta page of a HASH index. For example:

```
test=# SELECT magic, version, ntuples, ffactor, bsize, bmsize, bmshift,
test-#     maxbucket, highmask, lowmask, ovflpoint, firstfree, nmaps, procid,
test-#     regexp_replace(spares::text, '(,0)*}', '}') as spares,
test-#     regexp_replace(mapp::text, '(,0)*}', '}') as mapp
```

```
test-# FROM hash_metapage_info(get_raw_page('con_hash_index', 0));
-[ RECORD 1 ]-------------------------------------------------
-----------------------------
magic     | 105121344
version   | 4
ntuples   | 500500
ffactor   | 40
bsize     | 8152
bmsize    | 4096
bmshift   | 15
maxbucket | 12512
highmask  | 16383
lowmask   | 8191
ovflpoint | 28
firstfree | 1204
nmaps     | 1
procid    | 450
spares    | {0,0,0,0,0,0,1,1,1,1,1,1,1,3,4,4,4,45,55,58,59,
508,567,628,704,1193,1202,1204}
mapp      | {65}
```

F.36. passwordcheck

The `passwordcheck` module checks users' passwords whenever they are set with CREATE ROLE or ALTER ROLE (it doesn't work, if a non-default profile is assigned to the user). If a password is considered too weak, it will be rejected and the command will terminate with an error.

To enable this module, add `'$libdir/passwordcheck'` to shared_preload_libraries in `postgresql.conf`, then restart the server.

> **Caution**
>
> To prevent unencrypted passwords from being sent across the network, written to the server log or otherwise stolen by a database administrator, Postgres Pro allows the user to supply pre-encrypted passwords. Many client programs make use of this functionality and encrypt the password before sending it to the server.
>
> This limits the usefulness of the `passwordcheck` module, because in that case it can only try to guess the password. For this reason, `passwordcheck` is not recommended if your security requirements are high. It is more secure to use an external authentication method such as GSSAPI (see Chapter 20) than to rely on passwords within the database.

F.37. pg_buffercache

The `pg_buffercache` module provides a means for examining what's happening in the shared buffer cache in real time.

The module provides a C function `pg_buffercache_pages` that returns a set of records, plus a view `pg_buffercache` that wraps the function for convenient use.

By default, use is restricted to superusers and members of the `pg_monitor` role. Access may be granted to others using `GRANT`.

F.37.1. The `pg_buffercache` View

The definitions of the columns exposed by the view are shown in Table F.26.

Table F.26. `pg_buffercache` Columns

Column Type Description
`bufferid integer` ID, in the range 1..`shared_buffers`
`relfilenode oid` (references `pg_class .relfilenode`) Filenode number of the relation
`reltablespace oid` (references `pg_tablespace .oid`) Tablespace OID of the relation
`reldatabase oid` (references `pg_database .oid`) Database OID of the relation
`relforknumber smallint` Fork number within the relation
`relblocknumber bigint` Page number within the relation
`isdirty boolean` Is the page dirty?
`usagecount smallint` Clock-sweep access count
`pinning_backends integer` Number of backends pinning this buffer

There is one row for each buffer in the shared cache. Unused buffers are shown with all fields null except `bufferid`. Shared system catalogs are shown as belonging to database zero.

Because the cache is shared by all the databases, there will normally be pages from relations not belonging to the current database. This means that there may not be matching join rows in `pg_class` for some rows, or that there could even be incorrect joins. If you are trying to join against `pg_class`, it's a good idea to restrict the join to rows having `reldatabase` equal to the current database's OID or zero.

Since buffer manager locks are not taken to copy the buffer state data that the view will display, accessing `pg_buffercache` view has less impact on normal buffer activity but it doesn't provide a consistent set of results across all buffers. However, we ensure that the information of each buffer is self-consistent.

F.37.2. Sample Output

```
regression=# SELECT n.nspname, c.relname, count(*) AS buffers
             FROM pg_buffercache b JOIN pg_class c
             ON b.relfilenode = pg_relation_filenode(c.oid) AND
                b.reldatabase IN (0, (SELECT oid FROM pg_database
                                      WHERE datname = current_database()))
             JOIN pg_namespace n ON n.oid = c.relnamespace
             GROUP BY n.nspname, c.relname
             ORDER BY 3 DESC
             LIMIT 10;

  nspname   |        relname         | buffers
------------+------------------------+---------
 public     | delete_test_table      |     593
 public     | delete_test_table_pkey |     494
 pg_catalog | pg_attribute           |     472
 public     | quad_poly_tbl          |     353
 public     | tenk2                  |     349
 public     | tenk1                  |     349
```

```
 public     | gin_test_idx           |     306
 pg_catalog | pg_largeobject         |     206
 public     | gin_test_tbl           |     188
 public     | spgist_text_tbl        |     182
(10 rows)
```

F.37.3. Authors

Mark Kirkwood <markir@paradise.net.nz>

Design suggestions: Neil Conway <neilc@samurai.com>

Debugging advice: Tom Lane <tgl@sss.pgh.pa.us>

F.38. pgcrypto

The pgcrypto module provides cryptographic functions for Postgres Pro.

This module is considered “trusted”, that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.38.1. General Hashing Functions

F.38.1.1. digest()

```
digest(data text, type text) returns bytea
digest(data bytea, type text) returns bytea
```

Computes a binary hash of the given *data*. *type* is the algorithm to use. Standard algorithms are md5, sha1, sha224, sha256, sha384 and sha512. If pgcrypto was built with OpenSSL, more algorithms are available, as detailed in Table F.30.

If you want the digest as a hexadecimal string, use encode() on the result. For example:

```
CREATE OR REPLACE FUNCTION sha1(bytea) returns text AS $$
    SELECT encode(digest($1, 'sha1'), 'hex')
$$ LANGUAGE SQL STRICT IMMUTABLE;
```

F.38.1.2. hmac()

```
hmac(data text, key text, type text) returns bytea
hmac(data bytea, key bytea, type text) returns bytea
```

Calculates hashed MAC for *data* with key *key*. *type* is the same as in digest().

This is similar to digest() but the hash can only be recalculated knowing the key. This prevents the scenario of someone altering data and also changing the hash to match.

If the key is larger than the hash block size it will first be hashed and the result will be used as key.

F.38.2. Password Hashing Functions

The functions crypt() and gen_salt() are specifically designed for hashing passwords. crypt() does the hashing and gen_salt() prepares algorithm parameters for it.

The algorithms in crypt() differ from the usual MD5 or SHA1 hashing algorithms in the following respects:

1. They are slow. As the amount of data is so small, this is the only way to make brute-forcing passwords hard.
2. They use a random value, called the *salt*, so that users having the same password will have different encrypted passwords. This is also an additional defense against reversing the algorithm.

3. They include the algorithm type in the result, so passwords hashed with different algorithms can co-exist.
4. Some of them are adaptive — that means when computers get faster, you can tune the algorithm to be slower, without introducing incompatibility with existing passwords.

Table F.27 lists the algorithms supported by the `crypt()` function.

Table F.27. Supported Algorithms for `crypt()`

Algorithm	Max Password Length	Adaptive?	Salt Bits	Output Length	Description
`bf`	72	yes	128	60	Blowfish-based, variant 2a
`md5`	unlimited	no	48	34	MD5-based crypt
`xdes`	8	yes	24	20	Extended DES
`des`	8	no	12	13	Original UNIX crypt

F.38.2.1. `crypt()`

```
crypt(password text, salt text) returns text
```

Calculates a crypt(3)-style hash of *`password`*. When storing a new password, you need to use `gen_salt()` to generate a new *`salt`* value. To check a password, pass the stored hash value as *`salt`*, and test whether the result matches the stored value.

Example of setting a new password:

```
UPDATE ... SET pswhash = crypt('new password', gen_salt('md5'));
```

Example of authentication:

```
SELECT (pswhash = crypt('entered password', pswhash)) AS pswmatch FROM ... ;
```

This returns `true` if the entered password is correct.

F.38.2.2. `gen_salt()`

```
gen_salt(type text [, iter_count integer ]) returns text
```

Generates a new random salt string for use in `crypt()`. The salt string also tells `crypt()` which algorithm to use.

The *`type`* parameter specifies the hashing algorithm. The accepted types are: `des`, `xdes`, `md5` and `bf`.

The *`iter_count`* parameter lets the user specify the iteration count, for algorithms that have one. The higher the count, the more time it takes to hash the password and therefore the more time to break it. Although with too high a count the time to calculate a hash may be several years — which is somewhat impractical. If the *`iter_count`* parameter is omitted, the default iteration count is used. Allowed values for *`iter_count`* depend on the algorithm and are shown in Table F.28.

Table F.28. Iteration Counts for `crypt()`

Algorithm	Default	Min	Max
`xdes`	725	1	16777215
`bf`	6	4	31

For `xdes` there is an additional limitation that the iteration count must be an odd number.

To pick an appropriate iteration count, consider that the original DES crypt was designed to have the speed of 4 hashes per second on the hardware of that time. Slower than 4 hashes per second would probably dampen usability. Faster than 100 hashes per second is probably too fast.

Table F.29 gives an overview of the relative slowness of different hashing algorithms. The table shows how much time it would take to try all combinations of characters in an 8-character password, assuming that the password contains either only lower case letters, or upper- and lower-case letters and numbers. In the `crypt-bf` entries, the number after a slash is the *`iter_count`* parameter of `gen_salt`.

Table F.29. Hash Algorithm Speeds

Algorithm	**Hashes/sec**	**For** `[a-z]`	**For** `[A-Za-z0-9]`	**Duration relative to** `md5 hash`
`crypt-bf/8`	1792	4 years	3927 years	100k
`crypt-bf/7`	3648	2 years	1929 years	50k
`crypt-bf/6`	7168	1 year	982 years	25k
`crypt-bf/5`	13504	188 days	521 years	12.5k
`crypt-md5`	171584	15 days	41 years	1k
`crypt-des`	23221568	157.5 minutes	108 days	7
`sha1`	37774272	90 minutes	68 days	4
`md5` (hash)	150085504	22.5 minutes	17 days	1

Notes:

- The machine used is an Intel Mobile Core i3.
- `crypt-des` and `crypt-md5` algorithm numbers are taken from John the Ripper v1.6.38 `-test` output.
- `md5 hash` numbers are from mdcrack 1.2.
- `sha1` numbers are from lcrack-20031130-beta.
- `crypt-bf` numbers are taken using a simple program that loops over 1000 8-character passwords. That way I can show the speed with different numbers of iterations. For reference: `john -test` shows 13506 loops/sec for `crypt-bf/5`. (The very small difference in results is in accordance with the fact that the `crypt-bf` implementation in `pgcrypto` is the same one used in John the Ripper.)

Note that “try all combinations” is not a realistic exercise. Usually password cracking is done with the help of dictionaries, which contain both regular words and various mutations of them. So, even somewhat word-like passwords could be cracked much faster than the above numbers suggest, while a 6-character non-word-like password may escape cracking. Or not.

F.38.3. PGP Encryption Functions

The functions here implement the encryption part of the OpenPGP (*RFC 4880*) standard. Supported are both symmetric-key and public-key encryption.

An encrypted PGP message consists of 2 parts, or *packets*:

- Packet containing a session key — either symmetric-key or public-key encrypted.
- Packet containing data encrypted with the session key.

When encrypting with a symmetric key (i.e., a password):

1. The given password is hashed using a String2Key (S2K) algorithm. This is rather similar to `crypt()` algorithms — purposefully slow and with random salt — but it produces a full-length binary key.
2. If a separate session key is requested, a new random key will be generated. Otherwise the S2K key will be used directly as the session key.

3. If the S2K key is to be used directly, then only S2K settings will be put into the session key packet. Otherwise the session key will be encrypted with the S2K key and put into the session key packet.

When encrypting with a public key:

1. A new random session key is generated.
2. It is encrypted using the public key and put into the session key packet.

In either case the data to be encrypted is processed as follows:

1. Optional data-manipulation: compression, conversion to UTF-8, and/or conversion of line-endings.
2. The data is prefixed with a block of random bytes. This is equivalent to using a random IV.
3. A SHA1 hash of the random prefix and data is appended.
4. All this is encrypted with the session key and placed in the data packet.

F.38.3.1. pgp_sym_encrypt()

```
pgp_sym_encrypt(data text, psw text [, options text ]) returns bytea
pgp_sym_encrypt_bytea(data bytea, psw text [, options text ]) returns bytea
```

Encrypt *data* with a symmetric PGP key *psw*. The *options* parameter can contain option settings, as described below.

F.38.3.2. pgp_sym_decrypt()

```
pgp_sym_decrypt(msg bytea, psw text [, options text ]) returns text
pgp_sym_decrypt_bytea(msg bytea, psw text [, options text ]) returns bytea
```

Decrypt a symmetric-key-encrypted PGP message.

Decrypting `bytea` data with `pgp_sym_decrypt` is disallowed. This is to avoid outputting invalid character data. Decrypting originally textual data with `pgp_sym_decrypt_bytea` is fine.

The *options* parameter can contain option settings, as described below.

F.38.3.3. pgp_pub_encrypt()

```
pgp_pub_encrypt(data text, key bytea [, options text ]) returns bytea
pgp_pub_encrypt_bytea(data bytea, key bytea [, options text ]) returns bytea
```

Encrypt *data* with a public PGP key *key*. Giving this function a secret key will produce an error.

The *options* parameter can contain option settings, as described below.

F.38.3.4. pgp_pub_decrypt()

```
pgp_pub_decrypt(msg bytea, key bytea [, psw text [, options text ]]) returns text
pgp_pub_decrypt_bytea(msg bytea, key bytea [, psw text [, options text ]]) returns
 bytea
```

Decrypt a public-key-encrypted message. *key* must be the secret key corresponding to the public key that was used to encrypt. If the secret key is password-protected, you must give the password in *psw*. If there is no password, but you want to specify options, you need to give an empty password.

Decrypting `bytea` data with `pgp_pub_decrypt` is disallowed. This is to avoid outputting invalid character data. Decrypting originally textual data with `pgp_pub_decrypt_bytea` is fine.

The *options* parameter can contain option settings, as described below.

F.38.3.5. pgp_key_id()

```
pgp_key_id(bytea) returns text
```

`pgp_key_id` extracts the key ID of a PGP public or secret key. Or it gives the key ID that was used for encrypting the data, if given an encrypted message.

It can return 2 special key IDs:

- `SYMKEY`

  The message is encrypted with a symmetric key.

- `ANYKEY`

  The message is public-key encrypted, but the key ID has been removed. That means you will need to try all your secret keys on it to see which one decrypts it. `pgcrypto` itself does not produce such messages.

Note that different keys may have the same ID. This is rare but a normal event. The client application should then try to decrypt with each one, to see which fits — like handling `ANYKEY`.

F.38.3.6. `armor()`, `dearmor()`

```
armor(data bytea [ , keys text[], values text[] ]) returns text
dearmor(data text) returns bytea
```

These functions wrap/unwrap binary data into PGP ASCII-armor format, which is basically Base64 with CRC and additional formatting.

If the *`keys`* and *`values`* arrays are specified, an *armor header* is added to the armored format for each key/value pair. Both arrays must be single-dimensional, and they must be of the same length. The keys and values cannot contain any non-ASCII characters.

F.38.3.7. `pgp_armor_headers`

```
pgp_armor_headers(data text, key out text, value out text) returns setof record
```

`pgp_armor_headers()` extracts the armor headers from *`data`*. The return value is a set of rows with two columns, key and value. If the keys or values contain any non-ASCII characters, they are treated as UTF-8.

F.38.3.8. Options for PGP Functions

Options are named to be similar to GnuPG. An option's value should be given after an equal sign; separate options from each other with commas. For example:

```
pgp_sym_encrypt(data, psw, 'compress-algo=1, cipher-algo=aes256')
```

All of the options except `convert-crlf` apply only to encrypt functions. Decrypt functions get the parameters from the PGP data.

The most interesting options are probably `compress-algo` and `unicode-mode`. The rest should have reasonable defaults.

F.38.3.8.1. cipher-algo

Which cipher algorithm to use.

Values: bf, aes128, aes192, aes256 (OpenSSL-only: `3des`, `cast5`)
Default: aes128
Applies to: pgp_sym_encrypt, pgp_pub_encrypt

F.38.3.8.2. compress-algo

Which compression algorithm to use. Only available if Postgres Pro was built with zlib.

Values:
0 - no compression
1 - ZIP compression

2 - ZLIB compression (= ZIP plus meta-data and block CRCs)
Default: 0
Applies to: pgp_sym_encrypt, pgp_pub_encrypt

F.38.3.8.3. compress-level

How much to compress. Higher levels compress smaller but are slower. 0 disables compression.

Values: 0, 1-9
Default: 6
Applies to: pgp_sym_encrypt, pgp_pub_encrypt

F.38.3.8.4. convert-crlf

Whether to convert `\n` into `\r\n` when encrypting and `\r\n` to `\n` when decrypting. RFC 4880 specifies that text data should be stored using `\r\n` line-feeds. Use this to get fully RFC-compliant behavior.

Values: 0, 1
Default: 0
Applies to: pgp_sym_encrypt, pgp_pub_encrypt, pgp_sym_decrypt, pgp_pub_decrypt

F.38.3.8.5. disable-mdc

Do not protect data with SHA-1. The only good reason to use this option is to achieve compatibility with ancient PGP products, predating the addition of SHA-1 protected packets to RFC 4880. Recent gnupg.org and pgp.com software supports it fine.

Values: 0, 1
Default: 0
Applies to: pgp_sym_encrypt, pgp_pub_encrypt

F.38.3.8.6. sess-key

Use separate session key. Public-key encryption always uses a separate session key; this option is for symmetric-key encryption, which by default uses the S2K key directly.

Values: 0, 1
Default: 0
Applies to: pgp_sym_encrypt

F.38.3.8.7. s2k-mode

Which S2K algorithm to use.

Values:
0 - Without salt. Dangerous!
1 - With salt but with fixed iteration count.
3 - Variable iteration count.
Default: 3
Applies to: pgp_sym_encrypt

F.38.3.8.8. s2k-count

The number of iterations of the S2K algorithm to use. It must be a value between 1024 and 65011712, inclusive.

Default: A random value between 65536 and 253952
Applies to: pgp_sym_encrypt, only with s2k-mode=3

F.38.3.8.9. s2k-digest-algo

Which digest algorithm to use in S2K calculation.

Values: md5, sha1
Default: sha1

Applies to: pgp_sym_encrypt

F.38.3.8.10. s2k-cipher-algo

Which cipher to use for encrypting separate session key.

Values: bf, aes, aes128, aes192, aes256
Default: use cipher-algo
Applies to: pgp_sym_encrypt

F.38.3.8.11. unicode-mode

Whether to convert textual data from database internal encoding to UTF-8 and back. If your database already is UTF-8, no conversion will be done, but the message will be tagged as UTF-8. Without this option it will not be.

Values: 0, 1
Default: 0
Applies to: pgp_sym_encrypt, pgp_pub_encrypt

F.38.3.9. Generating PGP Keys with GnuPG

To generate a new key:

```
gpg --gen-key
```

The preferred key type is “DSA and Elgamal”.

For RSA encryption you must create either DSA or RSA sign-only key as master and then add an RSA encryption subkey with `gpg --edit-key`.

To list keys:

```
gpg --list-secret-keys
```

To export a public key in ASCII-armor format:

```
gpg -a --export KEYID > public.key
```

To export a secret key in ASCII-armor format:

```
gpg -a --export-secret-keys KEYID > secret.key
```

You need to use `dearmor()` on these keys before giving them to the PGP functions. Or if you can handle binary data, you can drop `-a` from the command.

For more details see `man gpg`, *The GNU Privacy Handbook* and other documentation on *https://www.gnupg.org/*.

F.38.3.10. Limitations of PGP Code

- No support for signing. That also means that it is not checked whether the encryption subkey belongs to the master key.
- No support for encryption key as master key. As such practice is generally discouraged, this should not be a problem.
- No support for several subkeys. This may seem like a problem, as this is common practice. On the other hand, you should not use your regular GPG/PGP keys with `pgcrypto`, but create new ones, as the usage scenario is rather different.

F.38.4. Raw Encryption Functions

These functions only run a cipher over data; they don't have any advanced features of PGP encryption. Therefore they have some major problems:

1. They use user key directly as cipher key.

2. They don't provide any integrity checking, to see if the encrypted data was modified.
3. They expect that users manage all encryption parameters themselves, even IV.
4. They don't handle text.

So, with the introduction of PGP encryption, usage of raw encryption functions is discouraged.

```
encrypt(data bytea, key bytea, type text) returns bytea
decrypt(data bytea, key bytea, type text) returns bytea

encrypt_iv(data bytea, key bytea, iv bytea, type text) returns bytea
decrypt_iv(data bytea, key bytea, iv bytea, type text) returns bytea
```

Encrypt/decrypt data using the cipher method specified by *type*. The syntax of the *type* string is:

algorithm [- *mode*] [/pad: *padding*]

where *algorithm* is one of:

- bf — Blowfish
- aes — AES (Rijndael-128, -192 or -256)

and *mode* is one of:

- cbc — next block depends on previous (default)
- ecb — each block is encrypted separately (for testing only)

and *padding* is one of:

- pkcs — data may be any length (default)
- none — data must be multiple of cipher block size

So, for example, these are equivalent:

```
encrypt(data, 'fooz', 'bf')
encrypt(data, 'fooz', 'bf-cbc/pad:pkcs')
```

In encrypt_iv and decrypt_iv, the *iv* parameter is the initial value for the CBC mode; it is ignored for ECB. It is clipped or padded with zeroes if not exactly block size. It defaults to all zeroes in the functions without this parameter.

F.38.5. Random-Data Functions

```
gen_random_bytes(count integer) returns bytea
```

Returns *count* cryptographically strong random bytes. At most 1024 bytes can be extracted at a time. This is to avoid draining the randomness generator pool.

```
gen_random_uuid() returns uuid
```

Returns a version 4 (random) UUID. (Obsolete, this function internally calls the core function of the same name.)

F.38.6. Notes

F.38.6.1. Configuration

pgcrypto configures itself according to the findings of the main Postgres Pro configure script. The options that affect it are --with-zlib and --with-ssl=openssl.

When compiled with zlib, PGP encryption functions are able to compress data before encrypting.

When compiled with OpenSSL, there will be more algorithms available. Also public-key encryption functions will be faster as OpenSSL has more optimized BIGNUM functions.

Table F.30. Summary of Functionality with and without OpenSSL

Functionality	Built-in	With OpenSSL
MD5	yes	yes
SHA1	yes	yes
SHA224/256/384/512	yes	yes
Other digest algorithms	no	yes (Note 1)
Blowfish	yes	yes
AES	yes	yes
DES/3DES/CAST5	no	yes
Raw encryption	yes	yes
PGP Symmetric encryption	yes	yes
PGP Public-Key encryption	yes	yes

When compiled against OpenSSL 3.0.0 and later versions, the legacy provider must be activated in the `openssl.cnf` configuration file in order to use older ciphers like DES or Blowfish.

Notes:

1. Any digest algorithm OpenSSL supports is automatically picked up. This is not possible with ciphers, which need to be supported explicitly.

F.38.6.2. NULL Handling

As is standard in SQL, all functions return NULL, if any of the arguments are NULL. This may create security risks on careless usage.

F.38.6.3. Security Limitations

All `pgcrypto` functions run inside the database server. That means that all the data and passwords move between `pgcrypto` and client applications in clear text. Thus you must:

1. Connect locally or use SSL connections.
2. Trust both system and database administrator.

If you cannot, then better do crypto inside client application.

The implementation does not resist *side-channel attacks*. For example, the time required for a `pgcrypto` decryption function to complete varies among ciphertexts of a given size.

F.38.7. Author

Marko Kreen `<markokr@gmail.com>`

`pgcrypto` uses code from the following sources:

Algorithm	Author	Source origin
DES crypt	David Burren and others	FreeBSD libcrypt
MD5 crypt	Poul-Henning Kamp	FreeBSD libcrypt
Blowfish crypt	Solar Designer	www.openwall.com
Blowfish cipher	Simon Tatham	PuTTY
Rijndael cipher	Brian Gladman	OpenBSD sys/crypto
MD5 hash and SHA1	WIDE Project	KAME kame/sys/crypto
SHA256/384/512	Aaron D. Gifford	OpenBSD sys/crypto

Algorithm	Author	Source origin
BIGNUM math	Michael J. Fromberger	dartmouth.edu/~sting/sw/imath

F.39. pg_freespacemap

The pg_freespacemap module provides a means for examining the free space map (FSM). It provides a function called pg_freespace, or two overloaded functions, to be precise. The functions show the value recorded in the free space map for a given page, or for all pages in the relation.

By default use is restricted to superusers and members of the pg_stat_scan_tables role. Access may be granted to others using GRANT.

F.39.1. Functions

pg_freespace(rel regclass IN, blkno bigint IN) returns int2

Returns the amount of free space on the page of the relation, specified by blkno, according to the FSM.

pg_freespace(rel regclass IN, blkno OUT bigint, avail OUT int2)

Displays the amount of free space on each page of the relation, according to the FSM. A set of (blkno bigint, avail int2) tuples is returned, one tuple for each page in the relation.

The values stored in the free space map are not exact. They're rounded to precision of 1/256th of BLCKSZ (32 bytes with default BLCKSZ), and they're not kept fully up-to-date as tuples are inserted and updated.

For indexes, what is tracked is entirely-unused pages, rather than free space within pages. Therefore, the values are not meaningful, just whether a page is in-use or empty.

F.39.2. Sample Output

```
postgres=# SELECT * FROM pg_freespace('foo');
 blkno | avail
-------+-------
     0 |     0
     1 |     0
     2 |     0
     3 |    32
     4 |   704
     5 |   704
     6 |   704
     7 |  1216
     8 |   704
     9 |   704
    10 |   704
    11 |   704
    12 |   704
    13 |   704
    14 |   704
    15 |   704
    16 |   704
    17 |   704
    18 |   704
    19 |  3648
(20 rows)

postgres=# SELECT * FROM pg_freespace('foo', 7);
 pg_freespace
--------------
```

```
         1216
(1 row)
```

F.39.3. Author

Original version by Mark Kirkwood <markir@paradise.net.nz>. Rewritten in version 8.4 to suit new FSM implementation by Heikki Linnakangas <heikki@enterprisedb.com>

F.40. pg_hint_plan

F.40.1. Description

pg_hint_plan is a module that allows a user to control an execution plan with hinting phrases mentioned in comments of a special form.

Postgres Pro Enterprise uses a cost-based optimizer, which utilizes data statistics rather than static rules. The planner (optimizer) estimates costs of all possible execution plans for an SQL statement, then the execution plan with the lowest cost is executed. The planner makes every effort to select the best execution plan, but it is not always perfect, since it does not take into account some of the data properties or correlations between columns.

pg_hint_plan makes it possible to tweak execution plans using so-called “hints”, which are simple descriptions added in SQL comments of a special form.

F.40.2. Overview

F.40.2.1. Basic Usage

pg_hint_plan reads hinting phrases in comments of a special form given with the target SQL statement. The special comment begins with the character sequence `/*+` and ends with `*/`. Hinting phrases consist of a hint name and following parameters enclosed in parentheses and delimited by whitespaces. Each hinting phrase can be delimited by new lines for readability.

In the example below, a hash join is selected as a joining method and `pgbench_accounts` is scanned by a sequential scan method.

```
 /*+
    HashJoin(a b)
    SeqScan(a)
  */
 EXPLAIN SELECT *
    FROM pgbench_branches b
    JOIN pgbench_accounts a ON b.bid = a.bid
    ORDER BY a.aid;
                                        QUERY PLAN
-------------------------------------------------------------------------------------
 Sort  (cost=31465.84..31715.84 rows=100000 width=197)
   Sort Key: a.aid
   ->  Hash Join  (cost=1.02..4016.02 rows=100000 width=197)
         Hash Cond: (a.bid = b.bid)
         ->  Seq Scan on pgbench_accounts a  (cost=0.00..2640.00 rows=100000 width=97)
         ->  Hash  (cost=1.01..1.01 rows=1 width=100)
               ->  Seq Scan on pgbench_branches b  (cost=0.00..1.01 rows=1 width=100)
(7 rows)
```

F.40.3. Hint Table

The above section mentions that hints are inserted in a comment of a special form. This is inconvenient if a query cannot be edited. For such cases, hints can be placed in a special table called `hint_plan.hints`, which looks as follows:

Column	Description
id	A unique number to identify a row for a hint. This column is filled automatically by sequence.
norm_query_string	A pattern that matches the query to be hinted. Constants in the query should be replaced with `?` as in the example below. Whitespaces are significant in the pattern.
application_name	A value of *application_name* of sessions to apply the hint to. The hint in the example below applies to sessions connected from psql. An empty string means sessions with any *application_name*.
hint	A hint phrase. This must be a series of hints excluding surrounding comment marks.

The following example shows how to work with the hint table.

```
INSERT INTO hint_plan.hints(norm_query_string, application_name, hints)
    VALUES (
        'EXPLAIN (COSTS false) SELECT * FROM t1 WHERE t1.id = ?;',
        '',
        'SeqScan(t1)');
INSERT 0 1
UPDATE hint_plan.hints
   SET hints = 'IndexScan(t1)'
 WHERE id = 1;
UPDATE 1
DELETE FROM hint_plan.hints
 WHERE id = 1;
DELETE 1
```

The hint table is owned by the extension owner and has the same default privileges as at the time of its creation, i.e. during `CREATE EXTENSION`. Hints in the hint table take priority over the hints specified in comments.

F.40.3.1. Types of Hints

Hinting phrases are classified into several types depending on the kind of object and how they can affect the planner. For more details, see Section F.40.9.

F.40.3.1.1. Hints for Scan Methods

Scan method hints enforce a specific scanning method on the target table. pg_hint_plan recognizes the target table by alias names, if any. They are, for example, `SeqScan` or `IndexScan`.

Scan hints work with ordinary tables, inheritance tables, `UNLOGGED` tables, temporary tables, and system catalogs. External (foreign) tables, table functions, `VALUES` clause, CTEs, views, and subqueries are not affected.

```
/*+
    SeqScan(t1)
    IndexScan(t2 t2_pkey)
 */
SELECT * FROM table1 t1 JOIN table table2 t2 ON (t1.key = t2.key);
```

F.40.3.1.2. Hints for Join Methods

Join method hints enforce join methods of the joins involving the specified tables.

This can affect joins only on ordinary tables. Inheritance tables, `UNLOGGED` tables, temporary tables, external (foreign) tables, system catalogs, table functions, `VALUES` command results, and CTEs are allowed to be in the parameter list. Joins on views and subqueries are not affected.

Join method hints are recommended to be used together with the `Leading` joining order hint because it guarantees that a joining order specified in the request will be executed.

The hint below prompts the `NestLoop(MergeJoin(c b) a)` joining structure:

```
/*+ Leading(((c b) a)) MergeJoin(c b) NestLoop(a b c) */ EXPLAIN(COSTS OFF, TIMING OFF,
 SUMMARY OFF)
SELECT count(*) FROM t1 a, t1 b, t1 c WHERE a.f1 = b.f1 AND b.f1 = c.f1;

                           QUERY PLAN
-----------------------------------------------------------------
 Aggregate
   ->  Nested Loop
         ->  Merge Join
               Merge Cond: (c.f1 = b.f1)
               ->  Index Only Scan using t1_idx1 on t1 c
               ->  Materialize
                     ->  Index Only Scan using t1_idx1 on t1 b
         ->  Memoize
               Cache Key: b.f1
               Cache Mode: logical
               ->  Index Only Scan using t1_idx1 on t1 a
                     Index Cond: (f1 = b.f1)
```

F.40.3.1.3. Hint for Joining Order

The `Leading` hint enforces the joining order for two or more tables. There are two ways of enforcing. One is enforcing specific joining order but not restricting direction at each join level:

```
 /*+
     NestLoop(t1 t2)
     MergeJoin(t1 t2 t3)
     Leading(t1 t2 t3)
  */
 SELECT * FROM table1 t1
     JOIN table table2 t2 ON (t1.key = t2.key)
     JOIN table table3 t3 ON (t2.key = t3.key);
```

Another way also enforces join direction. When the above join order is specified, the join direction chosen by the planner (outer table — inner table) may be different from the expected one. If you want to change the join direction in such a situation, use the following format:

```
 /*+ Leading ((t1 (t2 t3))) * / SELECT ...
```

In this format, two elements enclosed in parentheses are nested, and within one parenthesis, the first element is the outer table, and the second element is the inner table.

Note that the `Leading` hint (just like join methods) does not operate together with GEQO if the number of tables specified in the request exceeds `geqo_threshold`.

Some extra examples of using the hint for joining order:

```
/*+ Leading(((c b) a)) */ EXPLAIN (COSTS OFF, TIMING OFF, SUMMARY OFF)
SELECT count(*) FROM t1 a, t1 b, t1 c WHERE a.f1 = b.f1 AND b.f1 = c.f1;
                           QUERY PLAN
-----------------------------------------------------------------
 Aggregate
   ->  Hash Join
```

```
         Hash Cond: (b.f1 = a.f1)
         ->  Nested Loop
               ->  Index Only Scan using t1_idx1 on t1 c
               ->  Memoize
                     Cache Key: c.f1
                     Cache Mode: logical
                     ->  Index Only Scan using t1_idx1 on t1 b
                           Index Cond: (f1 = c.f1)
         ->  Hash
               ->  Seq Scan on t1 a
```

And an example below:

```
/*+ Leading(((d c) (b a))) */ EXPLAIN (COSTS OFF, TIMING OFF, SUMMARY OFF)
SELECT count(*) FROM t1 a, t1 b, t1 c, t1 d WHERE a.f1 = b.f1 AND b.f1 = c.f1 AND c.f1
 = d.f1;

                          QUERY PLAN
---------------------------------------------------------------
 Aggregate
   ->  Hash Join
         Hash Cond: (c.f1 = a.f1)
         ->  Nested Loop
               ->  Index Only Scan using t1_idx1 on t1 d
               ->  Memoize
                     Cache Key: d.f1
                     Cache Mode: logical
                     ->  Index Only Scan using t1_idx1 on t1 c
                           Index Cond: (f1 = d.f1)
         ->  Hash
               ->  Hash Join
                     Hash Cond: (b.f1 = a.f1)
                     ->  Seq Scan on t1 b
                     ->  Hash
                           ->  Seq Scan on t1 a
```

For details, see Section F.40.9.

F.40.3.1.4. Hints for Controlling Join Behavior

The “Memoize” hint allows the join to memoize the inner result, and the “NoMemoize” hint disallows it. In the example below, the “NoMemoize” hint prohibits the topmost hash join from memoizing the result of the table `a`.

```
/*+ NoMemoize(a b) */
EXPLAIN SELECT * FROM a, b WHERE a.val = b.val;
                            QUERY PLAN
------------------------------------------------------------------
 Hash Join  (cost=270.00..1412.50 rows=100000 width=16)
   Hash Cond: (b.val = a.val)
   ->  Seq Scan on b  (cost=0.00..15.00 rows=1000 width=8)
   ->  Hash  (cost=145.00..145.00 rows=10000 width=8)
         ->  Seq Scan on a  (cost=0.00..145.00 rows=10000 width=8)
```

F.40.3.1.5. Hint for Row Number Correction

The `Rows` hint corrects the row number misestimation of joins that comes from restrictions in the planner. For example:

```
/*+ Rows(a b #10) */ SELECT... ; Sets rows of join result to 10
/*+ Rows(a b +10) */ SELECT... ; Increments row number by 10
/*+ Rows(a b -10) */ SELECT... ; Subtracts 10 from the row number.
```

```
/*+ Rows(a b *10) */ SELECT... ; Makes the number 10 times larger.
```

F.40.3.1.6. Hint for Parallel Plans

The `Parallel` hint enforces parallel execution configuration on scans. The third parameter specifies the strength of enforcement. “soft” means that pg_hint_plan only changes `max_parallel_workers_per_gather` and leaves all others to the planner. “hard” changes other planner parameters so as to forcibly apply the number. This can affect ordinary tables, inheritance parents, `UNLOGGED` tables, and system catalog. External tables, table functions, `VALUES` clause, CTEs, views, and subqueries are not affected. Internal tables of a view can be specified by its real name or its alias as the target object. The following example shows that the query is enforced differently on each table.

```
 EXPLAIN /*+ Parallel(c1 3 hard) Parallel(c2 5 hard) */
       SELECT c2.a FROM c1 JOIN c2 ON (c1.a = c2.a);
                                    QUERY PLAN
-------------------------------------------------------------------------------
 Hash Join  (cost=2.86..11406.38 rows=101 width=4)
   Hash Cond: (c1.a = c2.a)
   ->  Gather  (cost=0.00..7652.13 rows=1000101 width=4)
         Workers Planned: 3
         ->  Parallel Seq Scan on c1  (cost=0.00..7652.13 rows=322613 width=4)
   ->  Hash  (cost=1.59..1.59 rows=101 width=4)
         ->  Gather  (cost=0.00..1.59 rows=101 width=4)
               Workers Planned: 5
               ->  Parallel Seq Scan on c2  (cost=0.00..1.59 rows=59 width=4)

 EXPLAIN /*+ Parallel(tl 5 hard) */ SELECT sum(a) FROM tl;
                                     QUERY PLAN
-------------------------------------------------------------------------------------
 Finalize Aggregate  (cost=693.02..693.03 rows=1 width=8)
   ->  Gather  (cost=693.00..693.01 rows=5 width=8)
         Workers Planned: 5
         ->  Partial Aggregate  (cost=693.00..693.01 rows=1 width=8)
               ->  Parallel Seq Scan on tl  (cost=0.00..643.00 rows=20000 width=4)
```

F.40.3.1.7. Hints for Stored Procedures

Hints can be used with stored procedures. Be careful when using hints, since they can be inherited.

```
CREATE OR REPLACE FUNCTION test_1() RETURNS bool AS $$
BEGIN
EXECUTE 'SELECT count(*) FROM t1 WHERE f1 < 2' ;
RETURN true;
END; $$ language plpgsql;

CREATE OR REPLACE FUNCTION test_2() RETURNS void AS $$
BEGIN
EXECUTE 'SELECT /*+ SET(enable_bitmapscan off)*/ test_1()' ;
END;
$$ language plpgsql;

 SELECT test_2();

    Query Text: SELECT count(*) FROM t1 WHERE f1 < 2
    Aggregate  (cost=18.00..18.01 rows=1 width=8) (actual time=0.511..0.512 rows=1
 loops=1)
      ->  Seq Scan on t1  (cost=0.00..17.50 rows=200 width=0) (actual time=0.105..0.457
 rows=200 loops=1)
            Filter: (f1 < 2)
            Rows Removed by Filter: 800
```

F.40.3.1.8. Hints for Prepared Statements

The pg_hint_plan extension allows using hints with prepared statements. Hints should be specified in the `PREPARE` statement and are ignored in the `EXECUTE` statement.

Below are a couple of sample queries. With the `IndexOnlyScan(t1)` hint:

```
/*+ IndexOnlyScan(t1) */ PREPARE stmt AS SELECT count(*) FROM t1 WHERE f1 < 2;

EXPLAIN EXECUTE stmt;
EXPLAIN (COSTS OFF, TIMING OFF, SUMMARY OFF) EXECUTE stmt;
                QUERY PLAN
------------------------------------------
 Aggregate
   ->  Index Only Scan using t1_idx1 on t1
         Index Cond: (f1 < 2)
```

And with the `BitmapScan(t1)` hint:

```
 /*+ BitmapScan(t1) */ EXPLAIN (COSTS OFF, TIMING OFF, SUMMARY OFF) EXECUTE stmt;
                QUERY PLAN
------------------------------------------
 Aggregate
   ->  Index Only Scan using t1_idx1 on t1
         Index Cond: (f1 < 2)
```

F.40.3.1.9. Setting GUC Parameters During Planning

The `Set` hint changes GUC parameters during planning. The GUC parameter shown in Section 19.7.2 can have the expected effects on planning unless any other hint conflicts with the planner method configuration parameters. When multiple hints change the same GUC, the last hint takes effect. GUC parameters for pg_hint_plan are also settable by this hint, but it may not work as you expect.

```
 /*+ Set(random_page_cost 2.0) */
 SELECT * FROM table1 t1 WHERE key = 'value';
...
```

F.40.3.2. GUC Parameters for pg_hint_plan

GUC parameters described below affect the behavior of pg_hint_plan.

Table F.31. GUC Parameters

Parameter Name	Description	Default Value
pg_hint_plan.enable_hint	True enables pg_hint_plan.	on
pg_hint_plan.enable_hint_table	True enables hinting by table.	off
pg_hint_plan.parse_messages	Specifies the log level of hint parse error. Valid values are `error`, `warning`, `notice`, `info`, `log`, `debug`.	info
pg_hint_plan.debug_print	Controls debug print and verbosity. Valid values are `off`, `on`, `detailed`, and `verbose`.	off
pg_hint_plan.message_level	Specifies message level of debug print. Valid values are `error`, `warning`, `notice`, `info`, `log`, `debug`.	log
pg_hint_plan.hints_anywhere	If it is `on`, pg_hint_plan reads hints ignoring SQL syntax. This allows placing hints anywhere	off

Parameter Name	Description	Default Value
	in the query but may cause false reads.	

F.40.4. Installation

The pg_hint_plan extension is provided together with Postgres Pro Enterprise as a separate pre-built package. For detailed package installation instructions, see Chapter 17. Once you have Postgres Pro Enterprise installed, activate pg_hint_plan:

```
LOAD 'pg_hint_plan';
LOAD
```

You can also load it globally by adding `pg_hint_plan` to the shared_preload_libraries parameter in the `postgresql.conf` file.

```
shared_preload_libraries = 'pg_hint_plan'
```

For automatic loading for specific sessions, use `ALTER USER SET/ALTER DATABASE SET`.

pg_hint_plan does not require `CREATE EXTENSION`, but if you plan to use the hint table, create the extension and enable the `enable_hint_table` parameter:

```
CREATE EXTENSION pg_hint_plan;
SET pg_hint_plan.enable_hint_table TO on;
```

F.40.5. Details in Hinting

F.40.5.1. Syntax and Placement

pg_hint_plan reads hints only from the first block comment and immediately stops parsing of any characters except alphabetical characters, digits, spaces, underscores, commas, and parentheses. In the following example `HashJoin(a b)` and `SeqScan(a)` are parsed as hints, but `IndexScan(a)` and `MergeJoin(a b)` are not:

```
 /*+
    HashJoin(a b)
    SeqScan(a)
  */
 /*+ IndexScan(a) */
 EXPLAIN SELECT /*+ MergeJoin(a b) */ *
    FROM pgbench_branches b
    JOIN pgbench_accounts a ON b.bid = a.bid
    ORDER BY a.aid;
                                      QUERY PLAN
-------------------------------------------------------------------------------------
 Sort  (cost=31465.84..31715.84 rows=100000 width=197)
   Sort Key: a.aid
   ->  Hash Join  (cost=1.02..4016.02 rows=100000 width=197)
         Hash Cond: (a.bid = b.bid)
         ->  Seq Scan on pgbench_accounts a  (cost=0.00..2640.00 rows=100000 width=97)
         ->  Hash  (cost=1.01..1.01 rows=1 width=100)
               ->  Seq Scan on pgbench_branches b  (cost=0.00..1.01 rows=1 width=100)
(7 rows)
```

However, when the `hints_anywhere` parameter is `on`, pg_hint_plan reads hints from anywhere in the query so the following hint uses would be equivalent:

```
EXPLAIN /*+ SeqScan(t1)*/
SELECT * FROM table1 t1 WHERE a < 10;
                        QUERY PLAN
-----------------------------------------------------------
```

```
 Seq Scan on table1 t1  (cost=0.00..17.50 rows=9 width=8)
   Filter: (a < 10)
(2 rows)


EXPLAIN
SELECT * FROM table1 t1 WHERE a < 10 AND '/*+SeqScan(t1)*/' <> '';
                        QUERY PLAN
-----------------------------------------------------------
 Seq Scan on table1 t1  (cost=0.00..17.50 rows=9 width=8)
   Filter: (a < 10)
(2 rows)


EXPLAIN
SELECT * FROM table1 t1 WHERE a < 10 /*+SeqScan(t1)*/;
                        QUERY PLAN
-----------------------------------------------------------
 Seq Scan on table1 t1  (cost=0.00..17.50 rows=9 width=8)
   Filter: (a < 10)
(2 rows)
```

F.40.5.2. Using with PL/pgSQL

pg_hint_plan works for queries in PL/pgSQL scripts with some restrictions.

- Hints affect only the following kinds of queries:
  - Queries that return one row (`SELECT`, `INSERT`, `UPDATE`, and `DELETE`)
  - Queries that return multiple rows (`RETURN QUERY`)
  - Dynamic SQL statements (`EXECUTE`)
  - Cursor open (`OPEN`)
  - Loop over result of a query (`FOR`)
- A hint comment should be placed after the first word in a query as in the example below, since preceding comments are not sent as a part of the query.

```
CREATE FUNCTION hints_func(integer) RETURNS integer AS $$
DECLARE
    id  integer;
    cnt integer;
BEGIN
    SELECT /*+ NoIndexScan(a) */ aid
        INTO id FROM pgbench_accounts a WHERE aid = $1;
    SELECT /*+ SeqScan(a) */ count(*)
        INTO cnt FROM pgbench_accounts a;
    RETURN id + cnt;
END;
$$ LANGUAGE plpgsql;
```

F.40.5.3. Letter Case in Object Names

Unlike the way PostgreSQL handles object names, pg_hint_plan compares bare object names in hints against the database internal object names in a case-sensitive manner. Therefore, an object name `TBL` in a hint matches only `"TBL"` in database and does not match any unquoted names like `TBL`, `tbl`, or `Tbl`.

F.40.5.4. Escaping Special Characters in Object Names

The objects defined as the hint parameter should be enclosed in double quotes if they include parentheses, double quotes, and whitespaces. The escaping rules are the same as in PostgreSQL.

F.40.5.5. Distinction Between Multiple Occurrences of a Table

pg_hint_plan identifies the target object by using aliases if they exist. This behavior is useful to point at a specific occurrence among multiple occurrences of one table.

```
 /*+ HashJoin(t1 t1) */
 EXPLAIN SELECT * FROM s1.t1
  JOIN public.t1 ON (s1.t1.id=public.t1.id);
 INFO:  hint syntax error at or near "HashJoin(t1 t1)"
 DETAIL:  Relation name "t1" is ambiguous.
...
 /*+ HashJoin(pt st) */
 EXPLAIN SELECT * FROM s1.t1 st
  JOIN public.t1 pt ON (st.id=pt.id);
                              QUERY PLAN
------------------------------------------------------------------------
 Hash Join  (cost=64.00..1112.00 rows=28800 width=8)
   Hash Cond: (st.id = pt.id)
   ->  Seq Scan on t1 st  (cost=0.00..34.00 rows=2400 width=4)
   ->  Hash  (cost=34.00..34.00 rows=2400 width=4)
         ->  Seq Scan on t1 pt  (cost=0.00..34.00 rows=2400 width=4)
```

F.40.5.6. Underlying Tables of Views or Rules

Hints are not applicable on views themselves, but they can affect the queries within the view if the object names match the object names in the expanded query on the view. Assigning aliases to the tables in the view enables them to be manipulated from outside of the view.

```
 CREATE VIEW v1 AS SELECT * FROM t2;
 EXPLAIN /*+ HashJoin(t1 v1) */
          SELECT * FROM t1 JOIN v1 ON (c1.a = v1.a);
                           QUERY PLAN
-----------------------------------------------------------------------
 Hash Join  (cost=3.27..18181.67 rows=101 width=8)
   Hash Cond: (t1.a = t2.a)
   ->  Seq Scan on t1  (cost=0.00..14427.01 rows=1000101 width=4)
   ->  Hash  (cost=2.01..2.01 rows=101 width=4)
         ->  Seq Scan on t2  (cost=0.00..2.01 rows=101 width=4)
```

And one more example:

```
CREATE VIEW v1 AS SELECT count(*) FROM t1 WHERE f1 < 2;
/*+ IndexOnlyScan(t1) */ EXPLAIN (COSTS OFF, TIMING OFF, SUMMARY OFF)
SELECT * FROM v1;
                QUERY PLAN
-----------------------------------------
 Aggregate
   ->  Index Only Scan using t1_idx1 on t1
         Index Cond: (f1 < 2)
```

Be careful not to select tables with identical names in different views because these tables may become affected. To avoid this, try using unique aliases, for example, a combination of a view name and a table name:

```
/*+ SeqScan(t1) */ EXPLAIN (COSTS OFF, TIMING OFF, SUMMARY OFF)
SELECT * FROM v2;

             QUERY PLAN
-------------------------------------
 Nested Loop Semi Join
   Join Filter: ((count(*)) = t1.f1)
   ->  Aggregate
```

```
          ->  Seq Scan on t1 t1_1
                Filter: (f1 < 2)
    ->  Seq Scan on t1
```

F.40.5.7. Inheritance

Hints can point only at the parent of an inheritance tree, yet they affect all the tables in the inheritance tree. Hints pointing directly at children will not take effect.

F.40.5.8. Hinting in Multistatements

One multistatement can have exactly one hint comment and this hint affects all individual statements in the multistatement.

F.40.5.9. VALUES Expressions

`VALUES` expressions in the `FROM` clause are named as `*VALUES*` internally, so they are hintable if it is the only `VALUES` expression in a query. Two or more `VALUES` expressions in a query cannot be distinguished by looking at `EXPLAIN`, which makes the results ambiguous:

```
/*+ MergeJoin(*VALUES*_1 *VALUES*) */
      EXPLAIN SELECT * FROM (VALUES (1, 1), (2, 2)) v (a, b)
        JOIN (VALUES (1, 5), (2, 8), (3, 4)) w (a, c) ON v.a = w.a;
INFO:  pg_hint_plan: hint syntax error at or near "MergeJoin(*VALUES*_1 *VALUES*) "
DETAIL:  Relation name "*VALUES*" is ambiguous.
                               QUERY PLAN
-------------------------------------------------------------------------
 Hash Join  (cost=0.05..0.12 rows=2 width=16)
   Hash Cond: ("*VALUES*_1".column1 = "*VALUES*".column1)
   ->  Values Scan on "*VALUES*_1"  (cost=0.00..0.04 rows=3 width=8)
   ->  Hash  (cost=0.03..0.03 rows=2 width=8)
         ->  Values Scan on "*VALUES*"  (cost=0.00..0.03 rows=2 width=8)
```

F.40.6. Subqueries

Subqueries in the following context can be hinted using the `ANY_subquery` name:

```
IN (SELECT ... {LIMIT | OFFSET ...} ...)
= ANY (SELECT ... {LIMIT | OFFSET ...} ...)
= SOME (SELECT ... {LIMIT | OFFSET ...} ...)
```

For these syntaxes, the planner internally assigns a name to the subquery when planning joins on tables including it, so join hints are applicable on such joins using the implicit name. For example:

```
 /*+ HashJoin(a1 ANY_subquery)*/
 EXPLAIN SELECT *
  FROM pgbench_accounts a1
 WHERE aid IN (SELECT bid FROM pgbench_accounts a2 LIMIT 10);
                                          QUERY PLAN

 ------------------------------------------------------------------------------------------------
 Hash Semi Join  (cost=0.49..2903.00 rows=1 width=97)
    Hash Cond: (a1.aid = a2.bid)
    ->  Seq Scan on pgbench_accounts a1  (cost=0.00..2640.00 rows=100000 width=97)
    ->  Hash  (cost=0.36..0.36 rows=10 width=4)
          ->  Limit  (cost=0.00..0.26 rows=10 width=4)
                ->   Seq Scan on pgbench_accounts a2  (cost=0.00..2640.00 rows=100000
 width=4)
```

F.40.6.1. Using the `IndexOnlyScan` Hint

The index scan may be unexpectedly performed on another index when the index specified in the `IndexOnlyScan` hint cannot perform the index-only scan.

F.40.6.2. The NoIndexScan Hint

The NoIndexScan hint implies NoIndexOnlyScan.

F.40.6.3. Parallel Hints and UNION

A UNION can run in parallel only when all underlying subqueries are parallel-safe. Therefore, enforcing parallel on any of the subqueries allows a parallel-executable UNION to run in parallel. Meanwhile, the Parallel hint with zero workers prevents a scan from being executed in parallel.

F.40.6.4. Setting pg_hint_plan Parameters by Set Hints

pg_hint_plan parameters influence the behavior of the module, so some parameters do not work as expected:

- Hints to change enable_hint, enable_hint_table are ignored even though they are reported as "used hints" in debug logs.
- Setting debug_print and message_level starts working in the middle of the query processing.

F.40.7. Errors

pg_hint_plan stops parsing on any error and uses the already parsed hints. Typical errors are listed below.

F.40.7.1. Syntax Errors

Any syntactical errors or wrong hint names are reported as syntax errors. These errors are reported in the server log with the message level, which is specified by pg_hint_plan.message_level if pg_hint_plan.debug_print is on or above.

F.40.7.2. Incorrect Object Definitions

Hints with incorrect object definitions are simply ignored. This kind of error is reported as "Not Used Hint" in the server log.

F.40.7.3. Redundant or Conflicting Hints

The last hint will take effect in case of redundant or conflicting hints. This kind of error is reported as "Duplication Hint" in the server log under the same conditions as syntax errors.

F.40.7.4. Nested Comments

A hint comment cannot be recursive. If pg_hint_plan finds it, hint parsing is immediately stopped and all the hints already parsed are ignored.

F.40.8. Functional Limitations

F.40.8.1. Influences of Planner GUC Parameters

The planner does not try to consider the joining order for the FROM clause entries more than from_collapse_limit. In such cases pg_hint_plan cannot affect the joining order.

F.40.8.2. Hints Trying to Enforce Non-Executable Plans

The planner selects any executable plan when the enforced plan cannot be executed.

- FULL OUTER JOIN to use nested loop.
- Use of indexes that do not have columns used in quals.
- TID scans for queries without ctid conditions.

F.40.8.3. Queries in ECPG

ECPG removes comments from queries written as embedded SQL, so hints cannot be passed to it. The only exception is the EXECUTE command that passes the query string to the server as is. The hint table can be used in this case.

F.40.8.4. Query Identifiers

When compute_query_id is enabled, Postgres Pro generates a query ID, ignoring comments. Hence, queries with different hints, still written the same way, may compute the same query ID.

F.40.9. Available Hints

The available hints are listed below.

Table F.32. Hints List

Group	Format	Description
Scan method	SeqScan(*table*)	Forces the sequential scan on a table.
	TidScan(*table*)	Forces the TID scan on a table.
	IndexScan(*table*[*index*...])	Forces the index scan on a table. Restricts to specified indexes, if any.
	IndexOnlyScan(*table*[*index*...])	Forces the index-only scan on a table. Restricts to specified indexes, if any. The index scan may be used if the index-only scan is not available.
	BitmapScan(*table*[*index*...])	Forces the bitmap scan on a table. Restricts to specified indexes, if any.
	IndexScanRegexp(*table*[*POSIX regexp*...])	Forces the index scan on a table. Restricts to indexes that match the specified POSIX regular expression.
	IndexOnlyScanRegexp(*table*[*POSIX regexp*...])	Forces the index-only scan on a table. Restricts to indexes that match the specified POSIX regular expression.
	BitmapScanRegexp(*table*[*POSIX regexp*...])	Forces the bitmap scan on a table. Restricts to indexes that match the specified POSIX regular expression.
	NoSeqScan(*table*)	Forces the deactivation of the sequential scan on a table.
	NoTidScan(*table*)	Forces the deactivation of the TID scan on a table.
	NoIndexScan(*table*)	Forces the deactivation of the index scan and index-only scan on a table.
	NoIndexOnlyScan(*table*)	Forces the deactivation of the index-only scan on a table.
	NoBitmapScan(*table*)	Forces the deactivation of the bitmap scan on a table.
Join method	NestLoop(*table table*[*table*...])	Forces the nested loop for joins with specified tables.
	HashJoin(*table table*[*table*...])	Forces the hash join for joins with specified tables.

Group	Format	Description
	MergeJoin(*table table*[*table*...])	Forces the merge join for joins with specified tables.
	NoNestLoop(*table table*[*table*...])	Forces the deactivation of the nested loop for joins with specified tables.
	NoHashJoin(*table table*[*table*...])	Forces the deactivation of the hash join for joins with specified tables.
	NoMergeJoin(*table table*[*table*...])	Forces the deactivation of the merge join for joins with specified tables.
Join order	Leading(*table table*[*table*...])	Forces the join order as specified.
	Leading(*<join pair>*)	Forces the join order and directions as specified. A join pair is a pair of tables and/or other join pairs enclosed in parentheses, which can make a nested structure.
Control join behavior	Memoize(*table table*[*table*...])	Allows the topmost join of the joins involving the specified tables to memoize the inner result. Note that it does not enforce memoizing.
	NoMemoize(*table table*[*table*...])	Disallows the topmost join of the joins involving the specified tables to memoize the inner result.
Row number correction	Rows(*table table*[*table*...] *correction*)	Corrects row number of a result of the joins with the specified tables. The available correction methods are absolute (#<n>), addition (+<n>), subtraction (-<n>) and multiplication (*<n>). <n> should be a string that strtod() can read.
Parallel query configuration	Parallel(table <# of workers> [soft|hard])	Enforces or inhibits parallel execution of the specified table. <# of workers> is the desired number of parallel workers, where zero means inhibiting parallel execution. If the third parameter is `soft` (default), it only changes `max_parallel_workers_per_gather` and leaves everything else to the planner. The `hard` value enforces the specified number of workers.
GUC	Set(*GUC-parameter value*)	Sets the GUC parameter to the value while the planner is running.

F.40.10. See Also

EXPLAIN, SET, Chapter 19, Section 15.3

F.41. pg_pathman

> **Important**
>
> Starting from Postgres Pro 12, using pg_pathman is not recommended. Use vanilla declarative partitioning instead, as described in Section 5.11.

The `pg_pathman` is a Postgres Pro extension that provides an optimized partitioning solution for large and distributed databases. Using `pg_pathman`, you can:

- Partition large databases without downtime.
- Speed up query execution for partitioned tables.
- Manage existing partitions and add new partitions on the fly.
- Add foreign tables as partitions.
- Join partitioned tables for read and write operations.

The extension is compatible with Postgres Pro 9.5 or higher.

F.41.1. Installation and Setup

The `pg_pathman` extension is included into the Postgres Pro. Once you have Postgres Pro installed, complete the following steps to enable `pg_pathman`:

1. Add `pg_pathman` to the `shared_preload_libraries` variable in the `postgresql.conf` file:

   ```
   shared_preload_libraries = 'pg_pathman'
   ```

   > **Important**
   >
   > `pg_pathman` may have conflicts with other extensions that use the same hook functions. For example, `pg_pathman` may interfere with the `pg_stat_statements` extension as they both use `ProcessUtility_hook`. To avoid such issues, `pg_pathman` must always be the last in the list of libraries: `shared_preload_libraries = 'pg_stat_statements, pg_pathman'`

2. Restart the Postgres Pro instance for the settings to take effect.
3. Create the `pg_pathman` extension as follows:

   ```
   CREATE SCHEMA pathman;
   GRANT USAGE ON SCHEMA pathman TO PUBLIC;
   CREATE EXTENSION pg_pathman WITH SCHEMA pathman;
   ```

   > **Important**
   >
   > To ensure that your calls to `pg_pathman`'s functions are always secure against `search_path`-based attacks (see CREATE EXTENSION for details), install it only into a clean schema where nobody except superusers has the `CREATE` privilege for database objects.

Once `pg_pathman` is enabled, you can start partitioning tables.

Note

During installation, pg_pathman creates a few RLS policies to restrict access to its own tables. Postgres Pro core, however, does not support dump/restore of databases where extensions issuing `CREATE POLICY` statements are installed. Therefore, when restoring a dump of a database where pg_pathman is installed, you will get error messages such as:

```
ERROR: policy "allow_select" for table "pathman_config" already exists
```

Ignore them since they do not affect whether the data being restored is complete.

Tip

You can also build `pg_pathman` from source code by executing the following command in the `pg_pathman` directory:

```
make install USE_PGXS=1
```

When this operation is complete, follow the steps described above to complete the setup.

In addition, do not forget to set the `PG_CONFIG` variable if you want to test `pg_pathman` on a custom build of Postgres Pro. For details, see *Building and Installing PostgreSQL Extension Modules*.

You can toggle `pg_pathman` or its specific custom nodes on and off using GUC variables. For details, see Section F.41.5.1.

If you want to permanently disable `pg_pathman` for a previously partitioned table, use the `disable_pathman_for()` function:

```
SELECT disable_pathman_for('range_rel');
```

All sections and data will remain unchanged and will be handled by the standard Postgres Pro inheritance mechanism.

F.41.1.1. Updating pg_pathman

If you already have a previous version of `pg_pathman` installed, complete the following steps to upgrade to a newer version:

1. Install Postgres Pro.
2. Restart your Postgres Pro cluster.
3. If you are running a previous major version of `pg_pathman` (the second digit in the version number is different), complete the update as follows:

   ```
   ALTER EXTENSION pg_pathman UPDATE TO version;
   SET pg_pathman.enable = t;
   ```

   where *version* is the `pg_pathman` major version number, such as 1.5.

   You can check the current `pg_pathman` version by running the `pathman_version()` function.

F.41.2. Usage

Choosing Partitioning Strategies

Running Non-Blocking Data Migration

Partitioning by a Single Expression

Partitioning by Composite Key

Running Multilevel Partitioning

Using Declarative Syntax

Managing Partitions

As your database grows, indexing mechanisms may become inefficient and cause high latency as you run queries. To improve performance, ensure scalability, and optimize database administration processes you can use partitioning — splitting a large table into smaller pieces, with each row moved to a single partition according to the partitioning key.

Traditionally, Postgres Pro has supported partitioning via table inheritance, with each partition created as a child table with a CHECK constraint. In Postgres Pro 10, support for declarative partitioning was added, which also relies on inheritance. With these approaches, the query planner has to perform an exhaustive search and check constraints on each partition to build a query plan, which may slow down queries for tables with a large number of partitions. The `pg_pathman` extension uses an optimized planning algorithms and partitioning functions based on the internal structure of the partitioned tables, which allows to achieve better performance results. For details on `pg_pathman` implementation specifics, see Section F.41.4.

F.41.2.1. Choosing Partitioning Strategies

The `pg_pathman` extension supports the following partitioning strategies:

- Hash — maps rows to partitions using a generic hash function. Choose this strategy if most of your queries will be of the exact-match type.
- Range — maps rows to partitions based on partitioning key ranges assigned to each partition. Choose this strategy if your database contains numeric data that you are likely to query or manage by ranges. For example, you may want to query historical data by years, or review experiment results by specific numeric ranges. To achieve performance gains, `pg_pathman` uses the binary search algorithm.

By default, `pg_pathman` migrates all data from the parent table to the newly created partitions at once (*blocking partitioning*). This approach enables you to restructure the table in a single transaction, but may cause downtime if you have a lot of data. If it is critical to avoid downtime, you can use *concurrent partitioning*. In this case, `pg_pathman` writes all the updates to the newly created partitions, but keeps the original data in the parent table until you explicitly migrate it. This enables you to partition large databases without downtime, as you can choose convenient time for migration and copy data in small batches without blocking other transactions. For details on concurrent partitioning, see Section F.41.2.2.

F.41.2.1.1. Setting up Hash Partitioning

To perform hash partitioning with `pg_pathman`, run the `create_hash_partitions()` function:

```
create_hash_partitions(parent_relid     REGCLASS,
                       expression       TEXT,
                       partitions_count INTEGER,
                       partition_data   BOOLEAN DEFAULT TRUE,
                       partition_names  TEXT[] DEFAULT NULL,
                       tablespaces      TEXT[] DEFAULT NULL)
```

The `pg_pathman` module creates the specified number of partitions based on the hash function. Optionally, you can specify partition names and tablespaces by setting `partition_names` and `tablespaces` options, respectively.

You cannot add or remove partitions after the parent table is split. If required, you can replace the specified partition with another table:

```
replace_hash_partition(old_partition       REGCLASS,
```

```
                        new_partition       REGCLASS,
                        lock_parent         BOOL DEFAULT TRUE);
```

When set to `true`, `lock_parent` parameter will prevent any `INSERT`/`UPDATE`/`ALTER TABLE` queries to parent table.

If you omit the optional `partition_data` parameter or set it to `true`, all the data from the parent table gets migrated to partitions. The `pg_pathman` module blocks the table for other transactions until data migration completes. To avoid downtime, you can set the `partition_data` parameter to `false` and later use the `partition_table_concurrently()` function to migrate your data to partitions without blocking other queries. For details, see the Section F.41.2.2.

F.41.2.1.2. Setting up Range Partitioning

The `pg_pathman` module provides the `create_range_partitions()` for range partitioning. This function creates partitions based on the specified interval and the initial partitioning key value. New partitions are created automatically when you insert data outside of the already covered range.

```
create_range_partitions(parent_relid   REGCLASS,
                        expression     TEXT,
                        start_value    ANYELEMENT,
                        p_interval     ANYELEMENT | INTERVAL,
                        p_count        INTEGER DEFAULT NULL,
                        partition_data BOOLEAN DEFAULT TRUE)
```

The `pg_pathman` module creates partitions based on the specified parameters. If you omit the optional `p_count` parameter, `pg_pathman` calculates the required number of partitions based on the specified start value and interval. If you insert new data outside of the existing partition range, `pg_pathman` creates new partitions automatically, keeping the specified interval. This approach ensures that all partitions are of the same size, which can improve query performance and facilitate database management.

Alternatively, you can specify an array defining the bounds of partitions to be created using the `bounds` parameter:

```
create_range_partitions(parent_relid    REGCLASS,
                        expression      TEXT,
                        bounds          ANYARRAY,
                        partition_names TEXT[] DEFAULT NULL,
                        tablespaces     TEXT[] DEFAULT NULL,
                        partition_data  BOOLEAN DEFAULT TRUE)
```

If required, you can also use partition management functions to add partitions manually. For example, if there is a gap between the created partitions, `pg_pathman` cannot fill it with a new partition in an automated mode.

By default, all the data from the parent table gets migrated to the specified number of partitions. The `pg_pathman` module blocks the table for other transactions until data migration completes. To avoid downtime, you can set the `partition_data` parameter to `false` and later use the `partition_table_concurrently()` function to migrate your data to partitions without blocking other queries. For details, see the Section F.41.2.2.

F.41.2.2. Running Non-Blocking Data Migration

If it is critical to avoid downtime, you can perform concurrent partitioning by setting the `partition_data` parameter of the partitioning function to `false`. In this case, `pg_pathman` creates empty partitions, keeping all the original data in the parent table. At the same time, all the database updates are written to the newly created partitions. You can later migrate the original data to partitions without blocking other queries using the `partition_table_concurrently()` function:

```
partition_table_concurrently(relation   REGCLASS,
                             batch_size INTEGER DEFAULT 1000,
```

```
sleep_time FLOAT8 DEFAULT 1.0)
```

where:

- `relation` is the parent table.
- `batch_size` is the number of rows to copy from the parent table to partitions at a time. You can set this parameter to any integer value from 1 to 10000.
- `sleep_time` is the time interval between migration attempts, in seconds.

The `pg_pathman` module starts a background worker to move the data from the parent table to partitions in small batches of the specified `batch_size`. If one or more rows in the batch are locked by other queries, `pg_pathman` waits for the specified `sleep_time` and tries again, up to 60 times. You can monitor the migration process in the `pathman_concurrent_part_tasks` view that shows the number of rows migrated so far:

```
[user]postgres: select * from pathman_concurrent_part_tasks ;
 userid |  pid  | dbid  | relid | processed | status
--------+-------+-------+-------+-----------+---------
 user   | 20012 | 12413 | test  |    334000 | working
(1 row)
```

If you need to stop data migration, run the `stop_concurrent_part_task()` function at any time:

```
SELECT stop_concurrent_part_task(relation REGCLASS);
```

`pg_pathman` completes the migration of the current batch and terminates the migration process.

> **Tip**
>
> When `pg_pathman` migrates all the data from the parent table, you can exclude the parent table from the query plan. See the `set_enable_parent()` function description for details.

F.41.2.3. Partitioning by a Single Expression

For both range and hash partitioning strategies, `pg_pathman` supports partitioning by expression that returns a single scalar value. The partitioning expression can reference a table column, as well as calculate the partitioning key based on one or more column values.

> **Tip**
>
> If you would like to partition a table by a tuple, see Section F.41.2.4.

To partition a table by expression, use `pg_pathman` partitioning functions. The partitioning expression must satisfy the following conditions:

- Expression must reference at least one column of the partitioned table.
- All referenced columns must be marked as `NOT NULL`.
- Expression cannot reference system attributes, such as `oid`, `xmin`, `xmax`, etc.
- Expression cannot include subqueries.
- All functions used by expression must be marked as `IMMUTABLE`.

As the expression can return a value of virtually any type, make sure to convert it to the type you need for partitioning.

To access a partition, you must use the exact expression used for partitioning. Otherwise, `pg_pathman` cannot optimize the query. You can view the partitioning expression for each partitioned table in the `pathman_config` table.

F.41.2.3.1. Examples

Suppose you have the `test` table that stores some `jsonb` data:

```
CREATE TABLE test(col jsonb NOT NULL);
INSERT INTO test
SELECT format('{"key": %s, "date": "%s", "value": "%s"}',
              i, current_date, md5(i::text))::jsonb
FROM generate_series(1, 10000 * 10) as g(i);
```

To partition this data by range of the `key` value, you need to extract this value from the `jsonb` object and convert it to a numeric type, such as `bigint`:

```
SELECT create_range_partitions('test', '(col->>''key'')::bigint', 1, 10000, 10);
```

`pg_pathman` splits the parent table into ten partitions, with each partition storing 10000 rows:

```
SELECT * FROM pathman_partition_list;
 parent | partition | parttype |              expr               | range_min |
 range_max
--------+-----------+----------+---------------------------------+-----------
+-----------
 test   | test_1    |        2 | ((col ->> 'key'::text))::bigint | 1         | 10001
 test   | test_2    |        2 | ((col ->> 'key'::text))::bigint | 10001     | 20001
 test   | test_3    |        2 | ((col ->> 'key'::text))::bigint | 20001     | 30001
 test   | test_4    |        2 | ((col ->> 'key'::text))::bigint | 30001     | 40001
 test   | test_5    |        2 | ((col ->> 'key'::text))::bigint | 40001     | 50001
 test   | test_6    |        2 | ((col ->> 'key'::text))::bigint | 50001     | 60001
 test   | test_7    |        2 | ((col ->> 'key'::text))::bigint | 60001     | 70001
 test   | test_8    |        2 | ((col ->> 'key'::text))::bigint | 70001     | 80001
 test   | test_9    |        2 | ((col ->> 'key'::text))::bigint | 80001     | 90001
 test   | test_10   |        2 | ((col ->> 'key'::text))::bigint | 90001     | 100001
(10 rows)
```

F.41.2.4. Partitioning by Composite Key

Using `pg_pathman`, you can also perform range partitioning by composite key. A composite key consists of two or more comma-separated values, which can be columns or expressions extracting the values from the table. The expressions defining the composite key must satisfy the conditions described in Section F.41.2.3.

Although `pg_pathman` does not support automatic partition creation by composite key, you can add partitions using the `add_range_partition()` function. A typical workflow is as follows:

1. Enable automatic partition naming for your table by running the `create_naming_sequence()` function.
2. Create a composite partitioning key.
3. Register a table you are going to partition with `pg_pathman` using the `add_to_pathman_config()` function.
4. Add a partition based on the defined composite partitioning key using the `add_range_partition()` function.

F.41.2.4.1. Examples

Suppose you have the `test` table that stores some temporal data:

```
CREATE TABLE test (logdate date NOT NULL, comment text);
```

To partition this data by month and year, you have to create a composite key:

```
CREATE TYPE test_key AS (year float8, month float8);
```

To enable automatic partition naming, run the `create_naming_sequence()` function passing the table name as an argument:

```
SELECT create_naming_sequence('test');
```

Register the `test` table with `pg_pathman`, specifying the partitioning key you are going to use:

```
SELECT add_to_pathman_config('test',
                             '( extract(year from logdate),
                                extract(month from logdate) )::test_key',
                             NULL);
```

Create a partition that includes all the data in the range of ten years, starting from January of the current year:

```
SELECT add_range_partition('test',
                           (extract(year from current_date), 1)::test_key,
                           (extract(year from current_date + '10 years'::interval),
 1)::test_key);
```

F.41.2.5. Running Multilevel Partitioning

`pg_pathman` supports multilevel partitioning for both hash and range partitioning strategies. You can use partitioning strategies in any combination: a hash- or range-partitioned table can be further partitioned by both hash or range.

To split an existing partition into several child ones, use the regular `pg_pathman` partitioning functions as explained in Section F.41.2.1, passing the name of the partition to be split as the *`parent_relid`* parameter. You can check the exact partition names in the pathman_partition_list view.

When opting for the range-range partitioning combination, you can either choose a different partitioning expression, or use the same expression as for the parent table. In the latter case, if the selected range is larger than that of the parent partition, only those child partitions that intersect with the parent range will be in use. Other child partitions will remain empty unless their parent is merged with an adjacent partition that covers at least a part of their range.

F.41.2.5.1. Examples

Suppose you have the `journal` table with some logs, which is partitioned by month:

```
-- create an empty table
CREATE TABLE journal (
id      SERIAL,
dt      TIMESTAMP NOT NULL,
level   INTEGER,
msg     TEXT);

-- generate some log data into the table
INSERT INTO journal (dt, level, msg)
SELECT g, random() * 6, md5(g::text)
FROM generate_series('2015-01-01'::date, '2015-12-31'::date, '1 minute') as g;

-- partition the table by range
SELECT create_range_partitions('journal', 'dt', '2015-01-01'::date, '1
 month'::interval);
```

If having smaller partitions makes more sense at some point, you can further split the partitions by hash or range. For example, to split the `journal_1` partition into subpartitions by day, run:

```
SELECT create_range_partitions('journal_1', 'dt', '2015-01-01'::date, '1
 day'::interval);
```

Similarly, you can use hash partitioning to create child partitions. For example, split the `journal_2` partition into five partitions by hash using the `id` column as the partitioning key:

```
SELECT create_hash_partitions('journal_2', 'id', '5');
```

F.41.2.6. Using Declarative Syntax

Declarative syntax for partitioning enables you to define the partitioning strategy when creating a table, as well as partition existing tables and manage table partitions using SQL commands. Postgres Pro Enterprise offers the following implementations of declarative syntax:

- Postgres Pro core functionality, described in detail in Section 5.11.2.
- pg_pathman implementation of declarative syntax.

Depending on the chosen implementation, the available SQL command forms will differ, as explained in CREATE TABLE and ALTER TABLE descriptions.

By default, Postgres Pro core functionality is used for declarative partitioning. To enable declarative partitioning provided by `pg_pathman`, set the partition_backend parameter to the `pg_pathman` value. In this case, you can use declarative range and hash partitioning strategies as explained below. For the CREATE TABLE command, you can also override the partition_backend setting by specifying the `USING` *`partition_backend`* clause. Do not confuse this clause with `USING` *`method`*, which cannot be used when creating partitioned tables.

When running the `CREATE TABLE` command, you can use the `PARTITION BY` clause to split the resulting table into partitions by range or hash.

To create a table partitioned by range, specify the partition names, the range of values to include into each partition and, optionally, a tablespace. For example:

```
CREATE TABLE abc(id serial NOT NULL)
    PARTITION BY RANGE(id)
    (
     PARTITION abc_100 VALUES LESS THAN (100) TABLESPACE ts1,
     PARTITION abc_200 VALUES LESS THAN (200) TABLESPACE ts2
    );
```

When creating a table partitioned by hash, you can either specify the number of partitions to create, or the exact partitions and tablespaces. For example, to create the `abc` table with three partitions, run:

```
CREATE TABLE abc(id serial NOT NULL)
    PARTITION BY HASH (id) PARTITIONS (3);
```

To define the exact partitions to create, use the following statement:

```
CREATE TABLE abc(id serial NOT NULL)
    PARTITION BY HASH (id)
    (
     PARTITION abc_first  TABLESPACE ts1,
     PARTITION abc_second TABLESPACE ts2
    );
```

To partition an already created table, you can use the `ALTER TABLE` command with the `PARTITION BY` clause. For example, to split the `abc` table into three hash partitions, run:

```
ALTER TABLE abc PARTITION BY HASH (id) PARTITIONS (3);
```

When performing range partitioning of an already created table, you have to specify the lower bound of the first partition, which must not be greater than the smallest value in the partition key column, and provide the partitioning interval that defines the range of values to include into a single partition:

```
ALTER TABLE abc PARTITION BY RANGE (id) START FROM (0) INTERVAL (2000);
```

If the table to partition contains a lot of data and it is critical to avoid downtime, consider using the optional `CONCURRENTLY` clause. In this case, `pg_pathman` first creates empty partitions, and then migrates the data in batches of 1000 rows. This clause can be used for both hash and range partitioning. For example:

```
ALTER TABLE abc PARTITION BY RANGE (id) START FROM (0) INTERVAL (50000) CONCURRENTLY;
ALTER TABLE abc PARTITION BY HASH (id) PARTITIONS (3) CONCURRENTLY;
```

`pg_pathman` declarative syntax also supports multilevel partitioning. Once the table is partitioned, you can run the `ALTER TABLE` command with the `PARTITION BY` clause on the partition that you would like to split. Consider the following example with hash partitioning:

```
CREATE TABLE test(a int NOT NULL, b int NOT NULL)
    PARTITION BY by hash(a) PARTITIONS (8);

ALTER TABLE test_1
    PARTITION BY hash(b) PARTITIONS (10);
```

As a result, the `test` table is split into eight hash partitions, and its `test_1` partition is further split into ten partitions by another key.

The `ALTER TABLE` command can also be run with partition management clauses to add, remove, or modify partitions, as explained in ALTER TABLE. You can perform these actions on tables partitioned with `pg_pathman` regardless of the partition_backend setting.

F.41.2.7. Managing Partitions

`pg_pathman` provides multiple functions for easy partition management. For details, see Section F.41.5.3.4.

F.41.3. Examples

F.41.3.1. Common Tips

- You can add `partition` column containing the names of the underlying partitions using the system attribute called `tableoid`:

  ```
  SELECT tableoid::regclass AS partition, * FROM partitioned_table;
  ```

- Though indices on a parent table are not particularly useful (since the parent table is supposed to be empty), they act as prototypes for indices on partitions. For each index on the parent table, `pg_pathman` creates a similar index on each partition.

- All running concurrent partitioning tasks can be listed using the `pathman_concurrent_part_tasks` view:

  ```
  SELECT * FROM pathman_concurrent_part_tasks;
  userid  | pid  | dbid  | relid | processed | status
  --------+------+-------+-------+-----------+---------
  user    | 7367 | 16384 | test  |    472000 | working
  (1 row)
  ```

- The `pathman_partition_list` in conjunction with `drop_range_partition()` can be used to drop range partitions in a more flexible way compared to `DROP TABLE`:

  ```
  SELECT drop_range_partition(partition, false) /* move data to parent */
  FROM pathman_partition_list
  WHERE parent = 'part_test'::regclass AND range_min::int < 500;
  NOTICE:  1 rows copied from part_test_11
  NOTICE:  100 rows copied from part_test_1
  NOTICE:  100 rows copied from part_test_2
  ```

```
drop_range_partition
----------------------
dummy_test_11
dummy_test_1
dummy_test_2
(3 rows)
```

- You can turn foreign tables into partitions using the `attach_range_partition()` function. Rows that were meant to be inserted into the parent will be redirected to foreign partitions using `PartitionFilter`. By default, it is only allowed to insert rows into partitions provided by `postgres_fdw`. This setting is controlled by the `pg_pathman.insert_into_fdw` variable. You must have superuser rights to change this setting.

F.41.3.2. Hash Partitioning

Consider an example of hash partitioning. First create a table with an integer column:

```
CREATE TABLE items (
id       SERIAL PRIMARY KEY,
name     TEXT,
code     BIGINT);

INSERT INTO items (id, name, code)
SELECT g, md5(g::text), random() * 100000
FROM generate_series(1, 100000) as g;
```

Now run the `create_hash_partitions()` function with appropriate arguments:

```
SELECT create_hash_partitions('items', 'id', 100);
```

This will create new partitions and move the data from the parent table to partitions.

Here is an example of the query performing filtering by partitioning key:

```
SELECT * FROM items WHERE id = 1234;
  id  |               name               | code
------+----------------------------------+------
 1234 | 81dc9bdb52d04dc20036dbd8313ed055 | 1855
(1 row)

EXPLAIN SELECT * FROM items WHERE id = 1234;
QUERY PLAN
-------------------------------------------------------------------------------------
Append  (cost=0.28..8.29 rows=0 width=0)
->  Index Scan using items_34_pkey on items_34  (cost=0.28..8.29 rows=0 width=0)
Index Cond: (id = 1234)
```

Notice that the `Append` node contains only one child scan, which corresponds to the `WHERE` clause.

> **Important**
>
> Pay attention to the fact that `pg_pathman` excludes the parent table from the query plan.

To access the parent table, use the `ONLY` modifier:

```
EXPLAIN SELECT * FROM ONLY items;
QUERY PLAN
---------------------------------------------------
Seq Scan on items  (cost=0.00..0.00 rows=1 width=45)
```

F.41.3.3. Range Partitioning

Consider an example of range partitioning. Let's create a table containing some dummy logs:

```
CREATE TABLE journal (
id      SERIAL,
dt      TIMESTAMP NOT NULL,
level   INTEGER,
msg     TEXT);

-- similar index will also be created for each partition
CREATE INDEX ON journal(dt);

-- generate some data
INSERT INTO journal (dt, level, msg)
SELECT g, random() * 6, md5(g::text)
FROM generate_series('2015-01-01'::date, '2015-12-31'::date, '1 minute') as g;
```

Run the `create_range_partitions()` function to create partitions so that each partition would contain the data for one day:

```
SELECT create_range_partitions('journal', 'dt', '2015-01-01'::date, '1 day'::interval);
```

It will create 364 partitions and move the data from the parent table to partitions.

New partitions are appended automatically by insert trigger, but it can be done manually with the following functions:

```
-- add new partition with specified range
SELECT add_range_partition('journal', '2016-01-01'::date, '2016-01-07'::date);

-- append new partition with default range
SELECT append_range_partition('journal');
```

The first one creates a partition with specified range. The second one creates a partition with default interval and appends it to the partition list. It is also possible to attach an existing table as partition. For example, we may want to attach an archive table (or even foreign table from another server) for some outdated data:

```
CREATE FOREIGN TABLE journal_archive (
id      INTEGER NOT NULL,
dt      TIMESTAMP NOT NULL,
level   INTEGER,
msg     TEXT)
SERVER archive_server;

SELECT attach_range_partition('journal', 'journal_archive', '2014-01-01'::date,
 '2015-01-01'::date);
```

> **Important**
>
> The attached table must have the same columns as the partitioned table, except for the dropped columns. The attached columns must have the same type, collation, and `NOT NULL` settings as the original columns.

To merge two adjacent partitions, use the `merge_range_partitions()` function:

```
SELECT merge_range_partitions('journal_archive', 'journal_1');
```

To split partition by value, use the `split_range_partition()` function:

```
SELECT split_range_partition('journal_366', '2016-01-03'::date);
```

To detach partition, use the `detach_range_partition()` function:

```
SELECT detach_range_partition('journal_archive');
```

Here is an example of the query performing filtering by partitioning key:

```
SELECT * FROM journal WHERE dt >= '2015-06-01' AND dt < '2015-06-03';
id      |         dt          | level |               msg
--------+---------------------+-------+----------------------------------
217441  | 2015-06-01 00:00:00 |     2 | 15053892d993ce19f580a128f87e3dbf
217442  | 2015-06-01 00:01:00 |     1 | 3a7c46f18a952d62ce5418ac2056010c
217443  | 2015-06-01 00:02:00 |     0 | 92c8de8f82faf0b139a3d99f2792311d
...
(2880 rows)

EXPLAIN SELECT * FROM journal WHERE dt >= '2015-06-01' AND dt < '2015-06-03';
QUERY PLAN
------------------------------------------------------------------
Append  (cost=0.00..58.80 rows=0 width=0)
->  Seq Scan on journal_152  (cost=0.00..29.40 rows=0 width=0)
->  Seq Scan on journal_153  (cost=0.00..29.40 rows=0 width=0)
(3 rows)
```

F.41.4. Internals

`pg_pathman` stores partitioning configuration in the `pathman_config` table; each row contains a single entry for a partitioned table (relation name, partitioning column and its type). During the initialization stage the `pg_pathman` module caches some information about child partitions in the shared memory, which is used later for plan construction. Before a `SELECT` query is executed, `pg_pathman` traverses the condition tree in search of expressions like:

```
VARIABLE OP CONST
```

where `VARIABLE` is a partitioning key, `OP` is a comparison operator (supported operators are =, <, <=, >, >=), `CONST` is a scalar value. For example:

```
WHERE id = 150
```

Based on the partitioning type and condition's operator, `pg_pathman` searches for the corresponding partitions and builds the plan.

F.41.4.1. Custom Plan Nodes

`pg_pathman` provides a couple of *custom plan nodes* which aim to reduce execution time, namely:

- `RuntimeAppend` (overrides `Append` plan node)
- `RuntimeMergeAppend` (overrides `MergeAppend` plan node)
- `PartitionFilter` (drop-in replacement for INSERT triggers)
- `PartitionRouter` for cross-partition UPDATE queries instead of triggers

`PartitionFilter` acts as a *proxy node* for INSERT's child scan, which means it can redirect output tuples to the corresponding partition:

```
EXPLAIN (COSTS OFF)
INSERT INTO partitioned_table
SELECT generate_series(1, 10), random();
```

```
                QUERY PLAN
----------------------------------------
 Insert on partitioned_table
   ->  Custom Scan (PartitionFilter)
         ->  Subquery Scan on "*SELECT*"
               ->  Result
(4 rows)
```

`PartitionRouter` is another proxy node used in conjunction with `PartitionFilter` to enable cross-partition `UPDATE` operations, for example, when you update any column of a partitioning key.

> **Important**
>
> The `PartitionRouter` node transforms cross-partition `UPDATE` commands into `DELETE` + `INSERT`. On Postgres Pro versions prior to 11, this operation is unsafe as `pg_pathman` cannot determine whether the updated row has been deleted or moved to another partition.

By default, `PartitionRouter` is disabled to avoid undesirable side effects. To enable this node, set the `pg_pathman.enable_partitionrouter` to `on`.

```
EXPLAIN (COSTS OFF)
UPDATE partitioned_table
SET value = value + 1 WHERE value = 2;
                    QUERY PLAN
--------------------------------------------------
 Update on partitioned_table_0
   ->  Custom Scan (PartitionRouter)
         ->  Custom Scan (PartitionFilter)
               ->  Seq Scan on partitioned_table_0
                     Filter: (value = 2)
(5 rows)
```

`RuntimeAppend` and `RuntimeMergeAppend` have much in common: they come in handy in a case when WHERE condition takes form of:

```
VARIABLE OP PARAM
```

This kind of expressions can no longer be optimized at planning time since the parameter's value is not known until the execution stage takes place. The problem can be solved by embedding the *WHERE condition analysis routine* into the original `Append`'s code, thus making it pick only required scans out of a whole bunch of planned partition scans. This effectively boils down to creation of a custom node capable of performing such a check.

There are at least several cases that demonstrate usefulness of these nodes:

```
/* create table we're going to partition */
CREATE TABLE partitioned_table(id INT NOT NULL, payload REAL);

/* insert some data */
INSERT INTO partitioned_table
SELECT generate_series(1, 1000), random();

/* perform partitioning */
SELECT create_hash_partitions('partitioned_table', 'id', 100);

/* create ordinary table */
CREATE TABLE some_table AS SELECT generate_series(1, 100) AS VAL;
```

- id = (select ... limit 1)

```
EXPLAIN (COSTS OFF, ANALYZE) SELECT * FROM partitioned_table
WHERE id = (SELECT * FROM some_table LIMIT 1);
                                                 QUERY PLAN
-------------------------------------------------------------------------------------------
 Custom Scan (RuntimeAppend) (actual time=0.030..0.033 rows=1 loops=1)
   InitPlan 1 (returns $0)
     ->  Limit (actual time=0.011..0.011 rows=1 loops=1)
           ->  Seq Scan on some_table (actual time=0.010..0.010 rows=1 loops=1)
   ->  Seq Scan on partitioned_table_70 partitioned_table (actual time=0.004..0.006
 rows=1 loops=1)
         Filter: (id = $0)
         Rows Removed by Filter: 9
 Planning time: 1.131 ms
 Execution time: 0.075 ms
(9 rows)

/* disable RuntimeAppend node */
SET pg_pathman.enable_runtimeappend = f;

EXPLAIN (COSTS OFF, ANALYZE) SELECT * FROM partitioned_table
WHERE id = (SELECT * FROM some_table LIMIT 1);
                                      QUERY PLAN
---------------------------------------------------------------------------------
 Append (actual time=0.196..0.274 rows=1 loops=1)
   InitPlan 1 (returns $0)
     ->  Limit (actual time=0.005..0.005 rows=1 loops=1)
           ->  Seq Scan on some_table (actual time=0.003..0.003 rows=1 loops=1)
   ->  Seq Scan on partitioned_table_0 (actual time=0.014..0.014 rows=0 loops=1)
         Filter: (id = $0)
         Rows Removed by Filter: 6
   ->  Seq Scan on partitioned_table_1 (actual time=0.003..0.003 rows=0 loops=1)
         Filter: (id = $0)
         Rows Removed by Filter: 5
         ... /* more plans follow */
 Planning time: 1.140 ms
 Execution time: 0.855 ms
(306 rows)
```

- id = ANY (select ...)

```
EXPLAIN (COSTS OFF, ANALYZE) SELECT * FROM partitioned_table
WHERE id = any (SELECT * FROM some_table limit 4);
                                                   QUERY PLAN
-------------------------------------------------------------------------------------------
 Nested Loop (actual time=0.025..0.060 rows=4 loops=1)
   ->  Limit (actual time=0.009..0.011 rows=4 loops=1)
         ->  Seq Scan on some_table (actual time=0.008..0.010 rows=4 loops=1)
   ->  Custom Scan (RuntimeAppend) (actual time=0.002..0.004 rows=1 loops=4)
         ->  Seq Scan on partitioned_table_70 partitioned_table (actual
 time=0.001..0.001 rows=10 loops=1)
         ->  Seq Scan on partitioned_table_26 partitioned_table (actual
 time=0.002..0.003 rows=9 loops=1)
         ->  Seq Scan on partitioned_table_27 partitioned_table (actual
 time=0.001..0.002 rows=20 loops=1)
         ->  Seq Scan on partitioned_table_63 partitioned_table (actual
 time=0.001..0.002 rows=9 loops=1)
 Planning time: 0.771 ms
```

```
 Execution time: 0.101 ms
(10 rows)

/* disable RuntimeAppend node */
SET pg_pathman.enable_runtimeappend = f;

EXPLAIN (COSTS OFF, ANALYZE) SELECT * FROM partitioned_table
WHERE id = any (SELECT * FROM some_table limit 4);
                                        QUERY PLAN
-----------------------------------------------------------------------------------------
 Nested Loop Semi Join (actual time=0.531..1.526 rows=4 loops=1)
   Join Filter: (partitioned_table.id = some_table.val)
   Rows Removed by Join Filter: 3990
   ->  Append (actual time=0.190..0.470 rows=1000 loops=1)
         ->  Seq Scan on partitioned_table (actual time=0.187..0.187 rows=0 loops=1)
         ->  Seq Scan on partitioned_table_0 (actual time=0.002..0.004 rows=6
 loops=1)
         ->  Seq Scan on partitioned_table_1 (actual time=0.001..0.001 rows=5
 loops=1)
         ->  Seq Scan on partitioned_table_2 (actual time=0.002..0.004 rows=14
 loops=1)
... /* 96 scans follow */
   ->  Materialize (actual time=0.000..0.000 rows=4 loops=1000)
         ->  Limit (actual time=0.005..0.006 rows=4 loops=1)
               ->  Seq Scan on some_table (actual time=0.003..0.004 rows=4 loops=1)
 Planning time: 2.169 ms
 Execution time: 2.059 ms
(110 rows)
```

- `NestLoop` **involving a partitioned table**, which is omitted since it's occasionally shown above.

To learn more about custom nodes, see Alexander Korotkov's *blog*.

F.41.5. Reference

F.41.5.1. GUC Variables

There are several user-accessible GUC variables designed to toggle `pg_pathman` or its specific custom nodes on and off.

- `pg_pathman.enable` — enable/disable the `pg_pathman` module.

  Default: `on`
- `pg_pathman.enable_runtimeappend` — toggle the `RuntimeAppend` custom node on/off.

  Default: `on`
- `pg_pathman.enable_runtimemergeappend` — toggle the `RuntimeMergeAppend` custom node on/off.

  Default: `on`
- `pg_pathman.enable_partitionfilter` — toggle the `PartitionFilter` custom node on/off to enable/disable cross-partition `INSERT` operations.

  Default: `on`
- `pg_pathman.enable_partitionrouter` — toggle the `PartitionRouter` custom node on/off to enable/disable cross-partition `UPDATE` operations.

  Default: `off`
- `pg_pathman.enable_auto_partition` — toggle automatic partition creation on/off (per session).

  Default: `on`

- pg_pathman.enable_bounds_cache — toggle bounds cache on/off.

  Default: on
- pg_pathman.insert_into_fdw — allow INSERT operations into various foreign-data wrappers. Possible values: disabled, postgres, and any_fdw.

  Default: postgres
- pg_pathman.override_copy — toggle COPY statement hooking on/off.

  Default: on

F.41.5.2. Views and Tables

F.41.5.2.1. pathman_config

This table stores the list of partitioned tables. This is the main configuration storage.

```
CREATE TABLE IF NOT EXISTS pathman_config (
    partrel         REGCLASS NOT NULL PRIMARY KEY,
    attname         TEXT NOT NULL,
    parttype        INTEGER NOT NULL,
    range_interval  TEXT);
```

F.41.5.2.2. pathman_config_params

This table stores optional parameters that override standard pg_pathman behavior.

```
CREATE TABLE IF NOT EXISTS pathman_config_params (
    partrel        REGCLASS NOT NULL PRIMARY KEY,
    enable_parent  BOOLEAN NOT NULL DEFAULT TRUE,
    auto           BOOLEAN NOT NULL DEFAULT TRUE,
    init_callback  REGPROCEDURE NOT NULL DEFAULT 0,
    spawn_using_bgw BOOLEAN NOT NULL DEFAULT FALSE);
```

F.41.5.2.3. pathman_concurrent_part_tasks

This view lists all currently running concurrent partitioning tasks.

```
-- helper SRF function
CREATE OR REPLACE FUNCTION show_concurrent_part_tasks()
RETURNS TABLE (
    userid     REGROLE,
    pid        INT,
    dbid       OID,
    relid      REGCLASS,
    processed  INT,
    status     TEXT)
AS 'pg_pathman', 'show_concurrent_part_tasks_internal'
LANGUAGE C STRICT;

CREATE OR REPLACE VIEW pathman_concurrent_part_tasks
AS SELECT * FROM show_concurrent_part_tasks();
```

F.41.5.2.4. pathman_partition_list

This view lists all existing partitions, as well as their parents and range boundaries (NULL for hash partitions).

```
-- helper SRF function
CREATE OR REPLACE FUNCTION show_partition_list()
RETURNS TABLE (
```

```
    parent     REGCLASS,
    partition  REGCLASS,
    parttype   INT4,
    expr       TEXT,
    range_min  TEXT,
    range_max  TEXT)
AS 'pg_pathman', 'show_partition_list_internal'
LANGUAGE C STRICT;

CREATE OR REPLACE VIEW pathman_partition_list
AS SELECT * FROM show_partition_list();
```

F.41.5.3. Functions

F.41.5.3.1. Partitioning Functions

```
create_hash_partitions(parent_relid     REGCLASS,
                       expression       TEXT,
                       partitions_count INTEGER,
                       partition_data   BOOLEAN DEFAULT TRUE,
                       partition_names  TEXT[] DEFAULT NULL,
                       tablespaces      TEXT[] DEFAULT NULL)
```

Performs hash partitioning for `relation` by integer key `expression`. The `partitions_count` parameter specifies the number of partitions to create; it cannot be changed afterwards. If `partition_data` is `true`, all the data will be automatically migrated from the parent table to partitions. Note that data migration may take a while to finish and the table will be locked until transaction commits. See `partition_table_concurrently()` for a lock-free way to migrate data. Partition creation callback is invoked for each partition if set beforehand (see `set_init_callback()`).

```
create_range_partitions(relation       REGCLASS,
                        expression     TEXT,
                        start_value    ANYELEMENT,
                        p_interval     ANYELEMENT,
                        p_count        INTEGER DEFAULT NULL,
                        partition_data BOOLEAN DEFAULT TRUE)

create_range_partitions(relation       REGCLASS,
                        expression     TEXT,
                        start_value    ANYELEMENT,
                        p_interval     INTERVAL,
                        p_count        INTEGER DEFAULT NULL,
                        partition_data BOOLEAN DEFAULT TRUE)

create_range_partitions(relation        REGCLASS,
                        expression      TEXT,
                        bounds          ANYARRAY,
                        partition_names TEXT[] DEFAULT NULL,
                        tablespaces     TEXT[] DEFAULT NULL,
                        partition_data  BOOLEAN DEFAULT TRUE)
```

Performs range partitioning for `relation` by partitioning key defined by `expression`. The `start_value` argument specifies the initial value, `p_interval` sets the default range for automatically created partitions or partitions created with `append_range_partition()` or `prepend_range_partition()`. If `p_interval` is set to `NULL`, automatic partition creation is disabled. `p_count` is the number of premade partitions. If `p_count` is not set, than `pg_pathman` tries to determine the number of partitions based on the `expression` value. The `bounds` array defines the bounds for partitions to be created. You can build this array using the `generate_range_bounds()` function. Partition creation callback is invoked for each partition if set beforehand.

F.41.5.3.2. Data Migration Functions

```
partition_table_concurrently(relation REGCLASS,
                             batch_size INTEGER DEFAULT 1000,
                             sleep_time FLOAT8 DEFAULT 1.0)
```

Starts a background worker to move data from parent table to partitions. The worker utilizes short transactions to copy small batches of data (up to 10K rows per transaction) and thus doesn't significantly interfere with user's activity.

```
stop_concurrent_part_task(relation REGCLASS)
```

Stops a background worker performing a concurrent partitioning task. Note: worker will exit after it finishes relocating a current batch.

F.41.5.3.3. Triggers

Triggers are no longer required for `INSERT` and cross-partition `UPDATE` operations. However, user-supplied triggers are supported:

- Each inserted row results in execution of BEFORE/AFTER INSERT trigger functions of a corresponding partition.
- Each updated row results in execution of BEFORE/AFTER UPDATE trigger functions of a corresponding partition.
- Each moved row (cross-partition update) results in execution of BEFORE UPDATE + BEFORE/AFTER DELETE + BEFORE/AFTER INSERT trigger functions of corresponding partitions.

F.41.5.3.4. Partition Management Functions

```
replace_hash_partition(old_partition       REGCLASS,
                       new_partition       REGCLASS,
                       lock_parent         BOOLEAN DEFAULT TRUE)
```

Replaces the specified partition of hash-partitioned table with another table. When set to `true`, the `lock_parent` parameter prevents any `INSERT`/`UPDATE`/`ALTER TABLE` queries to the parent table.

```
split_range_partition(partition_relid  REGCLASS,
                      split_value      ANYELEMENT,
                      partition_name   TEXT DEFAULT NULL,
                      tablespace       TEXT DEFAULT NULL)
```

Split range `partition` in two by `value`, with the specified `value` included into the second partition. Partition creation callback is invoked for a new partition if available.

```
merge_range_partitions(variadic partitions REGCLASS[])
```

Merge several adjacent range partitions. Partitions are automatically ordered by increasing bounds. All the data will be accumulated in the first partition, while other merged partitions are removed. If the remaining partition has any child partitions, new child partitions for the merged data will be created as required using the same partitioning expression.

```
append_range_partition(parent_relid   REGCLASS,
                       partition_name TEXT DEFAULT NULL,
                       tablespace     TEXT DEFAULT NULL)
```

Append new range partition with `pathman_config.range_interval` as interval.

```
prepend_range_partition(parent_relid   REGCLASS,
                        partition_name TEXT DEFAULT NULL,
                        tablespace     TEXT DEFAULT NULL)
```

Prepend new range partition with `pathman_config.range_interval` as interval.

```
add_range_partition(parent_relid   REGCLASS,
                    start_value    ANYELEMENT,
                    end_value      ANYELEMENT,
                    partition_name TEXT DEFAULT NULL,
                    tablespace     TEXT DEFAULT NULL)
```

Create a new range partition for `relation` with the specified range bounds. If the `start_value` or the `end_value` is NULL, the corresponding range bound will be infinite.

```
drop_range_partition(partition_relid TEXT, delete_data BOOLEAN DEFAULT TRUE)
```

Drop range partition and all of its data if `delete_data` is true.

```
attach_range_partition(parent_relid    REGCLASS,
                       partition_relid REGCLASS,
                       start_value     ANYELEMENT,
                       end_value       ANYELEMENT)
```

Attach partition to the existing range-partitioned relation. The attached table must have exactly the same structure as the parent table, including the dropped columns. Partition creation callback is invoked if set (see Section F.41.5.2.2).

```
detach_range_partition(partition_relid REGCLASS)
```

Detach partition from the existing range-partitioned relation.

```
disable_pathman_for(parent_relid REGCLASS)
```

Permanently disable `pg_pathman` partitioning mechanism for the specified parent table and remove the insert trigger if it exists. All partitions and data remain unchanged.

```
drop_partitions(parent_relid REGCLASS,
                delete_data  BOOLEAN DEFAULT FALSE)
```

Drop partitions of the parent table (both foreign and local relations). If `delete_data` is `false`, the data is copied to the parent table first. Default is `false`.

F.41.5.3.5. Additional Functions

```
pathman_version()
```

Returns the `pg_pathman` version number.

```
set_interval(relation REGCLASS, value ANYELEMENT)
```

Update range-partitioned table interval. Note that interval must not be negative and it must not be trivial, i.e. its value should be greater than zero for numeric types, at least 1 microsecond for `timestamp` and at least 1 day for `date`.

```
set_enable_parent(relation REGCLASS, value BOOLEAN)
```

Include/exclude parent table into/from query plan. In original Postgres Pro planner parent table is always included into query plan even if it's empty, which can lead to additional overhead. You can use `disable_parent()` if you are never going to use parent table as a storage. Default value depends on the `partition_data` parameter specified during initial partitioning with the `create_range_partitions()` function. If the `partition_data` parameter was `true`, then all data have already been migrated to partitions and the parent table is disabled. Otherwise, it is enabled.

```
set_auto(relation REGCLASS, value BOOLEAN)
```

Enable/disable auto partition propagation (only for range partitioning). It is enabled by default.

```
set_init_callback(relation REGCLASS, callback REGPROCEDURE DEFAULT 0)
```

Set partition creation callback to be invoked for each attached or created partition (both hash and range). If callback is marked with `SECURITY INVOKER`, it is executed with the privileges of the user who produced a statement that has led to creation of a new partition. For example:

```
INSERT INTO partitioned_table VALUES (-5)
```

The callback must have the following signature: `part_init_callback(args JSONB) RETURNS VOID`. Parameter `arg` consists of several fields whose presence depends on partitioning type:

```
/* Range-partitioned table abc (child abc_4) */
{
    "parent":    "abc",
    "parttype":  "2",
    "partition": "abc_4",
    "range_max": "401",
    "range_min": "301"
}

/* Hash-partitioned table abc (child abc_0) */
{
    "parent":    "abc",
    "parttype":  "1",
    "partition": "abc_0"
}
```

```
set_spawn_using_bgw(relation REGCLASS, value BOOLEAN)
```

When inserting new data beyond the partitioning range, use SpawnPartitionsWorker to create new partitions in a separate transaction.

```
create_naming_sequence(parent_relid REGCLASS)
```

Enable automatic partition naming for the specified `relation` table. You must run this function when partitioning this table by composite key.

```
add_to_pathman_config(parent_relid     REGCLASS,
                      expression       TEXT,
                      range_interval   TEXT)
add_to_pathman_config(parent_relid     REGCLASS,
                      expression       TEXT)
```

Register the specified `relation` table with `pg_pathman` to enable partitioning by the provided `expression`. For range partitioning, the `range_interval` argument is mandatory. You can set it to `NULL` if you are going to add partition manually.

```
generate_range_bounds(p_start     ANYELEMENT,
                      p_interval  INTERVAL,
                      p_count     INTEGER)

generate_range_bounds(p_start     ANYELEMENT,
                      p_interval  ANYELEMENT,
                      p_count     INTEGER)
```

Build the `bounds` array that defines the bounds for partitions to be created. You can pass this array as an argument to the `create_range_partitions()` function.

F.41.6. Authors

- Ildar Musin

- Alexander Korotkov
- Dmitry Ivanov

F.42. pg_proaudit

The pg_proaudit extension enables detailed logging of various security events.

pg_proaudit works in parallel with the standard PostgreSQL logging solutions (logging collector) and does not depend on them. Security event log of the pg_proaudit extension is stored separately from the server log. At the Postgres Pro Enterprise startup, pg_proaudit launches a special background process to log security events.

Logging rules are stored in the pg_proaudit.conf configuration file located in the cluster data directory (PGDATA). It is a text file that can be edited directly using operating system facilities. To modify the file using SQL, you can use several pg_proaudit functions. The pg_proaudit_settings view displays the current pg_proaudit rules, even if they have not been saved into the pg_proaudit.conf file yet.

All the logged events belong to the following classes:

- DDL commands for creating, changing, and deleting DBMS objects (databases, tablespaces, schemas, tables, views, sequences, languages, functions)
- access control commands for database objects (GRANT, REVOKE)
- DML commands for access to database objects (INSERT, UPDATE, DELETE, SELECT, TRUNCATE for tables and/or views, EXECUTE for functions)
- database authentication/disconnection events
- all commands executed by a particular user

Security events can be logged both in the centralized logging solution of the operating system (syslog) and in the standard file-system files. Event logs can be written both into the syslog and into the files simultaneously. For clear identification, all pg_proaudit records in the syslog are marked with AUDIT. Event log files are written in the CSV format. Each event is logged on a separate line that contains the following fields:

- date and time of the event
- current user name
- database name
- server process ID (PID)
- severity level: INFO or ERROR
- serial number of the command in a session
- subcommand number in complex commands (CREATE TABLE ... AS SELECT ...)
- operator name
- object type
- object name
- operator execution results: SUCCESS or FAILURE
- additional information like error message in case of FAILURE or connection parameters for the AUTHENTICATE event; unfinished authentication attempts are marked as [EOF. No credentials provided]
- text of the SQL command
- parameters of the command (for example, for PREPARE)
- session user name
- unique ID of the event (in the *UUIDv7* format)
- transaction ID (XID)
- virtual transaction ID (VXID)

An event contains the information about both session_user and current_user of the session. Therefore, it will be possible to identify the user, even if they execute the SET ROLE command to change user identifier.

The XID and VXID values can be zero if an event does not relate to a transaction (e. g. the DISCONNECT event).

You can define a directory to store security log files and set up log file rotation. pg_proaudit can switch to a new log file either after the specified time interval, or when the specified size of the log file is exceeded. This enables you to define a workflow for cleaning up security event logs.

Postgres Pro user with the SUPERUSER attribute should grant access to the pg_proaudit extension and security event log files only to the user with the information security administrator role.

F.42.1. Installing the pg_proaudit Extension

The pg_proaudit extension is a built-in extension included into Postgres Pro Enterprise. To enable pg_proaudit, complete the following steps:

1. Add pg_proaudit to the shared_preload_libraries variable in the postgresql.conf file:

   ```
   shared_preload_libraries = 'pg_proaudit'
   ```

2. Restart the database server for the changes to take effect. To verify that the pg_proaudit library was installed correctly, you can run the following command:

   ```
   SHOW shared_preload_libraries;
   ```

3. In each database for which you are going to log security events, create the pg_proaudit extension using the following query:

   ```
   CREATE EXTENSION pg_proaudit;
   ```

   The pg_proaudit extension adds several functions for managing the pg_proaudit.conf file, the pg_proaudit_settings view that displays the current pg_proaudit rules and event triggers.

F.42.2. Uninstalling the pg_proaudit Extension

To properly uninstall pg_proaudit, complete the following steps:

1. Delete the pg_proaudit extension using the following query:

   ```
   DROP EXTENSION pg_proaudit;
   ```

2. Remove pg_proaudit from the shared_preload_libraries variable in the postgresql.conf file.

   Skip this step if you have several databases in the cluster and you want to remove the extension only for one of them. In this case, it is recommended to remove logging rules related to the corresponding database prior to uninstalling the extension.

F.42.3. Functions to Configure Security Event Logging

To configure security event logging, pg_proaudit provides an SQL interface that consists of several functions and the pg_proaudit_settings view.

```
pg_proaudit_set_rule(db_name text, event_type text, object_type text, object_name text,
 role_name text, comment text)
```

Creates the logging rule with the specified parameters. When the pg_proaudit_set_rule() function completes, security event logging starts immediately, but the pg_proaudit.conf file is not updated. To save the changes in the pg_proaudit.conf file, call the pg_proaudit_save() function.

Arguments:

- *db_name* — name of the database for which the logging rule is established. An empty string or NULL specified in this argument means that events are logged for all databases where the

pg_proaudit extension is created. When set to current_database(), events for the current database are logged.

- *event_type* — type of the event that needs to be logged, including SQL operator names, as well as AUTHENTICATE and DISCONNECT events. When set to ALL, as well as when an empty string or NULL is specified, enables logging for all events available for the specified object type. For example, for the TABLE object type, the ALL keyword enables logging for commands SELECT, INSERT, UPDATE, DELETE, TRUNCATE, COPY, as well as CREATE, ALTER, DROP. You can also set up logging of event classes by specifying the following values: ALL_DDL, ALL_DDL_NONTEMP, ALL_DML, ALL_DML_NONTEMP, ALL_MOD, ALL_PROC, and ALL_ROLE. For the full list of possible *event_type* values, see Section F.42.5.
- *object_type* — type of the object for which security events need to be logged. When set to ALL, as well as when an empty string or the NULL is specified, enables logging of events for all object types. For example, specify FOREIGN TABLE object type for the SELECT event to log all attempts to access foreign tables. Use NULL if *event_type* is set to AUTHENTICATE, DISCONNECT, SET, or RESET, and the ROLE value for all events that reference user actions, such as CREATE USER or DROP USER. The following object types are supported: COMPOSITE TYPE, DATABASE, EVENT TRIGGER, FUNCTION, INDEX, PREPARED STATEMENT, ROLE, SEQUENCE, SCHEMA, TABLE, FOREIGN TABLE, TOAST TABLE, TABLESPACE, VIEW, MATERIALIZED VIEW, CATALOG RELATION, and CATALOG FUNCTION.

> **Note**
>
> To log security events for system catalog objects, it is required to enable the pg_proaudit.log_catalog_access configuration parameter. Otherwise, these events will not be logged, even if the CATALOG RELATION, CATALOG FUNCTION, or ALL object type is specified in the rule.

- *object_name* — name of the object for which the logging rule is established. When an empty string or NULL is specified, enables logging of events for all object names.
- *role_name* — name of the role for which the logging rule is established. If specified, allows logging the actions caused by the user who has the privileges of the role. This means that at least one of the user session attributes, session_user or current_user, should either be equal to the role_name, or be directly or indirectly a member of this role. When an empty string or NULL is specified, enables logging of actions caused by any user. When set to current_role, the logging rule is established for the user current role.
- *comment* — comment to describe the created logging rule. This argument does not affect the rule execution and is not reflected in the log.

```
pg_proaudit_remove_rule(db_name text, event_type text, object_type text, object_name
 text, role_name text)
```

Removes the specific logging rule with the set parameters. To save the changes in the pg_proaudit.conf file, call the pg_proaudit_save() function.

> **Note**
>
> If the rule that you want to remove is configured to log the DISCONNECT event type, then disconnect events may still be logged after the rule is removed. For additional information, see Section F.42.3.1.

Arguments:

- *db_name* — name of the database for which the logging rule needs to be removed.
- *event_type* — type of the event for which the logging rule needs to be removed. For the full list of possible *event_type* values, see Section F.42.5.
- *object_type* — type of the object for which the logging rule needs to be removed.
- *object_name* — name of the object for which the logging rule needs to be removed.
- *role_name* — name of the role for which the logging rule needs to be removed.

```
pg_proaudit_show()
```

Returns logged events in a table view. This function is used by the `pg_proaudit_settings` view.

`pg_proaudit_reload()`

Reads logging configuration from the `pg_proaudit.conf` file. You must call this function if the `pg_proaudit.conf` file was modified manually using the operating system facilities.

`pg_proaudit_reset()`

Removes all logging rules. To save information about the canceled logging in the `pg_proaudit.conf` file, call the `pg_proaudit_save()` function.

`pg_proaudit_save()`

Saves logging rules from memory into the `pg_proaudit.conf` file. The `pg_proaudit.conf` file is located in the cluster data directory (`PGDATA`). You cannot change the `pg_proaudit.conf` file location.

F.42.3.1. Handling Database Disconnection Events

When a logging rule is configured for `DISCONNECT` event type, and a user authenticates in a database, then the `pg_proaudit` extension checks whether the corresponding disconnection event satisfies the rule and must be logged.

If the event must be logged, then the removal of the logging rule has no effect on the event. This event will be logged no matter if the logging rule exists at the moment of disconnect.

Consider the following example:

1. An administrator configures the following logging rule:

   ```
   SELECT pg_proaudit_set_rule ('postgres', 'DISCONNECT', null, null, null, 'Any
    disconnect from the postgres DB');
   ```

2. A user connects to the `postgres` database and goes through authentication.

   For the rule in effect, a corresponding disconnection event will be logged later.

3. The administrator removes the logging rule, while the user is still connected to the database:

   ```
   SELECT pg_proaudit_remove_rule('postgres', 'DISCONNECT', null, null, null);
   ```

4. The user disconnects from the database.

   The corresponding disconnection event is logged despite the removal of the logging rule.

F.42.3.2. Handling Object Names

Comparison of string representations of names for database, user, role and other objects is case-insensitive even if the object name in the database is enclosed in quotes. These string representations are stored as lower-case strings.

Strings representing object names need to be passed to functions `pg_proaudit_set_rule` and `pg_proaudit_remove_rule` as regular strings: a single quote needs repeating, and other characters are passed as is, without escaping or wrapping.

For example, rules for tables `table1` and `"TaBlE1"` will be the same, and their names can be passed in upper-case or lower-case characters. The same holds for roles. As for databases, before creating a rule, pg_proaudit checks whether this database actually exists, and this check is case-sensitive.

The following examples illustrate creation of "weird" object names and specifying correct audit rules for them.

```
create table "TAbLe''123"();
```

```
SELECT pg_proaudit_set_rule(current_database(), null, null, 'public.TabLe''''123',
 null, 'tst cmnt');

create table "taBlE""123"();
SELECT pg_proaudit_set_rule(null, null, null, 'public.taBlE"123', null);

create schema "(BIG!) Schema";
create table "(BIG!) Schema"."My Tab.lE"();
SELECT pg_proaudit_set_rule(null, null, null, '(BIG!) Schema.My Tab.lE', null);

create role "Some '@#$%' person" with login;
SELECT pg_proaudit_set_rule(null, 'authenticate', null, null, 'Some ''@#$%'' person');

create role "Some '@#$%' person" with superuser;
\c - "Some '@#$%' person"
SELECT pg_proaudit_set_rule(null, 'disconnect', null, null, current_user);

create database " D B 1";
SELECT pg_proaudit_set_rule(' D B 1', 'authenticate', null, null, null);

create database " D b 2";
\c " D b 2"
create extension pg_proaudit;
SELECT pg_proaudit_set_rule(current_database(), 'disconnect', null, null, null);
```

F.42.4. pg_proaudit_settings View

This view displays the current `pg_proaudit` rules, even if they have not been saved into the `pg_proaudit.conf` file yet. The `pg_proaudit_settings` view consists of the following columns:

- *db_name* (`text`) — name of the database for which to log security events.
- *event_type* (`text`) — event type to log.
- *object_type* (`text`) — type of the object for which security events are to be logged.
- *object_name* (`text`) — name of the object for which security events are to be logged.
- *role_name* (`text`) — the role on behalf of which logged actions are performed.
- *comment* (`text`) — comment to describe the created logging rule.

F.42.5. Security Events

You can configure the `pg_proaudit` extension to log classes of security events and specific events by specifying the respective value in the *event_type* argument of the pg_proaudit_set_rule() function.

The following classes of security events are supported:

- `ALL_DDL`: `CREATE`, `ALTER`, `DROP` for any database object except stored procedures and functions.
- `ALL_DDL_NONTEMP`: same as `ALL_DDL` but the scope is limited to the objects that are not contained in `pg_temp_`*nnn* temporary schemas.
- `ALL_DML`: `SELECT`, `INSERT`, `UPDATE`, `DELETE`, `TRUNCATE` for any table type; `EXECUTE` for functions and stored procedures.
- `ALL_DML_NONTEMP`: same as `ALL_DML` but the scope is limited to the objects that are not contained in `pg_temp_`*nnn* temporary schemas.
- `ALL_MOD`: `INSERT`, `UPDATE`, `DELETE`, `TRUNCATE` for any table type.
- `ALL_PROC`: `CREATE`, `ALTER`, `DROP` for any function and stored procedure.
- `ALL_ROLE`: `CREATE`, `ALTER`, `DROP` for `USER`, `ROLE`, `GROUP`, `PROFILE`, as well as execution of the `GRANT` command.

The following specific security events are supported:

- AUTHENTICATE
- DISCONNECT

- ALTER AGGREGATE
- ALTER COLLATION
- ALTER CONVERSION
- ALTER DATABASE
- ALTER DEFAULT PRIVILEGES
- ALTER DOMAIN
- ALTER EVENT TRIGGER
- ALTER EXTENSION
- ALTER FOREIGN DATA WRAPPER
- ALTER FOREIGN TABLE
- ALTER FUNCTION
- ALTER INDEX
- ALTER LANGUAGE
- ALTER LARGE OBJECT
- ALTER MATERIALIZED VIEW
- ALTER OPERATOR
- ALTER OPERATOR CLASS
- ALTER OPERATOR FAMILY
- ALTER POLICY
- ALTER PROFILE
- ALTER ROLE, ALTER USER, ALTER GROUP
- ALTER RULE
- ALTER SCHEMA
- ALTER SEQUENCE
- ALTER SERVER
- ALTER SYSTEM
- ALTER TABLE
- ALTER TABLESPACE
- ALTER TEXT SEARCH CONFIGURATION
- ALTER TEXT SEARCH DICTIONARY
- ALTER TEXT SEARCH PARSER
- ALTER TEXT SEARCH TEMPLATE
- ALTER TRIGGER
- ALTER TYPE
- ALTER USER MAPPING
- ALTER VIEW
- CLUSTER
- COMMENT
- COPY
- CREATE ACCESS METHOD
- CREATE AGGREGATE
- CREATE CAST
- CREATE COLLATION
- CREATE CONVERSION
- CREATE DATABASE
- CREATE DOMAIN
- CREATE EVENT TRIGGER
- CREATE EXTENSION
- CREATE FOREIGN DATA WRAPPER
- CREATE FOREIGN TABLE
- CREATE FUNCTION
- CREATE INDEX
- CREATE LANGUAGE
- CREATE MATERIALIZED VIEW

- CREATE OPERATOR
- CREATE OPERATOR CLASS
- CREATE OPERATOR FAMILY
- CREATE POLICY
- CREATE PROFILE
- CREATE ROLE, CREATE USER, CREATE GROUP
- CREATE RULE
- CREATE SCHEMA
- CREATE SEQUENCE
- CREATE SERVER
- CREATE TABLE, CREATE TABLE AS, SELECT INTO
- CREATE TABLESPACE
- CREATE TEXT SEARCH CONFIGURATION
- CREATE TEXT SEARCH DICTIONARY
- CREATE TEXT SEARCH PARSER
- CREATE TEXT SEARCH TEMPLATE
- CREATE TRANSFORM
- CREATE TRIGGER
- CREATE TYPE
- CREATE USER MAPPING
- CREATE VIEW
- DEALLOCATE
- DELETE
- DO
- DROP ACCESS METHOD
- DROP AGGREGATE
- DROP CAST
- DROP COLLATION
- DROP CONVERSION
- DROP DATABASE
- DROP DOMAIN
- DROP EVENT TRIGGER
- DROP EXTENSION
- DROP FOREIGN DATA WRAPPER
- DROP FOREIGN TABLE
- DROP FUNCTION
- DROP INDEX
- DROP LANGUAGE
- DROP MATERIALIZED VIEW
- DROP OPERATOR
- DROP OPERATOR CLASS
- DROP OPERATOR FAMILY
- DROP OWNED
- DROP POLICY
- DROP PROFILE
- DROP ROLE, DROP USER, DROP GROUP
- DROP RULE
- DROP SCHEMA
- DROP SEQUENCE
- DROP SERVER
- DROP TABLE
- DROP TABLESPACE
- DROP TEXT SEARCH CONFIGURATION
- DROP TEXT SEARCH DICTIONARY

- DROP TEXT SEARCH PARSER
- DROP TEXT SEARCH TEMPLATE
- DROP TRANSFORM
- DROP TRIGGER
- DROP TYPE
- DROP USER MAPPING
- DROP VIEW
- EXECUTE
- GRANT
- INSERT
- PREPARE
- REASSIGN OWNED
- REFRESH MATERIALIZED VIEW
- REINDEX
- RESET
- REVOKE
- SECURITY LABEL
- SELECT
- SET
- UPDATE
- TRUNCATE TABLE

F.42.6. Security Event Log Configuration Parameters

The `pg_proaudit` extension provides several configuration parameters for managing security event log files. These parameters can be set in the `postgresql.conf` configuration file, or with the help of the `ALTER SYSTEM` command. For the changes to take effect, call the `pg_reload_conf()` function or restart the database server. For additional configuration, the syslog_ident and syslog_facility configuration parameters can be used.

`pg_proaudit.log_destination` (`string`)

Defines the method for logging security events. Possible values are:

- `csvlog` — log security events in a CSV file.
- `syslog` — log security events in syslog.

You can specify one or more values separated by commas.

Default: `csvlog`

`pg_proaudit.log_catalog_access` (`boolean`)

Specifies whether to log access to system catalog objects in the `pg_catalog` schema.

When set to `off`, no events will be logged, even if there are rules for the `CATALOG RELATION`, `CATALOG FUNCTION`, or `ALL` object types.

It is not recommended to set the parameter to `on`, if you do not plan to log events for system catalog objects. Doing otherwise may impact Postgres Pro performance, even if there are no rules for the aforementioned object types.

Default: `off`

`pg_proaudit.log_command_text` (`boolean`)

Specifies whether to log the SQL command text for security events.

Default: `on`

`pg_proaudit.log_directory` (`string`)

Specifies the path to the directory that stores CSV log files. This can be an absolute path, or a relative path to the cluster data directory (`PGDATA`). This parameter is used if `pg_proaudit.log_destination` contains the `csvlog` value.

Default: `pg_proaudit`

`pg_proaudit.log_filename` (`string`)

Defines the filenames of the created security event log files. The filename template can contain %-escapes, similar to the ones listed in the `strftime` specification of the Open Group (*http://pubs.opengroup.org/onlinepubs/009695399/functions/strftime.html*). This parameter is used if `pg_proaudit.log_destination` contains the `csvlog` value.

Default: `postgresql-%Y-%m-%d_%H%M%S.log`

`pg_proaudit.log_rotation_size` (`integer`)

Sets the maximum size of the CSV log file, in kilobytes. When this size is achieved, `pg_proaudit` creates a new file for logging security events. This parameter is used if `pg_proaudit.log_destination` contains the `csvlog`. If set to 0, disables size-based creation of new log files.

Default: 10MB

`pg_proaudit.log_rotation_age` (`integer`)

Sets the maximum lifetime of a log file, in minutes. After this timeframe has elapsed, `pg_proaudit` creates a new file for logging security events. This parameter is used if `pg_proaudit.log_destination` contains the `csvlog` value. If set to 0, disables time-based creation of new log files.

Default: 1 day

`pg_proaudit.log_truncate_on_rotation` (`boolean`)

Specifies whether to truncate log files when logging is switched to an existing log file. If set to `off`, `pg_proaudit` appends new log entries to the end of the file. This parameter is used if `pg_proaudit.log_destination` contains the `csvlog` value.

Default: `off`

`pg_proaudit.max_rules_count` (`integer`)

Specifies the maximum number of rules allowed. For the parameter changes to take effect, the database server must be restarted.

Default: 500

F.42.7. Viewing Security Event Log

Security event log files are text files that can be viewed by the operating system facilities. To access log files using SQL, you can use the `file_fdw` extension — a foreign data wrapper for accessing files on the database server. To use this method, complete the following steps:

1. Install the `file_fdw` and create an external server:

```
CREATE EXTENSION file_fdw;
CREATE SERVER pg_proauditlog FOREIGN DATA WRAPPER file_fdw;
```

2. Create a foreign table, specifying the columns and the absolute path to the log file. The actual log file location is determined by the `pg_proaudit.log_directory` and `pg_proaudit.log_filename` parameters.

```
CREATE FOREIGN TABLE pg_proaudit_log
      ( log_time timestamp(3) with time zone,
```

```
            current_usr_name text,
            database_name text,
            session_pid text,
            error_severity text,
            session_line_num bigint,
            session_line_subcommand_num bigint,
            event_type text,
            object_type text,
            object_name text,
            status text,
            error_message text,
            query_text text,
            query_args text,
            session_usr_name text,
            uuid text,
            xid text,
            vxid text )

   SERVER pg_proauditlog
   OPTIONS (filename 'absolute_file_path_to_log_file.csv', FORMAT 'csv' );
```

Make sure that the `pg_proaudit.log_destination` parameter contains the `csvlog` value, which enables writing security event logs to CSV files.

F.42.8. Examples

As an example, let's set up logging for the following security events:

- authentications/disconnections to the `postgres` database
- all actions of the user if at least one of the user session attributes, `session_user` or `current_user`, is either explicitly set to the `postgres` role, or is directly or indirectly a member of this role
- creating, updating, and deleting any tables
- all operations on the `app_table` table that belongs to the `public` schema

All events must be logged in the CSV format and stored for a week. It is required to set up SQL access to the security event log. To complete the scenario, do the following:

In psql, check that the preliminary setup of the `pg_proaudit` extension is complete in the `postgres` database:

```
SHOW shared_preload_libraries;
 shared_preload_libraries
--------------------------
 pg_proaudit

\dx pg_proaudit
                    List of installed extensions
    Name     | Version | Schema |           Description
-------------+---------+--------+---------------------------------
 pg_proaudit | 2.0     | public | provides auditing functionality
```

Add the following lines to the `postgresql.conf` configuration file:

```
pg_proaudit.log_destination = 'csvlog'
pg_proaudit.log_directory = 'audit'
pg_proaudit.log_filename = 'audit-%u.csv'
pg_proaudit.log_rotation_age = 1440
pg_proaudit.log_rotation_size = 0
pg_proaudit.log_truncate_on_rotation = on
pg_proaudit.log_command_text = on
```

For the changes to take effect, run the following query:

```
SELECT pg_reload_conf();
```

Check that the following parameters are set as expected:

```
SHOW pg_proaudit.log_destination;
SHOW pg_proaudit.log_directory;
SHOW pg_proaudit.log_filename;
SHOW pg_proaudit.log_rotation_age;
SHOW pg_proaudit.log_rotation_size;
SHOW pg_proaudit.log_truncate_on_rotation;
SHOW pg_proaudit.log_command_text;
```

Suppose your `PGDATA` environment variable points to the cluster data directory. Since the `pg_proaudit.log_directory` defines a relative path to the log files, they will be located in the `$PGDATA/audit` directory. Let's create an empty file for each day of the week and make them available to their owner only:

```
touch $PGDATA/audit/audit-1.csv
touch $PGDATA/audit/audit-2.csv
touch $PGDATA/audit/audit-3.csv
touch $PGDATA/audit/audit-4.csv
touch $PGDATA/audit/audit-5.csv
touch $PGDATA/audit/audit-6.csv
touch $PGDATA/audit/audit-7.csv
chmod 600 $PGDATA/audit/audit-*.csv
```

Create a table for reading log entries:

```
CREATE TABLE pg_proaudit_log (
  log_time timestamp(3) with time zone,
  current_usr_name text,
  database_name text,
  session_pid text,
  error_severity text,
  session_line_num bigint,
  session_line_subcommand_num bigint,
  event_type text,
  object_type text,
  object_name text,
  status text,
  error_message text,
  query_text text,
  query_args text,
  session_usr_name text,
  uuid text,
  xid text,
  vxid text
);
```

Install the `file_fdw` extension and create an external server:

```
CREATE EXTENSION file_fdw;
CREATE SERVER pg_proauditlog FOREIGN DATA WRAPPER file_fdw;
```

Now let's create seven child foreign tables for the `pg_proaudit_log` table, for each day of the week:

```
CREATE FOREIGN TABLE pg_proaudit_log_1 () INHERITS (pg_proaudit_log) SERVER
 pg_proauditlog
   OPTIONS (filename '/path_to_PGDATA/audit/audit-1.csv',  FORMAT 'csv');
CREATE FOREIGN TABLE pg_proaudit_log_2 () INHERITS (pg_proaudit_log) SERVER
 pg_proauditlog
```

```
   OPTIONS (filename '/path_to_PGDATA/audit/audit-2.csv',  FORMAT 'csv');
CREATE FOREIGN TABLE pg_proaudit_log_3 () INHERITS (pg_proaudit_log) SERVER
 pg_proauditlog
   OPTIONS (filename '/path_to_PGDATA/audit/audit-3.csv',  FORMAT 'csv');
CREATE FOREIGN TABLE pg_proaudit_log_4 () INHERITS (pg_proaudit_log) SERVER
 pg_proauditlog
   OPTIONS (filename '/path_to_PGDATA/audit/audit-4.csv',  FORMAT 'csv');
CREATE FOREIGN TABLE pg_proaudit_log_5 () INHERITS (pg_proaudit_log) SERVER
 pg_proauditlog
   OPTIONS (filename '/path_to_PGDATA/audit/audit-5.csv',  FORMAT 'csv');
CREATE FOREIGN TABLE pg_proaudit_log_6 () INHERITS (pg_proaudit_log) SERVER
 pg_proauditlog
   OPTIONS (filename '/path_to_PGDATA/audit/audit-6.csv',  FORMAT 'csv');
CREATE FOREIGN TABLE pg_proaudit_log_7 () INHERITS (pg_proaudit_log) SERVER
 pg_proauditlog
   OPTIONS (filename '/path_to_PGDATA/audit/audit-7.csv',  FORMAT 'csv');
```

To set up logging for the required security events, connect to the `postgres` database and execute the following commands:

```
SELECT pg_proaudit_set_rule (current_database(), 'AUTHENTICATE', null, null, null, 'Any
 authentication in the current DB');
SELECT pg_proaudit_set_rule (current_database(), 'DISCONNECT', null, null, null, 'Any
 disconnect from the current DB');
SELECT pg_proaudit_set_rule (current_database(), 'ALL', 'TABLE', null, null, 'Any
 operations with any table in the current DB');
SELECT pg_proaudit_set_rule (current_database(), 'ALL', null, null, 'postgres', 'Any
 operation by "postgres" user in the current DB');
```

Create the `app_table` table and enable logging for all operations on this table:

```
CREATE TABLE app_table (id int, name text);
SELECT pg_proaudit_set_rule (current_database(), 'ALL', null, 'public.app_table',
 null);
```

Check that event logging is configured as expected:

```
SELECT * FROM pg_proaudit_settings;
 db_name  |  event_type  | object_type |   object_name    | role_name |
      comment
----------+--------------+-------------+------------------+-----------
+-------------------------------------------------
 postgres | authenticate | ALL         |                  |           | Any
 authentication in the current DB
 postgres | disconnect   | ALL         |                  |           | Any disconnect
 from the current DB
 postgres | ALL          | table       |                  |           | Any operations
 with any table in the current DB
 postgres | ALL          | ALL         |                  | postgres  | Any operation
 by "postgres" user in the current DB
 postgres | ALL          | ALL         | public.app_table |           |
(5 rows)
```

Save these logging rules into the `pg_proaudit.conf` file, so that they are not lost after the server restart:

```
SELECT pg_proaudit_save();
```

Let's run several queries on the `app_table` table:

```
INSERT INTO app_table VALUES (1, 'first');
SELECT * FROM app_table;
```

Check the log entries for the app_table table:

```
SELECT to_char(log_time, 'DD.MM.YY HH24:MI:SS') AS when, current_usr_name,
      session_pid, event_type, query_text, session_usr_name
FROM pg_proaudit_log
WHERE object_name = 'public.app_table';
       when        | current_usr_name | session_pid |  event_type  |
 query_text                  | session_usr_name
-------------------+------------------+-------------+--------------
+-----------------------------------------+-----------------
 27.09.23 12:44:27 | postgres         | 2010        | CREATE TABLE | CREATE TABLE
 app_table (id int, name text); | postgres
 27.09.23 12:45:55 | postgres         | 2010        | INSERT       | INSERT INTO
 app_table VALUES (1, 'first');  | postgres
 27.09.23 12:46:00 | postgres         | 2010        | SELECT       | SELECT * FROM
 app_table;                    | postgres
(3 rows)
```

We have set up a weekly rotation of log files, with the log file switched once a day. It means that queries to the pg_proaudit_log table will return only those security events that have happened in the latest week. Older events will be automatically removed at log file rotation. To define additional access constraints for specific log entries, you can create separate views based on queries to the pg_proaudit_log table and grant read rights to such views using built-in Postgres Pro access control methods.

F.43. pgpro_bindump — a replication protocol module for backup and restore

pgpro_bindump is a module designed to implement additional commands for the Postgres Pro replication protocol, specifically for use with the *pg_probackup3* utility. pgpro_bindump offers the following benefits:

- Simplified communication: pgpro_bindump does not require the SSH protocol and associated configurations to connect to a database server.
- Integrated WAL transfer: WAL files are transferred together with data files, reducing the risk of data loss during backups.
- Optimized storage: Files are not copied as they are, but are archived using the pg_probackup3 own format, CBOR (RFC 8949 Concise Binary Object Representation), which enhances the storage efficiency.

F.43.1. Architecture

A dedicated backend process is created to handle connections from external applications. You can use the pg_probackup3 utility or a custom application to send requests to this backend.

Multiple connections can be established for the same application if needed.

Since the pgpro_bindump module has direct access to the database files, it does not require any additional permissions.

pgpro_bindump uses the *libpgprobackup*, along with its built-in encoder module, to send data to the application.

The walsender_plugin_libraries plugin has been added to simplify the process of adding and utilizing new replication commands, including custom ones.

F.43.2. Limitations and Requirements

pgpro_bindump currently has the following limitations and requirements:

- libpgprobackup.so and libpb3_encoder.so are required for pgpro_bindump operation.

F.43.3. Installation and Setup

Once you complete Postgres Pro installation, follow the steps below.

1. Specify the following parameters in the postgresql.conf file:

```
shared_preload_libraries = 'pgpro_bindump'
wal_level = 'replica' # or 'logical'
walsender_plugin_libraries = 'pgpro_bindump'
```

2. Restart the Postgres Pro instance.

F.43.4. Replication Commands

The pgpro_bindump module implements the following replication commands:

- just-noop — a do-nothing command.
- start_backup — starts the backup process.
- copy_files — copies files in the CBOR format.
- stop_backup — stops the backup process.

The backup process runs in the PRO mode — an advanced data source mode that incorporates all available optimizations and enhancements, including the proprietary replication protocol and specialized replication commands.

To send commands from a user application to pgpro_bindump and to receive the output data from pgpro_bindump by the application, use libpq.

> **Note**
>
> An established connection to a running Postgres Pro server is required.

F.43.4.1. start_backup

```
start_backup LABEL label, INCR_MODE incr_mode, START_LSN start_lsn,
 TRANSFER_MODE transfer_mode,
[TRANSFER_BUFFER_SIZE buffer_size]
```

Starts the backup process. Sends the following data to the application:

- start_lsn — LSN at the start of the backup.
- start_tli — the timeline ID at the start of the backup.
- min_xid — the minimal transaction ID at the start of the backup.
- min_multixact — the minimal multixact ID at the start of the backup.
- tablespace_list — a list of tablespaces included in the backup.
- database_list — a list of databases included in the backup.

LABEL *label*

The name of the backup.

INCR_MODE *incr_mode*

The type of incremental backup. Possible values: PTRACK, DELTA.

START_LSN *start_lsn*

An XLogRecPtr value representing LSN at the start of the backup.

TRANSFER_MODE *transfer_mode*

The method to be used for sending data from a server to an application. Possible values:

- raw — unpacked data is sent in random blocks of arbitrary size.
- packed — packed data is sent in blocks of 128 KB with a common header.

packed is the default value.

TRANSFER_BUFFER_SIZE *buffer_size*

A numeric value representing the buffer size. The preset (unchanged) value is 131072 (128 KB).

F.43.4.2. copy_files

```
copy_files VERIFY_CHECKSUMS [TRUE | FALSE], COMPRESS_ALG compress_alg,
 COMPRESS_LVL compress_lvl, TRANSFER_MODE transfer_mode,
[INCR_MODE incr_mode], [START_LSN start_lsn], [TRANSFER_BUFFER_SIZE buffer_size],
[WORKER_INFO number_of_workers:worker_id]
```

Forwards blocks of data files and WAL files packaged in the CBOR format.

VERIFY_CHECKSUMS

A boolean value (true or false) indicating whether to verify checksums.

COMPRESS_ALG *compress_alg*

The compression algorithm to be used. Possible values: zlib, zstd, lz4, none.

COMPRESS_LVL *compress_lvl*

The compression level. Possible values: 1, 2, 3, 4, 5.

TRANSFER_MODE *transfer_mode*

The method to be used for sending data from a server to an application. Possible values:

- raw — unpacked data is sent in random blocks of arbitrary size.
- packed — packed data is sent in blocks of 128 KB with a common header.

packed is the default value.

INCR_MODE *incr_mode*

The type of incremental backup. Possible values: PTRACK, DELTA.

START_LSN *start_lsn*

An XLogRecPtr value representing LSN at the start of the backup.

TRANSFER_BUFFER_SIZE *buffer_size*

A numeric value representing the buffer size. The preset (unchanged) value is 131072 (128 KB).

WORKER_INFO *number_of_workers*:*worker_id*

The number of workers and the worker ID.

F.43.4.3. stop_backup

```
stop_backup STREAM [TRUE | FALSE], COMPRESS_ALG compress_alg,
 COMPRESS_LVL compress_lvl,
[EXTERNALS externals] [TRANSFER_BUFFER_SIZE buffer_size], [TRANSFER_MODE transfer_mode]
```

Completes the copy process and closes the existing connection. Sends the following data to the application:

- `stop_lsn` — LSN at the end of the backup.
- `stop_tli` — the timeline ID at the end of the backup.
- The `backup.control` file.
- A set of WAL files (only if WAL streaming is enabled).

`STREAM`

A boolean value (`true` or `false`) indicating whether WAL streaming is enabled.

`COMPRESS_ALG` *`compress_alg`*

The compression algorithm to be used. Possible values: `zlib`, `zstd`, `lz4`, `none`.

`COMPRESS_LVL` *`compress_lvl`*

The compression level. Possible values: 1, 2, 3, 4, 5.

`EXTERNALS` *`externals`*

A list of external directories.

`TRANSFER_BUFFER_SIZE` *`buffer_size`*

A numeric value representing the buffer size. The preset (unchanged) value is 131072 (128 KB).

`TRANSFER_MODE` *`transfer_mode`*

The method to be used for sending data from a server to an application. Possible values:

- `raw` — unpacked data is sent in random blocks of arbitrary size.
- `packed` — packed data is sent in blocks of 128 KB with a common header.

`packed` is the default value.

F.43.5. Authors

Postgres Professional, Moscow, Russia.

F.44. pg_prewarm

The `pg_prewarm` module provides a convenient way to load relation data into either the operating system buffer cache or the Postgres Pro buffer cache. Prewarming can be performed manually using the `pg_prewarm` function, or can be performed automatically by including `pg_prewarm` in shared_preload_libraries. In the latter case, the system will run a background worker which periodically records the contents of shared buffers in a file called `autoprewarm.blocks` and will, using 2 background workers, reload those same blocks after a restart.

F.44.1. Functions

```
pg_prewarm(regclass, mode text default 'buffer', fork text default 'main',
           first_block int8 default null,
           last_block int8 default null) RETURNS int8
```

The first argument is the relation to be prewarmed. The second argument is the prewarming method to be used, as further discussed below; the third is the relation fork to be prewarmed, usually `main`. The

fourth argument is the first block number to prewarm (NULL is accepted as a synonym for zero). The fifth argument is the last block number to prewarm (NULL means prewarm through the last block in the relation). The return value is the number of blocks prewarmed.

There are three available prewarming methods. prefetch issues asynchronous prefetch requests to the operating system, if this is supported, or throws an error otherwise. read reads the requested range of blocks; unlike prefetch, this is synchronous and supported on all platforms and builds, but may be slower. buffer reads the requested range of blocks into the database buffer cache.

Note that with any of these methods, attempting to prewarm more blocks than can be cached — by the OS when using prefetch or read, or by Postgres Pro when using buffer — will likely result in lower-numbered blocks being evicted as higher numbered blocks are read in. Prewarmed data also enjoys no special protection from cache evictions, so it is possible that other system activity may evict the newly prewarmed blocks shortly after they are read; conversely, prewarming may also evict other data from cache. For these reasons, prewarming is typically most useful at startup, when caches are largely empty.

autoprewarm_start_worker() RETURNS void

Launch the main autoprewarm worker. This will normally happen automatically, but is useful if automatic prewarm was not configured at server startup time and you wish to start up the worker at a later time.

autoprewarm_dump_now() RETURNS int8

Update autoprewarm.blocks immediately. This may be useful if the autoprewarm worker is not running but you anticipate running it after the next restart. The return value is the number of records written to autoprewarm.blocks.

F.44.2. Configuration Parameters

pg_prewarm.autoprewarm (boolean)

Controls whether the server should run the autoprewarm worker. This is on by default. This parameter can only be set at server start.

pg_prewarm.autoprewarm_interval (int)

This is the interval between updates to autoprewarm.blocks. The default is 300 seconds. If set to 0, the file will not be dumped at regular intervals, but only when the server is shut down.

These parameters must be set in postgresql.conf. Typical usage might be:

```
# postgresql.conf
shared_preload_libraries = 'pg_prewarm'

pg_prewarm.autoprewarm = true
pg_prewarm.autoprewarm_interval = 300s
```

F.44.3. Author

Robert Haas <rhaas@postgresql.org>

F.45. pgpro_scheduler

pgpro_scheduler is a built-in Postgres Pro Enterprise extension for scheduling, monitoring, and managing job execution within the Postgres Pro Enterprise database. With pgpro_scheduler, you can:

- Set advanced schedules using jsonb objects or crontab strings.
- Dynamically calculate the next execution time for repeated jobs.

- Execute SQL commands of the job in a single transaction or in sequential transactions, if required.
- Submit jobs for immediate or delayed one-time execution in parallel with the scheduled jobs.

Unlike external scheduling daemons, pgpro_scheduler offers the following benefits:

- Any user can schedule jobs independently.
- Job scheduling can be managed on the fly without restarting the database.
- Scheduling is very lightweight since pgpro_scheduler uses background workers to schedule, monitor, and manage job execution. At the same time, pgpro_scheduler does not require any client connections for scheduling.
- For enhanced stability, each database has its own supervisor scheduler, with each scheduled job executed by a separate background worker.

> **Note**
>
> pgpro_scheduler waits in the suspended state on a standby server to be started when the standby is promoted to a primary server.

> **Note**
>
> Note that for all the executed jobs, the pg_stat_activity view will still show the name of the database superuser, which is used by the background worker.

F.45.1. Installation and Setup

The pgpro_scheduler extension is included into Postgres Pro Enterprise. Once you have Postgres Pro Enterprise installed, complete the following steps to enable pgpro_scheduler:

1. Add pgpro_scheduler to the shared_preload_libraries parameter in the postgresql.conf file:

   ```
   shared_preload_libraries = 'pgpro_scheduler'
   ```

2. Create the pgpro_scheduler extension using the following query:

   ```
   CREATE EXTENSION pgpro_scheduler;
   ```

   Make sure to create the pgpro_scheduler extension for each database you are planning to use.

Once you complete the installation and setup, configure pgpro_scheduler for your database.

F.45.2. Configuration

You must have superuser rights to configure pgpro_scheduler.

To configure pgpro_scheduler, modify the following settings in the postgresql.conf file:

1. Specify the names of the databases for which you need to schedule jobs, in the comma-separated format:

   ```
   schedule.database = 'database1,database2'
   ```

2. To control the workload in your system, set the maximum number of background workers that can run simultaneously on each database:

   ```
   schedule.max_workers = 5
   ```

3. Optionally, set the number of background workers available for one-time job execution:

```
schedule.max_parallel_workers = 3
```

By default, two background workers for one-time jobs are available. These workers are not included into the `schedule.max_workers` number. Thus, one-time jobs can run in parallel with the scheduled jobs even if all the `schedule.max_workers` workers are busy.

4. Run `pg_reload_conf()` for the changes to take effect:

```
SELECT pg_reload_conf();
```

> **Important**
>
> When setting the `schedule.max_workers` variable, make sure to leave enough workers for the rest of the system as other subsystems may also use background workers. The `schedule.max_workers` value cannot exceed the total number of workers enabled by the `max_worker_processes` Postgres Pro variable.
>
> The `pgpro_scheduler` extension starts a separate background worker for the system, each database, and each executed job. For example, if you work with two databases and set the maximum number of workers and parallel workers to 5 and 3, respectively, `pgpro_scheduler` can use up to 19 workers at peak times: one worker is supervising the system, two workers are monitoring the two databases, and each database uses five workers for job scheduling and three workers for running one-time jobs. If all background workers are busy, the jobs will wait for the next available worker. Scheduled and one-time jobs have separate job queues.
>
> If required, you can later change the number of workers. The running jobs will not be affected.

You can also dynamically configure `pgpro_scheduler` from the command line. In this case, you can set different number of workers for different databases:

```
ALTER SYSTEM SET schedule.database = 'database1,database2';
ALTER DATABASE database1 SET schedule.max_workers = 5;
ALTER DATABASE database2 SET schedule.max_workers = 3;
ALTER SYSTEM SET schedule.max_parallel_workers = 3;
SELECT pg_reload_conf();
```

Once `pgpro_scheduler` is configured, enable it on your system, as follows:

```
SELECT schedule.enable();
```

If this function returns `true`, `pgpro_scheduler` is ready to use, and you can start scheduling jobs as explained in Section F.45.3.1 and Section F.45.3.2.

> **Note**
>
> If you restart the server, `pgpro_scheduler` is not automatically restarted by default. To change this behavior, you can set the schedule.auto_enabled parameter to `on`.

See Also

Section F.45.4.1

F.45.3. Usage

F.45.3.1. Creating Scheduled Jobs

To create and schedule a job, run the `create_job()` function that takes scheduling options as a `jsonb` object:

```
schedule.create_job(options jsonb)
```

In the `jsonb` object, you must specify one or more SQL commands in the `commands` key, and set the job schedule with at least one of the following keys:

- `dates` — a single date or an array of dates, in the `timestamp with time zone` format
- `cron` — a string, in the `crontab` format. A traditional five-field `crontab` format is used. The first field stands for minute, the second — for hour, the third — for day of the month, the fourth — for month, and the fifth — for day of the week.

  ```
  ┌── minute (0 - 59)
  │ ┌──── hour (0 - 23)
  │ │ ┌──── day of the month (1 - 31)
  │ │ │ ┌────── month (1 - 12)
  │ │ │ │ ┌────── day of the week (0 - 6) (Sunday to Saturday)
  │ │ │ │ │
  * * * * *
  ```

  A six-field `crontab` format can be used alongside the traditional five-field format. In this case the first field stands for second. When you use the six-field format and do not want to specify a second you have to put 0 in the first field.

  Alternatively, the following keywords can be used instead of a `crontab` string to specify when the job will be started:

  - `@every_second` — each second
  - `@hourly` — at the beginning of each hour
  - `@daily` — at the beginning of each day
  - `@midnight` — at the beginning of each day
  - `@weekly` — at the beginning of each week
  - `@monthly` — at the beginning of each month
  - `@yearly` — at the beginning of each year
  - `@annually` — at the beginning of each year
- `rule` — a `jsonb` object that includes one or more of the following keys:
  - `seconds` — seconds; an array of integers in range [0, 59]
  - `minutes` — minutes; an array of integers in range [0, 59]
  - `hours` — hours; an array of integers in range [0, 23]
  - `days` — days of the month; an array of integers in range [1, 31]
  - `months` — months; an array of integers in range [1, 12]
  - `wdays` — days of the week; an array of integers in range [0, 6], where 0 is Sunday.
  - `onstart` — integer value 0 or 1. If `onstart` is set to 1, the job is executed only once when `pgpro_scheduler` is started.

You can combine `dates`, `cron`, and `rule` scheduling keys for advanced use cases.

As a result, `pgpro_scheduler` creates an active job with the specified schedule and returns the job ID.

> **Tip**
>
> For simple job schedules, you can use the following shortcut syntax:

```
schedule.create_job(cron, commands)
schedule.create_job(dates, commands)
```

For details, see schedule.create_job() function description.

If required, you can later modify one or more scheduling options with the `set_job_attribute()` or `set_job_attributes()` functions, respectively.

If all background workers are busy at the specified time, the job waits for the next available worker. By default, the job can wait forever. You can limit the maximum wait time by setting the `last_start_available` key, in the time interval format. If the timeout is reached, `pgpro_scheduler` cancels the job execution.

Examples:

To run the job every day at 3pm, and, additionally, on December 31, 2017 at 7pm , and on April 4, 2020 at 1pm:

```
SELECT schedule.create_job('{"commands": "SELECT 15", "cron": "0 15 * * *", "dates":
 [ "2017-12-31 19:00", "2020-04-04 13:00" ]}');
```

To limit the wait time for job execution to 30 seconds after the scheduled time:

```
SELECT schedule.create_job('{"commands": "SELECT pg_sleep(100)", "cron": "15 */2 * *
 *", "last_start_available": "30 seconds" }');
```

Note

Both for scheduled and one-time jobs, you cannot manage their main transactions, namely using `COMMIT` and `ROLLBACK`. However, you can create and manage autonomous transactions.

F.45.3.1.1. Specifying the Time Window for Job Execution

In addition to the general schedule, you can specify the timeframe during which the scheduled job can be executed. To ensure that `pgpro_scheduler` only executes the job within the specified time window, define the `start_date` and `end_date` keys, in the `timestamp with time zone` format. You can set one of these keys only to limit the start or the end time, respectively. If you define a time window for the job, `pgpro_scheduler` will only schedule this job within this time window. If the started job is incomplete when the specified time window ends, `pgpro_scheduler` completes the job and then excludes the job from further scheduling.

Examples:

To start scheduling the job only after 11am on May 1, 2017:

```
SELECT schedule.create_job('{"commands": "SELECT now()", "cron": "2 17 * * *",
 "start_date": "2017-05-01 11:00" }');
```

To schedule the job in the timeframe from 11am on May 1 to 3pm on June 4, 2017:

```
SELECT schedule.create_job('{"commands": "SELECT now()", "cron": "2 17 * * *",
 "start_date": "2017-05-01 11:00", "end_date": "2017-06-04 15:00" }');
```

F.45.3.1.2. Running SQL Commands in Separate Transactions

The `commands` key can have values of text and array types. If you specify several SQL commands as text separated by semicolons, the whole job is executed in a single transaction. If it is critical to perform each SQL command in a separate transaction, pass the SQL commands as an array. You can modify this

behavior by setting the use_same_transaction key to true. In this case, SQL commands in the array are executed in a single transaction.

Examples:

To run the whole job in a single transaction:

```
SELECT schedule.create_job('{"commands": "SELECT 1; SELECT 2; SELECT 3;", "cron": "23
 23 */2 * *" }');
```

To run commands in separate transactions:

```
SELECT schedule.create_job('{"commands": [ "SELECT 1", "SELECT 2", "SELECT 3" ],
 "cron": "23 23 */2 * *" }');
```

To run the whole job in a single transaction when passing the commands as an array:

```
SELECT schedule.create_job('{"commands": [ "SELECT 1", "SELECT 2", "SELECT 3" ],
 "cron": "23 23 */2 * *", "use_same_transaction": true }');
```

F.45.3.1.3. Calculating the Next Start Time of the Scheduled Job

For repeated jobs, the next start time can be computed by an SQL statement specified in the next_time_statement key. In this case, the first job starts on schedule, while all the successive job runs occur at the computed times.

After the job run completes, pgpro_scheduler executes the SQL statement in the next_time_statement key to calculate the next start time and returns the result, in the timestamp with time zone type. If the return value is of a different type or an error occurs, pgpro_scheduler marks the job as broken and cancels any further execution. This process is repeated for each successive job run.

> **Tip**
>
> When the job run completes, pgpro_scheduler sets the transaction state in the schedule.transaction_state variable, in the text format. You can use this variable in your next_time_statement to dynamically calculate the next start time depending on the transaction state. At the time of the next_time_statement execution, the schedule.transaction_state variable must contain either success or failure state values for the main transaction. Other values may indicate an internal pgpro_scheduler error.

Examples:

To run the job first at 10:45, and then in a day after the job completes:

```
SELECT schedule.create_job('{"commands": "SELECT random()", "cron": "45 10 * * *",
 "next_time_statement": "SELECT now() + ''1 day''::interval" }');
```

F.45.3.1.4. Setting Additional Conditions for Job Execution

The pgpro_scheduler extension enables you to define additional conditions for task execution:

- Set time limits for job execution with the max_run_time key. If the execution time is exceeded, pgpro_scheduler cancels the job.
- Define the maximum time a scheduled job can wait for execution using the last_start_available key. If the timeout is reached, pgpro_scheduler cancels the job.
- Schedule a job to be executed with the rights of another user by specifying the run_as key. You must have superuser rights to use this key.
- Define an SQL command to execute if the main command fails using the onrollback key.

Examples:

To limit job execution to 5 seconds:

```
SELECT schedule.create_job('{"commands": "SELECT pg_sleep(10)", "cron": "15 */10 * *
 *", "max_run_time": "5 seconds" }');
```

To limit the wait time for job execution to 30 seconds after the scheduled time:

```
SELECT schedule.create_job('{"commands": "SELECT pg_sleep(100)", "cron": "15 */2 * *
 *", "last_start_available": "30 seconds" }');
```

To start the job with the rights of the `robot` user:

```
SELECT schedule.create_job('{"commands": "SELECT session_user", "cron": "5 */5 * * *",
 "run_as": "robot" }');
```

To define a fallback SQL command in case the main command fails:

```
SELECT schedule.create_job('{"commands": "SELECT ''zzz''", "cron": "55 */12 * * *",
 "onrollback": "SELECT ''Cannot select zzz''" }');
```

F.45.3.2. Submitting One-Time Jobs

You can submit jobs for one-time execution using the `schedule.submit_job()` function. Such jobs use a separate pool of background workers defined by the `schedule.max_parallel_workers` variable, and can run in parallel with the scheduled jobs. By default, two one-time jobs can run concurrently. If you submit more jobs, they will wait in the queue for the next available background worker.

To execute a one-time job immediately, pass SQL commands in the *query* argument. For example:

```
schedule.submit_job(query := 'select 1');
```

Instead of passing SQL query parameters directly, you can define numbered placeholders in the *query* argument, such as $1 and $2, and pass an array of parameters in the *params* argument, with each array element corresponding to a placeholder. For brevity, you can omit the *query* and *params* names:

```
schedule.submit_job(query := 'select $1, $2', params := '{"text 1", "text 2"}')
```

To start a one-time job at the specified time, use the *run_after* argument:

```
schedule.submit_job('select ''flowers''', run_after := '2017-03-08 08:00:01');
```

Alternatively, you can delay the job start until the specified jobs are complete using the *depends_on* argument. For example, to run a job after completing the jobs with 23, 15, and 334 IDs, run:

```
schedule.submit_job('select ''well done''', depends_on := '{23, 15, 334}')
```

If required, you can repeat the job execution by passing the `schedule.resubmit()` function as part of the *query* argument. For example:

```
schedule.submit_job('select 1, schedule.resubmit(run_after := ''5'')');
```

The *run_after* argument specifies the time interval before the job is restarted, in seconds. By default, the interval is 1 second.

The resubmitted job cannot be executed more than the number of times set in the *resubmit_limit* argument. If this limit is reached, the job receives the `done` status, with the corresponding error message.

If you want to cancel a resubmitted job, run:

```
schedule.cancel_job(job_id bigint);
```

To monitor one-time jobs, use the job_status and all_job_status `pgpro_scheduler` views.

For details on all the functions available for managing one-time jobs, see Section F.45.4.6.3.

F.45.3.3. Changing and Removing Scheduled Jobs

When you create a new job with the `create_job()` function, the job becomes active and waits for execution based on the specified schedule. Using the job ID returned by the `create_job()` function, you can change the scheduling settings or remove the job from the schedule. To change the specified schedule for the jobs, use `set_job_attribute()` or `set_job_attributes()` functions:

- To modify a single property of the job, run the `set_job_attribute()` function with the job ID, the property name to change, and the new value for this property.
- To modify more than one property of the job, run the `set_job_attributes()` function instead. In this case, you can specify all the job properties at once in a `jsonb` object. For details on all the keys available for job scheduling, see the `create_job()` function description.

To temporarily exclude the job from scheduling, run the `deactivate_job()` function:

```
schedule.deactivate_job(job_id integer)
```

You can re-activate the job later by running the `activate_job()` function:

```
schedule.activate_job(job_id integer)
```

To permanently remove the job from the schedule, run the `drop_job()` function:

```
schedule.drop_job(job_id integer)
```

F.45.3.4. Monitoring Scheduled Jobs

You must have superuser rights to monitor job execution for the whole system. Otherwise, you can only monitor the jobs that you own. To monitor scheduled jobs, `pgpro_scheduler` provides multiple functions that return `cron_rec` or `cron_job` records:

- `get_job()` — retrieves information about the job.
- `get_owned_cron()` — retrieves the list of jobs owned by user.
- `get_cron()` — retrieves the list of jobs executed by user.
- `get_active_jobs()` — returns the list of jobs executed at the moment of the function call.
- `get_log()` — returns the list of all completed jobs.
- `get_user_log()` — returns list of the completed jobs executed by the specified user.
- `clean_log()` — deletes all records with information about completed jobs.

To learn more about each function, see Section F.45.4.6.

F.45.3.5. Auditing Job Scheduling

`pgpro_scheduler` enables you to audit job scheduling to rule out human error if you observe unexpected changes in scheduled job execution.

By default, `pgpro_scheduler` does not store information on schedule changes. To enable this feature, set the schedule.enable_history parameter to `true`. Once this parameter is enabled, `pgpro_scheduler` stores schedule modifications in the `schedule.cron__history` table, and logs all deleted jobs in the `schedule.cron__deleted` table. Logged history is never deleted from these tables, so a superuser can review schedule changes introduced by all users at any time.

For details on logged information, see Section F.45.4.5.

F.45.3.6. Scheduling Jobs on a Multi-Master Cluster

Using `pgpro_scheduler`, you can manage scheduled and one-time jobs on a cluster configured with multimaster. `pgpro_scheduler` can only manage jobs on the node on which it is installed. Thus, you

must install and enable pgpro_scheduler on all nodes on which you would like to schedule jobs. pgpro_scheduler instances will manage jobs on different nodes independently, but the executed jobs will be replicated to other nodes.

Even if you are planning to schedule jobs on a single node only, it is recommended to enable pgpro_scheduler on several nodes. In this case, if a node with scheduled jobs fails, another pgpro_scheduler instance picks up these jobs. If pgpro_scheduler is running on more than one node, the node with the smallest node ID is selected. The naming pattern of node IDs is defined by the schedule.nodename GUC variable.

F.45.4. Reference

F.45.4.1. GUC Variables

schedule.enabled (boolean)

Deprecated. Specifies whether pgpro_scheduler is enabled on your system.

Default: false.

For pgpro_scheduler 2.5 or higher, you can set the schedule.auto_enabled parameter to control whether pgpro_scheduler is enabled at the server start, or use schedule.enable()/schedule.disable() functions to enable/disable pgpro_scheduler on demand. To check if pgpro_scheduler is currently running, use the schedule.is_enabled() function.

schedule.auto_enabled (boolean)

Specifies whether to enable pgpro_scheduler at the server start.

Default: false.

schedule.database (text)

Specifies the databases for which pgpro_scheduler is enabled. Database names must be separated by commas.

Default: empty string.

schedule.database_to_connect (text)

The database to which pgpro_scheduler gets connected to receive Postgres Pro Enterprise cluster metadata. The specified database cannot be dropped while pgpro_scheduler is running. You can change this parameter only when restarting the server.

Default: postgres.

schedule.schema (text)

Deprecated. Specifies the name of a schema where the scheduler stores its tables and functions. If you need to change the default schema, use ALTER EXTENSION.

Default: schedule.

schedule.nodename (text)

Specifies the name of the cluster node on which pgpro_scheduler is running. Do not change or use this variable if you run a single-server cluster configuration.

On a cluster configured with multimaster, the node name is derived from the node ID provided by multimaster. For example, if the node ID is 3, the schedule.nodename variable is set to mtm-node-3. However, if you explicitly set the schedule.nodename variable by editing the postgresql.conf file

or running the ALTER command, pgpro_scheduler will ignore the node ID and use the provided value instead.

Default: primary.

schedule.max_workers (integer)

Specifies the maximum number of simultaneously running scheduled jobs in one database.

Default: 2.

schedule.max_parallel_workers (integer)

Specifies the maximum number of parallel threads that can be used for executing one-time jobs.

Default: 2.

schedule.transaction_state (text)

An internal variable containing the state of the executed job. pgpro_scheduler uses this variable when calculating the next job start time. Possible values are:

- success — transaction has finished successfully.
- failure — transaction has failed to finish.
- running — transaction is in progress.
- undefined — transaction has not started yet.

At the time of the next_time_statement execution, the schedule.transaction_state variable must contain either success or failure state values. Other values may indicate an internal pgpro_scheduler error.

schedule.enable_history (boolean)

Log all schedule changes, including the name of the user who initiated the change and the time when this change occurred. If a new job is added, or the schedule of an existing job is modified, this information is stored in the schedule.cron__history table. If a job is deleted, this information is stored in the schedule.cron__deleted table. If you later disable the schedule.enable_history parameter, the history of the already recorded changes is preserved.

Default: false

F.45.4.2. SQL Schema

To store its internal tables and functions, pgpro_scheduler uses the schedule SQL schema. Direct access to tables is not recommended and should not be attempted. To manage job scheduling, use the functions defined by the pgpro_scheduler extension.

F.45.4.3. SQL Types

pgpro_scheduler defines the following types that are used by some of the pgpro_scheduler functions.

F.45.4.3.1. cron_rec

This type contains information about the scheduled job.

```
CREATE TYPE schedule.cron_rec AS(
    id integer,             -- job ID
    node text,              -- name of the node
                            -- on which to execute the job
    name text,              -- job name
    comments text,          -- comments about the job
```

```
    rule jsonb,             -- scheduling rules
    commands text[],        -- SQL commands to be executed
    run_as text,            -- username of the job executor
    owner text,             -- username of the job owner
    start_date timestamptz,   -- lower bound of the execution window;
                            -- NULL if unbound
    end_date timestamptz,     -- upper bound of the execution window;
                            -- NULL if unbound
    use_same_transaction boolean,   -- true if an array of SQL
                                    -- commands will be executed
                                    -- in a single transaction
    last_start_available interval,  -- maximum wait time for
                                    -- the scheduled job if all
                                    -- allowed workers are busy
    max_run_time interval,  -- maximum execution time
    onrollback text,        -- SQL statement to execute
                            -- if the main transaction fails
    max_instances int,      -- maximum number of simultaneously
                            -- running job instances
    next_time_statement text,   -- SQL statement to calculate
                                -- the next start time
    active boolean,         -- true if job is scheduled
                            -- successfully
    broken boolean          -- true if job has errors in
                            -- configuration that prevented
                            -- its further execution
);
```

F.45.4.3.2. cron_job

This type contains information about a particular job execution.

```
CREATE TYPE schedule.cron_job AS(
    cron integer,           -- job id
    node text,              -- name of the node
                            -- on which to execute the job
    scheduled_at timestamptz, -- scheduled execution time
    name text,              -- job name
    comments text,          -- comments about the job
    commands text[],        -- SQL statement to be executed
    run_as text,            -- username of the job executor
    owner text,             -- username of the job owner
    use_same_transaction boolean,   -- true if an array of SQL
                                    -- commands will be executed
                                    -- in a single transaction
    started timestamptz,      -- timestamp of the job execution start
    last_start_available timestamp, -- maximum wait time for
                                    -- the scheduled job if all
                                    -- allowed workers are busy
    finished timestamptz,     -- timestamp of the job
                            -- execution finish
    max_run_time interval,  -- maximum execution time
    onrollback text,        -- SQL statement to execute if the main
                            -- transaction fails
    next_time_statement text,   -- SQL statement to calculate
                                -- the next start time
    max_instances int,      -- the number of simultaneously
                            -- running job instances
    status job_status_t,    -- status of the task:
```

```
                                -- working, done, or error
    message text                -- error message
);
```

F.45.4.3.3. job_status_t

Enumerated type. Can take the following values:

- `working` — the job is being executed.
- `done` — job execution is complete.
- `error` — job execution has failed.

F.45.4.3.4. job_at_status_t

Enumerated type. Can take the following values:

- `submitted` — the job is submitted into the queue, but the execution has not started yet.
- `processing` — the job is being executed.
- `done` — job execution is complete.

F.45.4.3.5. timetable_job_type_t

Enumerated type. Can take the following values:

- `periodical` — a scheduled job.
- `onetime` — a one-time job.

F.45.4.3.6. timetable_job_status_t

Enumerated type. Can take the following values:

- `inprogress` — the job is being executed.
- `done` — job execution is complete.
- `error` — job execution has failed.
- `submitted` — the job is submitted into the queue, but the execution has not started yet.

F.45.4.4. Views

`pgpro_scheduler` provides several views for monitoring execution status of one-time jobs.

F.45.4.4.1. job_status View

Shows the status of one-time jobs belonging to the current user.

Table F.33. job_status View

Column Name	Column Type	Description
`id`	`bigint`	Job ID.
`node`	`text`	Name of the node on which the job is being executed.
`name`	`text`	Name of the job.
`comments`	`text`	Comments about the job.
`run_after`	`timestamp with time zone`	Timestamp after which the job execution must start.
`query`	`text`	SQL commands executed by the job.

Column Name	Column Type	Description
params	text[]	An array of parameters for the SQL query.
depends_on	bigint[]	An array of job IDs on which the job execution depends.
run_as	text	User or role whose rights are used to execute the job.
attempt	bigint	The number of execution attempts.
resubmit_limit	bigint	The maximum number of allowed job resubmissions.
max_wait_interval	interval	The maximum time interval to postpone the job execution if all background workers are busy at the scheduled moment.
max_duration	interval	Time interval during which the job can be executed.
submit_time	timestamp with time zone	Time when the job was submitted to the execution queue.
canceled	boolean	Specifies whether the job was canceled by user.
start_time	timestamp with time zone	Job execution start time.
is_success	boolean	• true — job execution completed successfully. • false — job execution completed with errors.
error	text	Error message.
done_time	timestamp with time zone	Time when the job execution completed.
status	job_at_status_t	Job status. See the Section F.45.4.3.4 for details.

F.45.4.4.2. all_job_status View

Shows the status of all one-time jobs. You must have superuser rights to access this view.

Table F.34. all_job_status View

Column Name	Column Type	Description
id	bigint	Job ID.
node	text	Name of the node on which the job is being executed.
name	text	Name of the job.
comments	text	Comments about the job.
run_after	timestamp with time zone	Timestamp after which the job execution must start.
query	text	SQL commands executed by the job.
params	text[]	An array of parameters for the SQL query.

Column Name	Column Type	Description
depends_on	bigint[]	An array of job IDs on which the job execution depends.
run_as	text	User or role whose rights are used to execute the job.
owner	text	The user who created the job.
attempt	bigint	The number of execution attempts.
resubmit_limit	bigint	The maximum number of allowed job resubmissions.
max_wait_interval	interval	The maximum time interval to postpone the job execution for if all background workers are busy at the scheduled moment.
max_duration	interval	Time interval during which the job can be executed.
submit_time	timestamp with time zone	Time when the job was submitted to the execution queue.
canceled	boolean	Specifies whether the job was canceled by user.
start_time	timestamp with time zone	Job execution start time.
is_success	boolean	• true — job execution completed successfully. • false — job execution completed with errors.
error	text	Error message.
done_time	timestamp with time zone	Time when the job execution completed.
status	job_at_status_t	Job status. See the Section F.45.4.3.4 for details.

F.45.4.5. Audit Tables

The following tables store all schedule changes if the schedule.enable_history parameter is set to true. If you later disable the schedule.enable_history parameter, the history of the already recorded changes is preserved.

F.45.4.5.1. schedule.cron_history Table

Registers job scheduling changes. Whenever a new job is scheduled, or the schedule for an existing job is changed, a new row is inserted into this table to record the following information:

- All details about the scheduled job, as defined by the cron_rec data type. For details on the cron_rec type, see Section F.45.4.3.
- submitter — name of the user who updated the schedule.
- version_id — a unique ID for each registered change in the schedule.
- submit_time — time when the schedule was updated.

F.45.4.5.2. schedule.cron_deleted Table

Registers all jobs that were removed from the schedule:

- cron — ID of the deleted job.

- `submitter` — name of the user who deleted the job.
- `submit_time` — time when the job was deleted.

F.45.4.6. Functions

`pgpro_scheduler` provides two separate sets of functions for managing scheduled and one-time jobs, as well as several common functions that can toggle `pgpro_scheduler` on and off for your database and show the current status of the extension:

- Section F.45.4.6.1
- Section F.45.4.6.2
- Section F.45.4.6.3
- Section F.45.4.6.4

> **Important**
>
> With each job, you can only use the function specifically tailored for this job type.

F.45.4.6.1. Common Functions

These functions facilitate `pgpro_scheduler` management.

`schedule.enable()`

Enables `pgpro_scheduler` for the current Postgres Pro Enterprise instance.

Return values:

- `true` if `pgpro_scheduler` is enabled and ready to use.
- `false` if the command has failed.

`schedule.is_enabled()`

Checks whether `pgpro_scheduler` is enabled.

Return values:

- `true` if `pgpro_scheduler` is enabled and ready to use.
- `false` if `pgpro_scheduler` is not currently running.

`schedule.disable()`

Disables `pgpro_scheduler` for the current Postgres Pro Enterprise instance.

Return values:

- `true` if `pgpro_scheduler` is disabled.
- `false` if the command has failed.

`schedule.start()`

Launches `pgpro_scheduler` for the currently connected database.

Return values:

- `true` — `pgpro_scheduler` started successfully.
- `false` — if the command has failed, or `pgpro_scheduler` is already started.

`schedule.stop()`

Stops `pgpro_scheduler` for the currently connected database.

Return values:

- `true` — `pgpro_scheduler` is stopped.
- `false` — if the command has failed, or `pgpro_scheduler` is not running.

`schedule.status()`

Returns the status of `pgpro_scheduler` background workers:

- `pid` — process ID of the background worker. If the process ID is `NULL`, the background worker is not running.
- `database` — name of the database to which the background worker is connected.
- `type` — type of the background worker:
  - `supervisor` — distributes the scheduled jobs between the databases.
  - `database manager` distributes the scheduled jobs within the database.
  - `cron job executor` executes a scheduled job.
  - `at job executor` executes a one-time job.

`schedule.version()`

Returns `pgpro_scheduler` version.

F.45.4.6.2. Functions for Managing Scheduled Jobs

`schedule.create_job(`*`options`* `jsonb)`

Creates an active job and returns the job ID.

Alternative Syntax:

```
schedule.create_job(cron text, commands text [, node text])
schedule.create_job(cron text, commands text[] [, node text])
schedule.create_job(dates timestamp with time zone, commands text [, node text])
schedule.create_job(dates timestamp with time zone, commands text[] [, node text])
schedule.create_job(dates timestamp with time zone[], commands text [, node text])
schedule.create_job(dates timestamp with time zone[], commands text[] [, node text])
```

Arguments:

- *`options`* — a `jsonb` object defining all the job properties. You do not need to define other parameters if the *`data`* is set. All the available `jsonb` keys are listed in Table F.35.

  Type: `jsonb`

- *`cron`* — a crontab-like string defining the job schedule.

  Type: `text`

- *`dates`* — the exact date or an array of dates for job execution.

  Type: `timestamp with time zone`, `timestamp with time zone[]`

- *`commands`* — SQL statement to execute. You can pass one or more SQL commands separated by semicolons, or an array of SQL commands. When passed as an array, SQL commands are executed in separate transactions.

  Type: `text`, `text[]`

- *`node`* — the name of the node on which the scheduled jobs run. Optional. You may need to specify this argument if you are scheduling jobs on a multi-master cluster.

  Type: `text`

Return values:

- ID of the created job.

Table F.35. `jsonb` Keys for Job Scheduling

Key	Type	Description
`cron`	`text`	A crontab-like string defining the job schedule. A traditional five-field or nonstandard six-field (seconds in the first field) `crontab` format may be used. You can combine `cron` with `rule` and `dates` keys, but at least one of them is mandatory. Alternatively, the following keywords can be used instead of a `crontab` string to specify when the job will be started: • `@every_second` — each second • `@hourly` — at the beginning of each hour • `@daily` — at the beginning of each day • `@midnight` — at the beginning of each day • `@weekly` — at the beginning of each week • `@monthly` — at the beginning of each month • `@yearly` — at the beginning of each year • `@annually` — at the beginning of each year
`dates`	`timestamp with time zone`, `timestamp with time zone[]`	The exact date or an array of dates when the scheduled job will be executed. You can combine `dates` with `rule` and `cron` keys, but at least one of them is mandatory.
`rule`	`jsonb`	A `jsonb` object defining the job schedule. Mandatory, if both `cron` and `dates` keys are undefined. The `rule` object includes one or more of the following keys: • `seconds` — seconds; an array of integers in range [0, 59] • `minutes` — minutes; an array of integers in range [0, 59] • `hours` — hours; an array of integers in range [0, 23]

Key	Type	Description
		• days — days of the month; an array of integers in range [1, 31] • months — months; an array of integers in range [1, 12] • wdays — days of the week; an array of integers in range [0, 6], where 0 is Sunday. • onstart — integer value 0 or 1. If onstart is set to 1, the job is executed only once when pgpro_scheduler is started.
commands	text, text[]	SQL statements to execute. You can pass one or more SQL statements separated by semicolons, or an array of SQL statements. When passed as an array, SQL statements are executed in separate transactions by default. You can change this behavior by setting the use_same_transaction key.
name	text	Optional. Job name.
node	text	Optional. The name of the node on which the scheduled jobs run. You may need to specify this argument if you are scheduling jobs on a multi-master cluster.
comments	text	Optional. Comments about the scheduled job.
run_as	text	Optional. The user whose rights are used to execute the job.
start_date	timestamp with time zone	Optional. The start of the timeframe when the scheduled job can be executed. This key can be NULL.
end_date	timestamp with time zone	Optional. The end of the timeframe when the scheduled job can be executed. This key can be NULL.
use_same_transaction	boolean	Optional. If set to true, forces an array of SQL statements to be executed in a single transaction. Default: false
last_start_available	interval	Optional. The maximum time interval to postpone the job execution for if all background workers are busy at the scheduled moment. For example, if

Key	Type	Description
		this key is set to '00:02:34', the job will wait for 2 minutes 34 seconds. If this key is NULL or not set, the job can wait forever. Default: NULL.
max_instances	integer	Optional. The maximum number of job instances that can be executed simultaneously. Default: 1.
max_run_time	interval	Optional. The maximum time interval during which the scheduled job can be executed. If this key is NULL or not set, there are no time limits. Default: NULL.
onrollback	text	Optional. SQL statement to be executed if the main transaction fails.
next_time_statement	text	Optional. SQL statement to calculate the start time for the next job execution. For details, see Section F.45.3.1.3.

`schedule.set_job_attributes(`*`job_id`* `integer, `*`data`* `jsonb)`

Updates properties of the existing job.

Arguments:

- *`job_id`* — identifier of the existing job.
- *`data`* — a `jsonb` object with properties to be edited. For the list of keys and their structure, see Table F.35.

Return values:

- *`true`* — job properties were updated successfully.
- *`false`* — job properties were not updated.

To update the job properties, you must be the owner of the job or have superuser rights.

`schedule.set_job_attribute(`*`job_id`* `integer, `*`name`* `text, `*`value`* `text || anyarray)`

Updates a property of the existing job.

Arguments:

- *`job_id`* — identifier of the existing job.
- *`name`* — property name.
- *`value`* — property value.

See Table F.35 for the list of job properties you can update. Some values are of array types. They should be passed as an array. If a value of a wrong type is passed, an exception is raised.

Return values:

- *`true`* — job property was updated successfully.
- *`false`* — job property was not updated.

To update the job properties, you must be the owner of the job or have superuser rights.

`schedule.deactivate_job(job_id integer)`

Deactivates the job and suspends its further scheduling and execution.

Arguments:

- *job_id* — identifier of the existing job.

Return values:

- `true` — the job is deactivated successfully.
- `false` — job deactivation failed.

`schedule.activate_job(job_id integer)`

Activates a job and starts its scheduling and execution.

Arguments:

- *job_id* — identifier of the existing job.

Return values:

- `true` — the job was activated successfully.
- `false` — job activation failed.

`schedule.drop_job(job_id integer)`

Deletes a job.

Arguments:

- *job_id* — identifier of the existing job.

Return values:

- `true` — the job was deleted successfully.
- `false` — job was not deleted.

`schedule.get_job(job_id integer)`

Returns information about the specified job.

Arguments:

- *job_id* — identifier of the existing job.

Return values:

- An object of type `cron_rec`.

For details on the `cron_rec` type, see Section F.45.4.3.

`schedule.get_owned_cron(username text)`

Retrieves the list of jobs owned by the specified user.

Arguments:

- *username* — username, optional.

Return values:

- A set of records of type `cron_rec`. These records contain information about all jobs owned by the specified user. If the *username* is omitted, the session username is used. You must have superuser rights to retrieve jobs owned by another user.

For details on the `cron_rec` type, see Section F.45.4.3.

`schedule.get_cron()`

Retrieves the list of jobs executed by the session user.

Return values:

- A set of records of type `cron_rec`. These records contain information about all jobs executed by the session user. You must have superuser rights to retrieve the jobs.

For details on the `cron_rec` type, see Section F.45.4.3.

`schedule.get_active_jobs(`*`username`* `text)`

Returns the list of jobs currently being executed by the specified user.

Arguments:

- *`username`* — username, optional.

If *`username`* is omitted, the session username is used. You must have superuser rights to retrieve jobs executed by another user.

Return values:

- A set of records of type `cron_job`.

For details on the `cron_job` type, see Section F.45.4.3.

`schedule.get_active_jobs()`

Returns the list of jobs being currently executed. You must have superuser rights to call this function.

Return values:

- A set of records of type `cron_job`.

For details on the `cron_job` type, see Section F.45.4.3.

`schedule.get_log()`

Returns the list of all completed jobs. You must have superuser rights to call this function.

Return values:

- A set of records of type `cron_job`.

For details on the `cron_job` type, see Section F.45.4.3.

`schedule.get_user_log(`*`username`* `text)`

Returns the list of completed jobs executed by the specified user.

Arguments:

- *`username`* — username, optional.

If *`username`* is omitted, the session username is used. You must have superuser rights to retrieve the list of jobs executed by another user.

Return values:

- A set of records of type `cron_job`.

For details on the `cron_job` type, see Section F.45.4.3.

`schedule.clean_log()`

Deletes all records with information about the completed jobs. You must have superuser rights to call this function.

Return values:

- The number of records deleted.

`schedule.nodename()`

Returns the current node name.

F.45.4.6.3. Functions for Managing One-Time Jobs

`schedule.submit_job(`*`query`* `text [`*`options...`*`])`

Submits a job for immediate or delayed one-time execution. By default, the job is scheduled for immediate execution and can run in parallel with other scheduled jobs. To submit a job with a delayed start, you can set the execution start time using the *`run_after`* argument, or pass an array of job IDs in the *`depends_on`* argument to schedule job execution right after these jobs are complete.

Arguments:

- *`query`* — SQL commands to execute.

  Type: `text`

- *`params`* — an array of parameters for the SQL query that can substitute numbered placeholders in the *`query`* argument, such as $1, $2, etc. Default: `NULL`

  Type: `text[]`

- *`run_after`* — a timestamp after which the job execution starts. If this argument is set to `NULL`, the job is scheduled for immediate execution. You can also use the *`depends_on`* argument to delay the job start. Default: `NULL`

  Type: `timestamp with time zone`

- *`node`* — the name of the node on which to execute the job. Default: `NULL`

  Type: `text`

- *`max_duration`* — the maximum time interval during which the job can be executed. If this time is exceeded, the job is forced to stop. If this argument is `NULL` or not set, there are no time limits. Default: `NULL`

  Type: `interval`

- *`max_wait_interval`* — the maximum time interval to postpone the job execution for if all background workers are busy at the scheduled moment. For example, if this key is set to '00:02:34', the job will wait for 2 minutes 34 seconds. If this key is `NULL` or not set, the job can wait forever. Default: `NULL`

  Type: `interval`

- *`run_as`* — user or role whose rights are used to execute the job. If *`run_as`* is set to `NULL`, the job is executed with the rights of the current user. You must have superuser rights to set this argument. Default: `NULL`

  Type: `text`

- *`depends_on`* — an array of job IDs. The created job starts immediately after the specified jobs complete the execution. This argument is an alternative to *`run_after`*. Default: `NULL`

  Type: `bigint[]`

- *`name`* — name of the job. Default: `NULL`

  Type: `text`

- *`comments`* — comments about the job.

  Type: `text`

- *`resubmit_limit`* — maximum number of times the job can be resubmitted for execution. See the `schedule.resubmit()` function for details. Default: 100

  Type: `bigint`

Return values:

- ID of the created job.

  Type: `bigint`

`schedule.get_self_id()`

Returns the ID of the job, in the context of which it was called. The returned ID is of the `bigint` type. This function must be called inside the *`query`* of the `schedule.submit_job()` function. Otherwise, an exception is raised.

Return values:

- Job ID.

`schedule.cancel_job(`*`job_id`* `bigint)`

Cancels all subsequent runs of the specified job. If the job is currently being executed, it will not be interrupted, but cannot be resubmitted. You must have superuser rights or be the owner of the job to call this function.

Arguments:

- *`job_id`* — identifier of the job to cancel.

Return values:

- `true` if the operation completed successfully.
- `false` if the operation failed.

`schedule.resubmit(`*`run_after`* `interval default NULL)`

Sets the start time for the next execution of the job, without interrupting the current job run. This function must be called inside the *`query`* argument of the `schedule.submit_job()` function. Otherwise, an exception is raised. If this function is called several times within a single job execution, only the last function call is taken into account.

Arguments:

- *`run_after`* — time interval after which the job will be resubmitted for execution. If the time interval is less than a second but greater than zero, it is rounded to 1 second. Intervals longer than 1 second are rounded to integral values. If 0 is passed, the job is resubmitted immediately after execution. Default: 1 second

  Type: `interval`

Return values:

- The number of seconds after which the job will be resubmitted for execution.

F.45.4.6.4. Functions for Managing Scheduled and One-Time Jobs

`schedule.timetable(`*`start_time`* `timestamp with time zone,` *`end_time`*`timestamp with time zone)`

Returns a table, which describes all the jobs, both repeated and one-time, that are scheduled to execute within the specified time interval.

Table F.36. schedule.timetable Columns

Column Name	Column Type	Description
`id`	`bigint`	Job ID, which is unique for the jobs of this type.
`type`	`timetable_job_type_t`	Job type. See Section F.45.4.3.5 for details.
`node`	`text`	Name of the node on which the job is being executed.
`name`	`text`	Name of the job.

Column Name	Column Type	Description
comments	text	Comments about the job.
commands	text[]	An array of SQL commands executed by the job.
scheduled_at	timestamp with time zone	Scheduled job execution time.
start_time	timestamp with time zone	Job execution start time.
done_time	timestamp with time zone	Time when the job execution completed.
status	timetable_job_status_t	Job status. See Section F.45.4.3.6 for details.
error	text	Error message.

F.45.5. Authors

Postgres Professional, Moscow, Russia

F.46. pg_query_state

The pg_query_state module provides facility to know the current state of query execution on working backend.

F.46.1. Overview

Each non-utility query statement (SELECT/INSERT/UPDATE/DELETE) after optimization/planning stage is translated into plan tree, which is kind of imperative representation of declarative SQL query. EXPLAIN ANALYZE request allows to demonstrate execution statistics gathered from each node of plan tree (full time of execution, number of rows emitted to upper nodes, etc). But this statistics is collected after execution of query. This module allows to show actual statistics of query running on external backend. At that, format of resulting output is almost identical to ordinal EXPLAIN ANALYZE. Thus users are able to track of query execution in progress. In fact, this module is able to explore external backend and determine its actual state. Particularly it's helpful when backend executes a heavy query or gets stuck.

F.46.2. Use cases

Using this module there can help in the following things:

- detect a long query (along with other monitoring tools);
- supervise query execution.

F.46.3. Installation

To install pg_query_state run in psql:

```
CREATE EXTENSION pg_query_state;
```

Then modify shared_preload_libraries parameter in postgres.conf as following:

```
shared_preload_libraries = 'pg_query_state'
```

It will require to restart the Postgres Pro instance.

F.46.4. Function pg_query_state

```
pg_query_state(integer  pid,
               verbose  boolean DEFAULT FALSE,
               costs    boolean DEFAULT FALSE,
               timing   boolean DEFAULT FALSE,
               buffers  boolean DEFAULT FALSE,
```

```
                triggers boolean DEFAULT FALSE,
                format   text    DEFAULT 'text')
  returns TABLE (pid integer,
                 frame_number integer,
                 query_text text,
                 plan text,
                 leader_pid integer)
```

Extract current query state from backend with specified `pid`. Since parallel query can spawn multiple workers and function call causes nested subqueries so that state of execution may be viewed as stack of running queries, return value of pg_query_state has type `TABLE (pid integer, frame_number integer, query_text text, plan text, leader_pid integer)`. It represents tree structure consisting of leader process and its spawned workers identified by `pid`. Each worker refers to leader through `leader_pid` column. For leader process the value of this column is `null`. The state of each process is represented as stack of function calls. Each frame of that stack is specified as correspondence between `frame_number` starting from zero, `query_text` and `plan` with online statistics columns.

Thus, user can see the states of main query and queries generated from function calls for leader process and all workers spawned from it.

In process of execution some nodes of plan tree can take loops of full execution. Therefore statistics for each node consists of two parts: average statistics for previous loops just like in EXPLAIN ANALYZE output and statistics for current loop if node have not finished.

Optional arguments:

- verbose - use EXPLAIN VERBOSE for plan printing;
- costs - costs for each node;
- timing - print timing data for each node, if collecting of timing statistics is turned off on called side resulting output will contain WARNING message `timing statistics disabled`;
- buffers - print buffers usage, if collecting of buffers statistics is turned off on called side resulting output will contain WARNING message `buffers statistics disabled`;
- triggers - include triggers statistics in result plan trees;
- format - EXPLAIN format to be used for plans printing, possible values: text, xml, json, yaml.

If callable backend is not executing any query the function prints INFO message about backend's state taken from `pg_stat_activity` view if it exists there.

Calling role have to be superuser or member of the role whose backend is being called. Otherwise function prints ERROR message `permission denied`.

F.46.5. Configuration settings

There are several user-accessible GUC variables designed to toggle the whole module and the collecting of specific statistic parameters while query is running:

- pg_query_state.enable - disable (or enable) pg_query_state completely, default value is `true`
- pg_query_state.enable_timing - collect timing data for each node, default value is `false`
- pg_query_state.enable_buffers - collect buffers usage, default value is `false`

These parameters are set on called side before running any queries whose states are attempted to extract. `WARNING`: if pg_query_state.enable_timing is turned off the calling side cannot get time statistics, similarly for pg_query_state.enable_buffers parameter.

F.46.6. Examples

Set maximum number of parallel workers on `gather` node equals 2:

```
postgres=# set max_parallel_workers_per_gather = 2;
```

Assume one backend with `pid` = 49265 performs a simple query:

```
postgres=# select pg_backend_pid();
pg_backend_pid
----------------
    49265
(1 row)
postgres=# select count(*) from foo join bar on foo.c1=bar.c1;
```

Other backend can extract intermediate state of execution that query:

```
postgres=# \x
postgres=# select * from pg_query_state(49265);
-[ RECORD
 1 ]+-----------------------------------------------------------------------------------------
pid          | 49265
frame_number | 0
query_text   | select count(*) from foo join bar on foo.c1=bar.c1;
plan         | Finalize Aggregate (Current loop: actual rows=0, loop number=1)
                                                +
             |   ->  Gather (Current loop: actual rows=0, loop number=1)
                                                +
             |         Workers Planned: 2
                                                +
             |         Workers Launched: 2
                                                +
             |         ->  Partial Aggregate (Current loop: actual rows=0, loop
 number=1)                                        +
             |               ->  Nested Loop (Current loop: actual rows=12, loop
 number=1)                                       +
             |                     Join Filter: (foo.c1 = bar.c1)
                                                +
             |                     Rows Removed by Join Filter: 5673232
                                                +
             |                     ->  Parallel Seq Scan on foo (Current loop: actual
 rows=12, loop number=1)                          +
             |                     ->  Seq Scan on bar (actual rows=500000 loops=11)
 (Current loop: actual rows=173244, loop number=12)
leader_pid   | (null)
-[ RECORD
 2 ]+-----------------------------------------------------------------------------------------
pid          | 49324
frame_number | 0
query_text   | <parallel query>
plan         | Partial Aggregate (Current loop: actual rows=0, loop number=1)
                                                +
             |   ->  Nested Loop (Current loop: actual rows=10, loop number=1)
                                                +
             |         Join Filter: (foo.c1 = bar.c1)
                                                +
             |         Rows Removed by Join Filter: 4896779
                                                +
             |         ->  Parallel Seq Scan on foo (Current loop: actual rows=10, loop
 number=1)                                       +
             |         ->  Seq Scan on bar (actual rows=500000 loops=9) (Current loop:
 actual rows=396789, loop number=10)
leader_pid   | 49265
-[ RECORD
 3 ]+-----------------------------------------------------------------------------------------
pid          | 49323
```

```
frame_number | 0
query_text   | <parallel query>
plan         | Partial Aggregate (Current loop: actual rows=0, loop number=1)
                                        +
             |   ->  Nested Loop (Current loop: actual rows=11, loop number=1)
                                        +
             |         Join Filter: (foo.c1 = bar.c1)
                                        +
             |         Rows Removed by Join Filter: 5268783
                                        +
             |         ->  Parallel Seq Scan on foo (Current loop: actual rows=11, loop
 number=1)                              +
             |         ->  Seq Scan on bar (actual rows=500000 loops=10) (Current loop:
 actual rows=268794, loop number=11)
leader_pid   | 49265
```

In example above working backend spawns two parallel workers with pids 49324 and 49323. Their `leader_pid` column's values clarify that these workers belong to the main backend. `Seq Scan` node has statistics on passed loops (average number of rows delivered to `Nested Loop` and number of passed loops are shown) and statistics on current loop. Other nodes has statistics only for current loop as this loop is first (loop number = 1).

Assume first backend executes some function:

```
postgres=# select n_join_foo_bar();
```

Other backend can get the follow output:

```
postgres=# select * from pg_query_state(49265);
-[ RECORD
 1 ]+-----------------------------------------------------------------------------------------
pid          | 49265
frame_number | 0
query_text   | select n_join_foo_bar();
plan         | Result (Current loop: actual rows=0, loop number=1)
leader_pid   | (null)
-[ RECORD
 2 ]+-----------------------------------------------------------------------------------------
pid          | 49265
frame_number | 1
query_text   | SELECT (select count(*) from foo join bar on foo.c1=bar.c1)
plan         | Result (Current loop: actual rows=0, loop number=1)
                                      +
             |   InitPlan 1 (returns $0)
                                      +
             |     ->  Aggregate (Current loop: actual rows=0, loop number=1)
                                      +
             |           ->  Nested Loop (Current loop: actual rows=51, loop number=1)
                                      +
             |                 Join Filter: (foo.c1 = bar.c1)
                                      +
             |                 Rows Removed by Join Filter: 51636304
                                      +
             |                 ->  Seq Scan on bar (Current loop: actual rows=52, loop
 number=1)                             +
             |                 ->  Materialize (actual rows=1000000 loops=51) (Current
 loop: actual rows=636355, loop number=52)+
```

```
              |                        ->  Seq Scan on foo (Current loop: actual
 rows=1000000, loop number=1)
leader_pid    | (null)
```

First row corresponds to function call, second - to query which is in the body of that function.

We can get result plans in different format (e.g. json):

```
postgres=# select * from pg_query_state(pid := 49265, format := 'json');
-[ RECORD 1 ]+------------------------------------------------------------
pid          | 49265
frame_number | 0
query_text   | select * from n_join_foo_bar();
plan         | {                                                          +
             |   "Plan": {                                                +
             |     "Node Type": "Function Scan",                          +
             |     "Parallel Aware": false,                               +
             |     "Function Name": "n_join_foo_bar",                     +
             |     "Alias": "n_join_foo_bar",                             +
             |     "Current loop": {                                      +
             |       "Actual Loop Number": 1,                             +
             |       "Actual Rows": 0                                     +
             |     }                                                      +
             |   }                                                        +
             | }
leader_pid   | (null)
-[ RECORD 2 ]+------------------------------------------------------------
pid          | 49265
frame_number | 1
query_text   | SELECT (select count(*) from foo join bar on foo.c1=bar.c1)
plan         | {                                                          +
             |   "Plan": {                                                +
             |     "Node Type": "Result",                                 +
             |     "Parallel Aware": false,                               +
             |     "Current loop": {                                      +
             |       "Actual Loop Number": 1,                             +
             |       "Actual Rows": 0                                     +
             |     },                                                     +
             |     "Plans": [                                             +
             |       {                                                    +
             |         "Node Type": "Aggregate",                          +
             |         "Strategy": "Plain",                               +
             |         "Partial Mode": "Simple",                          +
             |         "Parent Relationship": "InitPlan",                 +
             |         "Subplan Name": "InitPlan 1 (returns $0)",         +
             |         "Parallel Aware": false,                           +
             |         "Current loop": {                                  +
             |           "Actual Loop Number": 1,                         +
             |           "Actual Rows": 0                                 +
             |         },                                                 +
             |         "Plans": [                                         +
             |           {                                                +
             |             "Node Type": "Nested Loop",                    +
             |             "Parent Relationship": "Outer",                +
             |             "Parallel Aware": false,                       +
             |             "Join Type": "Inner",                          +
             |             "Current loop": {                              +
             |               "Actual Loop Number": 1,                     +
```

```
                |                 "Actual Rows": 610                                +
                |               },                                                  +
                |               "Join Filter": "(foo.c1 = bar.c1)",                 +
                |               "Rows Removed by Join Filter": 610072944,           +
                |               "Plans": [                                          +
                |                 {                                                 +
                |                   "Node Type": "Seq Scan",                        +
                |                   "Parent Relationship": "Outer",                 +
                |                   "Parallel Aware": false,                        +
                |                   "Relation Name": "bar",                         +
                |                   "Alias": "bar",                                 +
                |                   "Current loop": {                               +
                |                     "Actual Loop Number": 1,                      +
                |                     "Actual Rows": 611                            +
                |                   }                                               +
                |                 },                                                +
                |                 {                                                 +
                |                   "Node Type": "Materialize",                     +
                |                   "Parent Relationship": "Inner",                 +
                |                   "Parallel Aware": false,                        +
                |                   "Actual Rows": 1000000,                         +
                |                   "Actual Loops": 610,                            +
                |                   "Current loop": {                               +
                |                     "Actual Loop Number": 611,                    +
                |                     "Actual Rows": 73554                          +
                |                   },                                              +
                |                   "Plans": [                                      +
                |                     {                                             +
                |                       "Node Type": "Seq Scan",                    +
                |                       "Parent Relationship": "Outer",             +
                |                       "Parallel Aware": false,                    +
                |                       "Relation Name": "foo",                     +
                |                       "Alias": "foo",                             +
                |                       "Current loop": {                           +
                |                         "Actual Loop Number": 1,                  +
                |                         "Actual Rows": 1000000                    +
                |                       }                                           +
                |                     }                                             +
                |                   ]                                               +
                |                 }                                                 +
                |               ]                                                   +
                |             }                                                     +
                |           ]                                                       +
                |         }                                                         +
                |       ]                                                           +
                |     }                                                             +
                | }
 leader_pid     | (null)
```

F.47. pgrowlocks

The `pgrowlocks` module provides a function to show row locking information for a specified table.

By default use is restricted to superusers, members of the `pg_stat_scan_tables` role, and users with `SELECT` permissions on the table.

F.47.1. Overview

```
pgrowlocks(text) returns setof record
```

The parameter is the name of a table. The result is a set of records, with one row for each locked row within the table. The output columns are shown in Table F.37.

Table F.37. `pgrowlocks` Output Columns

Name	Type	Description
`locked_row`	`tid`	Tuple ID (TID) of locked row
`locker`	`xid`	Transaction ID of locker, or multixact ID if multitransaction
`multi`	`boolean`	True if locker is a multitransaction
`xids`	`xid[]`	Transaction IDs of lockers (more than one if multitransaction)
`modes`	`text[]`	Lock mode of lockers (more than one if multitransaction), an array of `Key Share`, `Share`, `For No Key Update`, `No Key Update`, `For Update`, `Update`.
`pids`	`integer[]`	Process IDs of locking backends (more than one if multitransaction)

`pgrowlocks` takes `AccessShareLock` for the target table and reads each row one by one to collect the row locking information. This is not very speedy for a large table. Note that:

1. If an `ACCESS EXCLUSIVE` lock is taken on the table, `pgrowlocks` will be blocked.
2. `pgrowlocks` is not guaranteed to produce a self-consistent snapshot. It is possible that a new row lock is taken, or an old lock is freed, during its execution.

`pgrowlocks` does not show the contents of locked rows. If you want to take a look at the row contents at the same time, you could do something like this:

```
SELECT * FROM accounts AS a, pgrowlocks('accounts') AS p
  WHERE p.locked_row = a.ctid;
```

Be aware however that such a query will be very inefficient.

F.47.2. Sample Output

```
=# SELECT * FROM pgrowlocks('t1');
 locked_row | locker | multi | xids  |     modes      |  pids
------------+--------+-------+-------+----------------+--------
 (0,1)      |    609 | f     | {609} | {"For Share"}  | {3161}
 (0,2)      |    609 | f     | {609} | {"For Share"}  | {3161}
 (0,3)      |    607 | f     | {607} | {"For Update"} | {3107}
 (0,4)      |    607 | f     | {607} | {"For Update"} | {3107}
(4 rows)
```

F.47.3. Author

Tatsuo Ishii

F.48. pg_stat_statements

The `pg_stat_statements` module provides a means for tracking planning and execution statistics of all SQL statements executed by a server.

The module must be loaded by adding `pg_stat_statements` to shared_preload_libraries in `postgresql.conf`, because it requires additional shared memory. This means that a server restart is needed

to add or remove the module. In addition, query identifier calculation must be enabled in order for the module to be active, which is done automatically if compute_query_id is set to auto or on, or any third-party module that calculates query identifiers is loaded.

When pg_stat_statements is active, it tracks statistics across all databases of the server. To access and manipulate these statistics, the module provides views pg_stat_statements and pg_stat_statements_info, and the utility functions pg_stat_statements_reset and pg_stat_statements. These are not available globally but can be enabled for a specific database with CREATE EXTENSION pg_stat_statements.

F.48.1. The pg_stat_statements View

The statistics gathered by the module are made available via a view named pg_stat_statements. This view contains one row for each distinct combination of database ID, user ID, query ID and whether it's a top-level statement or not (up to the maximum number of distinct statements that the module can track). The columns of the view are shown in Table F.38.

Table F.38. pg_stat_statements Columns

Column Type Description
userid oid (references pg_authid .oid) OID of user who executed the statement
dbid oid (references pg_database .oid) OID of database in which the statement was executed
toplevel bool True if the query was executed as a top-level statement (always true if pg_stat_statements.track is set to top)
queryid bigint Hash code to identify identical normalized queries.
query text Text of a representative statement
plans bigint Number of times the statement was planned (if pg_stat_statements.track_planning is enabled, otherwise zero)
total_plan_time double precision Total time spent planning the statement, in milliseconds (if pg_stat_statements.track_planning is enabled, otherwise zero)
min_plan_time double precision Minimum time spent planning the statement, in milliseconds (if pg_stat_statements.track_planning is enabled, otherwise zero)
max_plan_time double precision Maximum time spent planning the statement, in milliseconds (if pg_stat_statements.track_planning is enabled, otherwise zero)
mean_plan_time double precision Mean time spent planning the statement, in milliseconds (if pg_stat_statements.track_planning is enabled, otherwise zero)
stddev_plan_time double precision Population standard deviation of time spent planning the statement, in milliseconds (if pg_stat_statements.track_planning is enabled, otherwise zero)
calls bigint Number of times the statement was executed
total_exec_time double precision

Column Type Description
Total time spent executing the statement, in milliseconds
min_exec_time double precision Minimum time spent executing the statement, in milliseconds
max_exec_time double precision Maximum time spent executing the statement, in milliseconds
mean_exec_time double precision Mean time spent executing the statement, in milliseconds
stddev_exec_time double precision Population standard deviation of time spent executing the statement, in milliseconds
rows bigint Total number of rows retrieved or affected by the statement
shared_blks_hit bigint Total number of shared block cache hits by the statement
shared_blks_read bigint Total number of shared blocks read by the statement
shared_blks_dirtied bigint Total number of shared blocks dirtied by the statement
shared_blks_written bigint Total number of shared blocks written by the statement
local_blks_hit bigint Total number of local block cache hits by the statement
local_blks_read bigint Total number of local blocks read by the statement
local_blks_dirtied bigint Total number of local blocks dirtied by the statement
local_blks_written bigint Total number of local blocks written by the statement
temp_blks_read bigint Total number of temp blocks read by the statement
temp_blks_written bigint Total number of temp blocks written by the statement
blk_read_time double precision Total time the statement spent reading blocks, in milliseconds (if track_io_timing is enabled, otherwise zero)
blk_write_time double precision Total time the statement spent writing blocks, in milliseconds (if track_io_timing is enabled, otherwise zero)
wal_records bigint Total number of WAL records generated by the statement
wal_fpi bigint Total number of WAL full page images generated by the statement
wal_bytes numeric Total amount of WAL generated by the statement in bytes

For security reasons, only superusers and members of the pg_read_all_stats role are allowed to see the SQL text and queryid of queries executed by other users. Other users can see the statistics, however, if the view has been installed in their database.

Plannable queries (that is, SELECT, INSERT, UPDATE, and DELETE) are combined into a single pg_stat_statements entry whenever they have identical query structures according to an internal hash calculation. Typically, two queries will be considered the same for this purpose if they are semantically equivalent except for the values of literal constants appearing in the query. Utility commands (that is, all other commands) are compared strictly on the basis of their textual query strings, however.

> **Note**
>
> The following details about constant replacement and queryid only apply when compute_query_id is enabled. If you use an external module instead to compute queryid, you should refer to its documentation for details.

When a constant's value has been ignored for purposes of matching the query to other queries, the constant is replaced by a parameter symbol, such as $1, in the pg_stat_statements display. The rest of the query text is that of the first query that had the particular queryid hash value associated with the pg_stat_statements entry.

In some cases, queries with visibly different texts might get merged into a single pg_stat_statements entry. Normally this will happen only for semantically equivalent queries, but there is a small chance of hash collisions causing unrelated queries to be merged into one entry. (This cannot happen for queries belonging to different users or databases, however.)

Since the queryid hash value is computed on the post-parse-analysis representation of the queries, the opposite is also possible: queries with identical texts might appear as separate entries, if they have different meanings as a result of factors such as different search_path settings.

Consumers of pg_stat_statements may wish to use queryid (perhaps in combination with dbid and userid) as a more stable and reliable identifier for each entry than its query text. However, it is important to understand that there are only limited guarantees around the stability of the queryid hash value. Since the identifier is derived from the post-parse-analysis tree, its value is a function of, among other things, the internal object identifiers appearing in this representation. This has some counterintuitive implications. For example, pg_stat_statements will consider two apparently-identical queries to be distinct, if they reference a table that was dropped and recreated between the executions of the two queries. The hashing process is also sensitive to differences in machine architecture and other facets of the platform. Furthermore, it is not safe to assume that queryid will be stable across major versions of Postgres Pro.

Two servers participating in replication based on physical WAL replay can be expected to have identical queryid values for the same query. However, logical replication schemes do not promise to keep replicas identical in all relevant details, so queryid will not be a useful identifier for accumulating costs across a set of logical replicas. If in doubt, direct testing is recommended.

Generally, it can be assumed that queryid values are stable between minor version releases of PostgreSQL, providing that instances are running on the same machine architecture and the catalog metadata details match. Compatibility will only be broken between minor versions as a last resort.

The parameter symbols used to replace constants in representative query texts start from the next number after the highest $*n* parameter in the original query text, or $1 if there was none. It's worth noting that in some cases there may be hidden parameter symbols that affect this numbering. For example, PL/pgSQL uses hidden parameter symbols to insert values of function local variables into queries, so that a PL/pgSQL statement like SELECT i + 1 INTO j would have representative text like SELECT i + $2.

The representative query texts are kept in an external disk file, and do not consume shared memory. Therefore, even very lengthy query texts can be stored successfully. However, if many long query texts are accumulated, the external file might grow unmanageably large. As a recovery method if that happens, pg_stat_statements may choose to discard the query texts, whereupon all existing entries in the pg_stat_statements view will show null query fields, though the statistics associated with each queryid are preserved. If this happens, consider reducing pg_stat_statements.max to prevent recurrences.

plans and calls aren't always expected to match because planning and execution statistics are updated at their respective end phase, and only for successful operations. For example, if a statement is successfully planned but fails during the execution phase, only its planning statistics will be updated. If planning is skipped because a cached plan is used, only its execution statistics will be updated.

F.48.2. The pg_stat_statements_info View

The statistics of the pg_stat_statements module itself are tracked and made available via a view named pg_stat_statements_info. This view contains only a single row. The columns of the view are shown in Table F.39.

Table F.39. pg_stat_statements_info Columns

Column Type Description
dealloc bigint Total number of times pg_stat_statements entries about the least-executed statements were deallocated because more distinct statements than pg_stat_statements.max were observed
stats_reset timestamp with time zone Time at which all statistics in the pg_stat_statements view were last reset.

F.48.3. Functions

pg_stat_statements_reset(userid Oid, dbid Oid, queryid bigint) returns void

pg_stat_statements_reset discards statistics gathered so far by pg_stat_statements corresponding to the specified userid, dbid and queryid. If any of the parameters are not specified, the default value 0(invalid) is used for each of them and the statistics that match with other parameters will be reset. If no parameter is specified or all the specified parameters are 0(invalid), it will discard all statistics. If all statistics in the pg_stat_statements view are discarded, it will also reset the statistics in the pg_stat_statements_info view. By default, this function can only be executed by superusers. Access may be granted to others using GRANT.

pg_stat_statements(showtext boolean) returns setof record

The pg_stat_statements view is defined in terms of a function also named pg_stat_statements. It is possible for clients to call the pg_stat_statements function directly, and by specifying showtext := false have query text be omitted (that is, the OUT argument that corresponds to the view's query column will return nulls). This feature is intended to support external tools that might wish to avoid the overhead of repeatedly retrieving query texts of indeterminate length. Such tools can instead cache the first query text observed for each entry themselves, since that is all pg_stat_statements itself does, and then retrieve query texts only as needed. Since the server stores query texts in a file, this approach may reduce physical I/O for repeated examination of the pg_stat_statements data.

F.48.4. Configuration Parameters

pg_stat_statements.max (integer)

pg_stat_statements.max is the maximum number of statements tracked by the module (i.e., the maximum number of rows in the pg_stat_statements view). If more distinct statements than that are observed, information about the least-executed statements is discarded. The number of times such information was discarded can be seen in the pg_stat_statements_info view. The default value is 5000. This parameter can only be set at server start.

pg_stat_statements.track (enum)

pg_stat_statements.track controls which statements are counted by the module. Specify top to track top-level statements (those issued directly by clients), all to also track nested statements (such as statements invoked within functions), or none to disable statement statistics collection. The default value is top. Only superusers can change this setting.

`pg_stat_statements.track_utility` (`boolean`)

`pg_stat_statements.track_utility` controls whether utility commands are tracked by the module. Utility commands are all those other than `SELECT`, `INSERT`, `UPDATE` and `DELETE`. The default value is `on`. Only superusers can change this setting.

`pg_stat_statements.track_planning` (`boolean`)

`pg_stat_statements.track_planning` controls whether planning operations and duration are tracked by the module. Enabling this parameter may incur a noticeable performance penalty, especially when statements with identical query structure are executed by many concurrent connections which compete to update a small number of `pg_stat_statements` entries. The default value is `off`. Only superusers can change this setting.

`pg_stat_statements.save` (`boolean`)

`pg_stat_statements.save` specifies whether to save statement statistics across server shutdowns. If it is `off` then statistics are not saved at shutdown nor reloaded at server start. The default value is `on`. This parameter can only be set in the `postgresql.conf` file or on the server command line.

The module requires additional shared memory proportional to `pg_stat_statements.max`. Note that this memory is consumed whenever the module is loaded, even if `pg_stat_statements.track` is set to `none`.

These parameters must be set in `postgresql.conf`. Typical usage might be:

```
# postgresql.conf
shared_preload_libraries = 'pg_stat_statements'

compute_query_id = on
pg_stat_statements.max = 10000
pg_stat_statements.track = all
```

F.48.5. Sample Output

```
bench=# SELECT pg_stat_statements_reset();

$ pgbench -i bench
$ pgbench -c10 -t300 bench

bench=# \x
bench=# SELECT query, calls, total_exec_time, rows, 100.0 * shared_blks_hit /
               nullif(shared_blks_hit + shared_blks_read, 0) AS hit_percent
          FROM pg_stat_statements ORDER BY total_exec_time DESC LIMIT 5;
-[ RECORD 1 ]---+----------------------------------------------------------------------
query           | UPDATE pgbench_branches SET bbalance = bbalance + $1 WHERE bid = $2
calls           | 3000
total_exec_time | 25565.855387
rows            | 3000
hit_percent     | 100.0000000000000000
-[ RECORD 2 ]---+----------------------------------------------------------------------
query           | UPDATE pgbench_tellers SET tbalance = tbalance + $1 WHERE tid = $2
calls           | 3000
total_exec_time | 20756.669379
rows            | 3000
hit_percent     | 100.0000000000000000
-[ RECORD 3 ]---+----------------------------------------------------------------------
query           | copy pgbench_accounts from stdin
calls           | 1
total_exec_time | 291.865911
rows            | 100000
hit_percent     | 100.0000000000000000
-[ RECORD 4 ]---+----------------------------------------------------------------------
```

```
query           | UPDATE pgbench_accounts SET abalance = abalance + $1 WHERE aid = $2
calls           | 3000
total_exec_time | 271.232977
rows            | 3000
hit_percent     | 98.8454011741682975
-[ RECORD 5 ]---+-----------------------------------------------------------------
query           | alter table pgbench_accounts add primary key (aid)
calls           | 1
total_exec_time | 160.588563
rows            | 0
hit_percent     | 100.0000000000000000


bench=# SELECT pg_stat_statements_reset(0,0,s.queryid) FROM pg_stat_statements AS s
            WHERE s.query = 'UPDATE pgbench_branches SET bbalance = bbalance + $1 WHERE
 bid = $2';

bench=# SELECT query, calls, total_exec_time, rows, 100.0 * shared_blks_hit /
              nullif(shared_blks_hit + shared_blks_read, 0) AS hit_percent
          FROM pg_stat_statements ORDER BY total_exec_time DESC LIMIT 5;
-[ RECORD 1 ]---+-----------------------------------------------------------------
query           | UPDATE pgbench_tellers SET tbalance = tbalance + $1 WHERE tid = $2
calls           | 3000
total_exec_time | 20756.669379
rows            | 3000
hit_percent     | 100.0000000000000000
-[ RECORD 2 ]---+-----------------------------------------------------------------
query           | copy pgbench_accounts from stdin
calls           | 1
total_exec_time | 291.865911
rows            | 100000
hit_percent     | 100.0000000000000000
-[ RECORD 3 ]---+-----------------------------------------------------------------
query           | UPDATE pgbench_accounts SET abalance = abalance + $1 WHERE aid = $2
calls           | 3000
total_exec_time | 271.232977
rows            | 3000
hit_percent     | 98.8454011741682975
-[ RECORD 4 ]---+-----------------------------------------------------------------
query           | alter table pgbench_accounts add primary key (aid)
calls           | 1
total_exec_time | 160.588563
rows            | 0
hit_percent     | 100.0000000000000000
-[ RECORD 5 ]---+-----------------------------------------------------------------
query           | vacuum analyze pgbench_accounts
calls           | 1
total_exec_time | 136.448116
rows            | 0
hit_percent     | 99.9201915403032721

bench=# SELECT pg_stat_statements_reset(0,0,0);

bench=# SELECT query, calls, total_exec_time, rows, 100.0 * shared_blks_hit /
              nullif(shared_blks_hit + shared_blks_read, 0) AS hit_percent
          FROM pg_stat_statements ORDER BY total_exec_time DESC LIMIT 5;
-[ RECORD 1 ]---+-------------------------------------------------
---------------------------
```

```
query           | SELECT pg_stat_statements_reset(0,0,0)
calls           | 1
total_exec_time | 0.189497
rows            | 1
hit_percent     |
-[ RECORD 2 ]---+-------------------------------------------------
---------------------------
query           | SELECT query, calls, total_exec_time, rows, $1 * shared_blks_hit /
       +
                |                nullif(shared_blks_hit + shared_blks_read, $2) AS
 hit_percent+
                |           FROM pg_stat_statements ORDER BY total_exec_time DESC LIMIT
 $3
calls           | 0
total_exec_time | 0
rows            | 0
hit_percent     |
```

F.48.6. Authors

Takahiro Itagaki <itagaki.takahiro@oss.ntt.co.jp>. Query normalization added by Peter Geoghegan <peter@2ndquadrant.com>.

F.49. pgstattuple

The pgstattuple module provides various functions to obtain tuple-level statistics.

Because these functions return detailed page-level information, access is restricted by default. By default, only the role pg_stat_scan_tables has EXECUTE privilege. Superusers of course bypass this restriction. After the extension has been installed, users may issue GRANT commands to change the privileges on the functions to allow others to execute them. However, it might be preferable to add those users to the pg_stat_scan_tables role instead.

F.49.1. Functions

pgstattuple(regclass) returns record

pgstattuple returns a relation's physical length, percentage of “dead” tuples, and other info. This may help users to determine whether vacuum is necessary or not. The argument is the target relation's name (optionally schema-qualified) or OID. For example:

```
test=> SELECT * FROM pgstattuple('pg_catalog.pg_proc');
-[ RECORD 1 ]------+-------
table_len          | 458752
tuple_count        | 1470
tuple_len          | 438896
tuple_percent      | 95.67
dead_tuple_count   | 11
dead_tuple_len     | 3157
dead_tuple_percent | 0.69
free_space         | 8932
free_percent       | 1.95
```

The output columns are described in Table F.40.

Table F.40. pgstattuple Output Columns

Column	Type	Description
table_len	bigint	Physical relation length in bytes

Column	Type	Description
tuple_count	bigint	Number of live tuples
tuple_len	bigint	Total length of live tuples in bytes
tuple_percent	float8	Percentage of live tuples
dead_tuple_count	bigint	Number of dead tuples
dead_tuple_len	bigint	Total length of dead tuples in bytes
dead_tuple_percent	float8	Percentage of dead tuples
free_space	bigint	Total free space in bytes
free_percent	float8	Percentage of free space

Note

The table_len will always be greater than the sum of the tuple_len, dead_tuple_len and free_space. The difference is accounted for by fixed page overhead, the per-page table of pointers to tuples, and padding to ensure that tuples are correctly aligned.

pgstattuple acquires only a read lock on the relation. So the results do not reflect an instantaneous snapshot; concurrent updates will affect them.

pgstattuple judges a tuple is "dead" if HeapTupleSatisfiesDirty returns false.

pgstattuple(text) returns record

This is the same as pgstattuple(regclass), except that the target relation is specified as TEXT. This function is kept because of backward-compatibility so far, and will be deprecated in some future release.

pgstatindex(regclass) returns record

pgstatindex returns a record showing information about a B-tree index. For example:

```
test=> SELECT * FROM pgstatindex('pg_cast_oid_index');
-[ RECORD 1 ]------+------
version            | 2
tree_level         | 0
index_size         | 16384
root_block_no      | 1
internal_pages     | 0
leaf_pages         | 1
empty_pages        | 0
deleted_pages      | 0
avg_leaf_density   | 54.27
leaf_fragmentation | 0
```

The output columns are:

Column	Type	Description
version	integer	B-tree version number
tree_level	integer	Tree level of the root page
index_size	bigint	Total index size in bytes

Column	Type	Description
root_block_no	bigint	Location of root page (zero if none)
internal_pages	bigint	Number of “internal” (upper-level) pages
leaf_pages	bigint	Number of leaf pages
empty_pages	bigint	Number of empty pages
deleted_pages	bigint	Number of deleted pages
avg_leaf_density	float8	Average density of leaf pages
leaf_fragmentation	float8	Leaf page fragmentation

The reported index_size will normally correspond to one more page than is accounted for by internal_pages + leaf_pages + empty_pages + deleted_pages, because it also includes the index's metapage.

As with pgstattuple, the results are accumulated page-by-page, and should not be expected to represent an instantaneous snapshot of the whole index.

pgstatindex(text) returns record

This is the same as pgstatindex(regclass), except that the target index is specified as TEXT. This function is kept because of backward-compatibility so far, and will be deprecated in some future release.

pgstatginindex(regclass) returns record

pgstatginindex returns a record showing information about a GIN index. For example:

```
test=> SELECT * FROM pgstatginindex('test_gin_index');
-[ RECORD 1 ]--+--
version        | 1
pending_pages  | 0
pending_tuples | 0
```

The output columns are:

Column	Type	Description
version	integer	GIN version number
pending_pages	integer	Number of pages in the pending list
pending_tuples	bigint	Number of tuples in the pending list

pgstathashindex(regclass) returns record

pgstathashindex returns a record showing information about a HASH index. For example:

```
test=> select * from pgstathashindex('con_hash_index');
-[ RECORD 1 ]--+-----------------
version        | 4
bucket_pages   | 33081
overflow_pages | 0
bitmap_pages   | 1
unused_pages   | 32455
live_items     | 10204006
```

```
dead_items      | 0
free_percent    | 61.8005949100872
```

The output columns are:

Column	Type	Description
version	integer	HASH version number
bucket_pages	bigint	Number of bucket pages
overflow_pages	bigint	Number of overflow pages
bitmap_pages	bigint	Number of bitmap pages
unused_pages	bigint	Number of unused pages
live_items	bigint	Number of live tuples
dead_tuples	bigint	Number of dead tuples
free_percent	float	Percentage of free space

`pg_relpages(regclass) returns bigint`

`pg_relpages` returns the number of pages in the relation.

`pg_relpages(text) returns bigint`

This is the same as `pg_relpages(regclass)`, except that the target relation is specified as TEXT. This function is kept because of backward-compatibility so far, and will be deprecated in some future release.

`pgstattuple_approx(regclass) returns record`

`pgstattuple_approx` is a faster alternative to `pgstattuple` that returns approximate results. The argument is the target relation's name or OID. For example:

```
test=> SELECT * FROM pgstattuple_approx('pg_catalog.pg_proc'::regclass);
-[ RECORD 1 ]--------+-------
table_len            | 573440
scanned_percent      | 2
approx_tuple_count   | 2740
approx_tuple_len     | 561210
approx_tuple_percent | 97.87
dead_tuple_count     | 0
dead_tuple_len       | 0
dead_tuple_percent   | 0
approx_free_space    | 11996
approx_free_percent  | 2.09
```

The output columns are described in Table F.41.

Whereas `pgstattuple` always performs a full-table scan and returns an exact count of live and dead tuples (and their sizes) and free space, `pgstattuple_approx` tries to avoid the full-table scan and returns exact dead tuple statistics along with an approximation of the number and size of live tuples and free space.

It does this by skipping pages that have only visible tuples according to the visibility map (if a page has the corresponding VM bit set, then it is assumed to contain no dead tuples). For such pages, it derives the free space value from the free space map, and assumes that the rest of the space on the page is taken up by live tuples.

For pages that cannot be skipped, it scans each tuple, recording its presence and size in the appropriate counters, and adding up the free space on the page. At the end, it estimates the total number

of live tuples based on the number of pages and tuples scanned (in the same way that VACUUM estimates pg_class.reltuples).

Table F.41. `pgstattuple_approx` Output Columns

Column	Type	Description
table_len	bigint	Physical relation length in bytes (exact)
scanned_percent	float8	Percentage of table scanned
approx_tuple_count	bigint	Number of live tuples (estimated)
approx_tuple_len	bigint	Total length of live tuples in bytes (estimated)
approx_tuple_percent	float8	Percentage of live tuples
dead_tuple_count	bigint	Number of dead tuples (exact)
dead_tuple_len	bigint	Total length of dead tuples in bytes (exact)
dead_tuple_percent	float8	Percentage of dead tuples
approx_free_space	bigint	Total free space in bytes (estimated)
approx_free_percent	float8	Percentage of free space

In the above output, the free space figures may not match the `pgstattuple` output exactly, because the free space map gives us an exact figure, but is not guaranteed to be accurate to the byte.

F.49.2. Authors

Tatsuo Ishii, Satoshi Nagayasu and Abhijit Menon-Sen

F.50. pg_surgery

The `pg_surgery` module provides various functions to perform surgery on a damaged relation. These functions are unsafe by design and using them may corrupt (or further corrupt) your database. For example, these functions can easily be used to make a table inconsistent with its own indexes, to cause `UNIQUE` or `FOREIGN KEY` constraint violations, or even to make tuples visible which, when read, will cause a database server crash. They should be used with great caution and only as a last resort.

F.50.1. Functions

`heap_force_kill(regclass, tid[]) returns void`

`heap_force_kill` marks “used” line pointers as “dead” without examining the tuples. The intended use of this function is to forcibly remove tuples that are not otherwise accessible. For example:

```
test=> select * from t1 where ctid = '(0, 1)';
ERROR:  could not access status of transaction 4007513275
DETAIL:  Could not open file "pg_xact/0EED": No such file or directory.

test=# select heap_force_kill('t1'::regclass, ARRAY['(0, 1)']::tid[]);
 heap_force_kill
-----------------


(1 row)

test=# select * from t1 where ctid = '(0, 1)';
(0 rows)
```

```
heap_force_freeze(regclass, tid[]) returns void
```

`heap_force_freeze` marks tuples as frozen without examining the tuple data. The intended use of this function is to make accessible tuples which are inaccessible due to corrupted visibility information, or which prevent the table from being successfully vacuumed due to corrupted visibility information. For example:

```
test=> vacuum t1;
ERROR:  found xmin 507 from before relfrozenxid 515
CONTEXT:  while scanning block 0 of relation "public.t1"

test=# select ctid from t1 where xmin = 507;
 ctid
-------
 (0,3)
(1 row)

test=# select heap_force_freeze('t1'::regclass, ARRAY['(0, 3)']::tid[]);
 heap_force_freeze
-------------------

(1 row)

test=# select ctid from t1 where xmin = 2;
 ctid
-------
 (0,3)
(1 row)
```

F.50.2. Authors

Ashutosh Sharma <ashu.coek88@gmail.com>

F.51. pg_transfer

The `pg_transfer` extension enables quick transfer of tables between Postgres Pro Enterprise instances.

It may sometimes be required to load large volumes of data into a database, for example, when consolidating data from regional servers into a central one. If your data needs to be uploaded to a server under heavy load, you can use a temporary database on another server to accumulate the data and then transfer it all at once when the main server load is minimal.

If you use pg_dump and pg_restore applications to transfer data, the load on the receiving server is usually higher than that on the sending server. Since the data is loaded using `INSERT` or `COPY` commands, it creates a significant impact on the disk subsystem. Besides, you will have to re-build indexes in the target database once all the data is loaded, which will also contribute to the server load.

To achieve a much higher load speed for read-only data, you can use the `pg_transfer` extension while doing dump/restore, which allows to copy data files directly, without using `COPY`/`INSERT` commands. `pg_transfer` also provides auxiliary functions for pg_dump and pg_restore to transfer tables together with pre-built indexes and collected statistics, so you can avoid extra load on the target server incurred by statistics re-collection.

> **Note**
>
> Postgres Pro Enterprise configuration and the architectures of source and target servers must provide binary-compatible file formats. When restoring data, `pg_transfer` checks that source and target servers have the same alignment, page and segment sizes, etc.

F.51.1. Installation

pg_transfer is included into Postgres Pro Enterprise. To enable pg_transfer, create its extension in your database using the following SQL command:

```
CREATE EXTENSION pg_transfer;
```

You must create pg_transfer extension in both source and target databases.

F.51.2. Usage

To transfer data using the pg_transfer module, do the following:

1. **Prepare source and target systems for data transfer**

   Before the actual data transfer, you first need to transfer data schema to the target server:

   1. In the source database, mark the table to be transferred as read-only:

      ```
      ALTER TABLE table_name SET CONSTANT;
      ```

   2. Run the VACUUM (ANALYZE) command to remove dead tuples and refresh statistics:

      ```
      VACUUM (ANALYZE) table_name;
      ```

   3. Take a logical dump of the data schema on the source server and restore it on the target server:

      ```
      pg_dump -Fc -t table_name --schema-only -f transfer_dir/archive.out old_database
      pg_restore -d new_database --schema-only transfer_dir/archive.out
      ```

2. **Prepare TOAST identifiers for the transfer**

   This step is only required if the tables to be transferred have toasted values.

   1. Determine TOAST identifiers (*reltoastid*) in the new database:

      ```
      psql new_database -c "SELECT reltoastrelid FROM pg_class WHERE
       relname='table_name';"
      ```

   2. Using the received *reltoastid* identifiers, prepare the table for the transfer and force data flush to disk:

      ```
      psql -d old_database -c "SELECT
       pg_transfer_freeze('table_name'::regclass::oid, reltoastrelid::oid);"
      ```

3. **Transfer the data to the target system**

   1. Copy the data into a separate directory using pg_dump utility:

      ```
      pg_dump -Fc -t table_name --transfer-dir transfer_dir/ -f transfer_dir/
      archive.out old_database
      ```

   2. Restore the data in the target database:

      ```
      pg_restore -d new_database --data-only --transfer-dir transfer_dir/ --copy-mode-
      transfer transfer_dir/archive.out
      ```

      When source and target databases are located in the same file system, the --copy-mode-transfer option must be specified at least once (for either pg_dump or pg_restore command) to get an independent copy of data. When restoring data on the primary server, --generate-wal option must be specified for pg_restore for changes to be replicated to a standby server.

F.51.3. Compatibility

The pg_transfer extension is only supported on Linux systems.

F.51.4. Authors

Postgres Professional, Moscow, Russia

F.52. pg_trgm

The pg_trgm module provides functions and operators for determining the similarity of alphanumeric text based on trigram matching, as well as index operator classes that support fast searching for similar strings.

This module is considered "trusted", that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.52.1. Trigram (or Trigraph) Concepts

A trigram is a group of three consecutive characters taken from a string. We can measure the similarity of two strings by counting the number of trigrams they share. This simple idea turns out to be very effective for measuring the similarity of words in many natural languages.

> **Note**
>
> pg_trgm ignores non-word characters (non-alphanumerics) when extracting trigrams from a string. Each word is considered to have two spaces prefixed and one space suffixed when determining the set of trigrams contained in the string. For example, the set of trigrams in the string "cat" is " c", " ca", "cat", and "at ". The set of trigrams in the string "foo|bar" is " f", " fo", "foo", "oo ", " b", " ba", "bar", and "ar ".

F.52.2. Functions and Operators

The functions provided by the pg_trgm module are shown in Table F.42, the operators in Table F.43.

Table F.42. pg_trgm Functions

Function Description
similarity (text, text) → real Returns a number that indicates how similar the two arguments are. The range of the result is zero (indicating that the two strings are completely dissimilar) to one (indicating that the two strings are identical).
show_trgm (text) → text[] Returns an array of all the trigrams in the given string. (In practice this is seldom useful except for debugging.)
word_similarity (text, text) → real Returns a number that indicates the greatest similarity between the set of trigrams in the first string and any continuous extent of an ordered set of trigrams in the second string. For details, see the explanation below.
strict_word_similarity (text, text) → real Same as word_similarity , but forces extent boundaries to match word boundaries. Since we don't have cross-word trigrams, this function actually returns greatest similarity between first string and any continuous extent of words of the second string.
show_limit () → real Returns the current similarity threshold used by the % operator. This sets the minimum similarity between two words for them to be considered similar enough to be misspellings of each other, for example. (*Deprecated*; instead use SHOW pg_trgm.similarity_threshold .)
set_limit (real) → real Sets the current similarity threshold that is used by the % operator. The threshold must be between 0 and 1 (default is 0.3). Returns the same value passed in. (*Deprecated*; instead use SET pg_trgm.similarity_threshold .)

Consider the following example:

```
# SELECT word_similarity('word', 'two words');
 word_similarity
-----------------
             0.8
(1 row)
```

In the first string, the set of trigrams is `{" w"," wo","wor","ord","rd "}`. In the second string, the ordered set of trigrams is `{" t"," tw","two","wo "," w"," wo","wor","ord","rds","ds "}`. The most similar extent of an ordered set of trigrams in the second string is `{" w"," wo","wor","ord"}`, and the similarity is `0.8`.

This function returns a value that can be approximately understood as the greatest similarity between the first string and any substring of the second string. However, this function does not add padding to the boundaries of the extent. Thus, the number of additional characters present in the second string is not considered, except for the mismatched word boundaries.

At the same time, `strict_word_similarity` selects an extent of words in the second string. In the example above, `strict_word_similarity` would select the extent of a single word `'words'`, whose set of trigrams is `{" w"," wo","wor","ord","rds","ds "}`.

```
# SELECT strict_word_similarity('word', 'two words'), similarity('word', 'words');
 strict_word_similarity | similarity
------------------------+------------
               0.571429 |   0.571429
(1 row)
```

Thus, the `strict_word_similarity` function is useful for finding the similarity to whole words, while `word_similarity` is more suitable for finding the similarity for parts of words.

Table F.43. `pg_trgm` Operators

Operator Description
`text % text → boolean` Returns `true` if its arguments have a similarity that is greater than the current similarity threshold set by `pg_trgm.similarity_threshold` .
`text <% text → boolean` Returns `true` if the similarity between the trigram set in the first argument and a continuous extent of an ordered trigram set in the second argument is greater than the current word similarity threshold set by `pg_trgm.word_similarity_threshold` parameter.
`text %> text → boolean` Commutator of the `<%` operator.
`text <<% text → boolean` Returns `true` if its second argument has a continuous extent of an ordered trigram set that matches word boundaries, and its similarity to the trigram set of the first argument is greater than the current strict word similarity threshold set by the `pg_trgm.strict_word_similarity_threshold` parameter.
`text %>> text → boolean` Commutator of the `<<%` operator.
`text <-> text → real` Returns the “distance” between the arguments, that is one minus the `similarity()` value.
`text <<-> text → real` Returns the “distance” between the arguments, that is one minus the `word_similarity()` value.

Operator Description
`text <->> text → real` Commutator of the `<<->` operator.
`text <<<-> text → real` Returns the “distance” between the arguments, that is one minus the `strict_word_similarity()` value.
`text <->>> text → real` Commutator of the `<<<->` operator.

F.52.3. GUC Parameters

`pg_trgm.similarity_threshold` (`real`)

Sets the current similarity threshold that is used by the `%` operator. The threshold must be between 0 and 1 (default is 0.3).

`pg_trgm.word_similarity_threshold` (`real`)

Sets the current word similarity threshold that is used by the `<%` and `%>` operators. The threshold must be between 0 and 1 (default is 0.6).

`pg_trgm.strict_word_similarity_threshold` (`real`)

Sets the current strict word similarity threshold that is used by the `<<%` and `%>>` operators. The threshold must be between 0 and 1 (default is 0.5).

F.52.4. Index Support

The `pg_trgm` module provides GiST and GIN index operator classes that allow you to create an index over a text column for the purpose of very fast similarity searches. These index types support the above-described similarity operators, and additionally support trigram-based index searches for `LIKE`, `ILIKE`, `~`, `~*` and `=` queries. Inequality operators are not supported. Note that those indexes may not be as efficient as regular B-tree indexes for equality operator.

Example:

```
CREATE TABLE test_trgm (t text);
CREATE INDEX trgm_idx ON test_trgm USING GIST (t gist_trgm_ops);
```

or

```
CREATE INDEX trgm_idx ON test_trgm USING GIN (t gin_trgm_ops);
```

`gist_trgm_ops` GiST opclass approximates a set of trigrams as a bitmap signature. Its optional integer parameter `siglen` determines the signature length in bytes. The default length is 12 bytes. Valid values of signature length are between 1 and 2024 bytes. Longer signatures lead to a more precise search (scanning a smaller fraction of the index and fewer heap pages), at the cost of a larger index.

Example of creating such an index with a signature length of 32 bytes:

```
CREATE INDEX trgm_idx ON test_trgm USING GIST (t gist_trgm_ops(siglen=32));
```

At this point, you will have an index on the `t` column that you can use for similarity searching. A typical query is

```
SELECT t, similarity(t, 'word') AS sml
  FROM test_trgm
  WHERE t % 'word'
  ORDER BY sml DESC, t;
```

This will return all values in the text column that are sufficiently similar to *word*, sorted from best match to worst. The index will be used to make this a fast operation even over very large data sets.

A variant of the above query is

```
SELECT t, t <-> 'word' AS dist
  FROM test_trgm
  ORDER BY dist LIMIT 10;
```

This can be implemented quite efficiently by GiST indexes, but not by GIN indexes. It will usually beat the first formulation when only a small number of the closest matches is wanted.

Also you can use an index on the `t` column for word similarity or strict word similarity. Typical queries are:

```
SELECT t, word_similarity('word', t) AS sml
  FROM test_trgm
  WHERE 'word' <% t
  ORDER BY sml DESC, t;
```

and

```
SELECT t, strict_word_similarity('word', t) AS sml
  FROM test_trgm
  WHERE 'word' <<% t
  ORDER BY sml DESC, t;
```

This will return all values in the text column for which there is a continuous extent in the corresponding ordered trigram set that is sufficiently similar to the trigram set of *word*, sorted from best match to worst. The index will be used to make this a fast operation even over very large data sets.

Possible variants of the above queries are:

```
SELECT t, 'word' <<-> t AS dist
  FROM test_trgm
  ORDER BY dist LIMIT 10;
```

and

```
SELECT t, 'word' <<<-> t AS dist
  FROM test_trgm
  ORDER BY dist LIMIT 10;
```

This can be implemented quite efficiently by GiST indexes, but not by GIN indexes.

Beginning in PostgreSQL 9.1, these index types also support index searches for `LIKE` and `ILIKE`, for example

```
SELECT * FROM test_trgm WHERE t LIKE '%foo%bar';
```

The index search works by extracting trigrams from the search string and then looking these up in the index. The more trigrams in the search string, the more effective the index search is. Unlike B-tree based searches, the search string need not be left-anchored.

Beginning in PostgreSQL 9.3, these index types also support index searches for regular-expression matches (`~` and `~*` operators), for example

```
SELECT * FROM test_trgm WHERE t ~ '(foo|bar)';
```

The index search works by extracting trigrams from the regular expression and then looking these up in the index. The more trigrams that can be extracted from the regular expression, the more effective the index search is. Unlike B-tree based searches, the search string need not be left-anchored.

For both `LIKE` and regular-expression searches, keep in mind that a pattern with no extractable trigrams will degenerate to a full-index scan.

The choice between GiST and GIN indexing depends on the relative performance characteristics of GiST and GIN, which are discussed elsewhere.

F.52.5. Text Search Integration

Trigram matching is a very useful tool when used in conjunction with a full text index. In particular it can help to recognize misspelled input words that will not be matched directly by the full text search mechanism.

The first step is to generate an auxiliary table containing all the unique words in the documents:

```
CREATE TABLE words AS SELECT word FROM
        ts_stat('SELECT to_tsvector(''simple'', bodytext) FROM documents');
```

where `documents` is a table that has a text field `bodytext` that we wish to search. The reason for using the `simple` configuration with the `to_tsvector` function, instead of using a language-specific configuration, is that we want a list of the original (unstemmed) words.

Next, create a trigram index on the word column:

```
CREATE INDEX words_idx ON words USING GIN (word gin_trgm_ops);
```

Now, a `SELECT` query similar to the previous example can be used to suggest spellings for misspelled words in user search terms. A useful extra test is to require that the selected words are also of similar length to the misspelled word.

> **Note**
>
> Since the `words` table has been generated as a separate, static table, it will need to be periodically regenerated so that it remains reasonably up-to-date with the document collection. Keeping it exactly current is usually unnecessary.

F.52.6. References

GiST Development Site *http://www.sai.msu.su/~megera/postgres/gist/*

Tsearch2 Development Site *http://www.sai.msu.su/~megera/postgres/gist/tsearch/V2/*

F.52.7. Authors

Oleg Bartunov `<oleg@sai.msu.su>`, Moscow, Moscow University, Russia

Teodor Sigaev `<teodor@sigaev.ru>`, Moscow, Delta-Soft Ltd.,Russia

Alexander Korotkov `<a.korotkov@postgrespro.ru>`, Moscow, Postgres Professional, Russia

Documentation: Christopher Kings-Lynne

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F.53. pg_tsparser

`pg_tsparser` is a Postgres Pro extension for text search. This extension modifies the default text parsing strategy for words that include:

- underscores
- numbers and letters separated by the hyphen character

In addition to separate word parts returned by default, `pg_tsparser` also returns the whole word.

F.53.1. Installation and Setup

pg_tsparser is included into the Postgres Pro distribution. To enable pg_tsparser, once Postgres Pro is installed, create the pg_tsparser extension for each database you are planning to use:

```
CREATE EXTENSION pg_tsparser;
```

Once pg_tsparser is enabled, you can create your own text search configuration. In addition to pg_tsparser, you can use any available dictionary.

For example, you can create english_ts configuration for the English language, as follows:

```
CREATE TEXT SEARCH CONFIGURATION english_ts (
    PARSER = tsparser
);

COMMENT ON TEXT SEARCH CONFIGURATION english_ts IS 'text search configuration for
 english language';

ALTER TEXT SEARCH CONFIGURATION english_ts
    ADD MAPPING FOR email, file, float, host, hword_numpart, int,
    numhword, numword, sfloat, uint, url, url_path, version
    WITH simple;

ALTER TEXT SEARCH CONFIGURATION english_ts
    ADD MAPPING FOR asciiword, asciihword, hword_asciipart,
    word, hword, hword_part
    WITH english_stem;
```

F.53.2. Examples

The following examples illustrate the difference in search results returned by pg_tsparser and the default parser:

```
SELECT to_tsvector('english', 'pg_trgm') as def_parser,
       to_tsvector('english_ts', 'pg_trgm')  as new_parser;
   def_parser    |         new_parser
-----------------+----------------------------
 'pg':1 'trgm':2 | 'pg':2 'pg_trgm':1 'trgm':3
(1 row)

SELECT to_tsvector('english', '123-abc') as def_parser,
       to_tsvector('english_ts', '123-abc')  as new_parser;
   def_parser    |         new_parser
-----------------+----------------------------
 '123':1 'abc':2 | '123':2 '123-abc':1 'abc':3
(1 row)

SELECT to_tsvector('english', 'rel-3.2-A') as def_parser,
       to_tsvector('english_ts', 'rel-3.2-A')  as new_parser;
    def_parser    |          new_parser
------------------+------------------------------
 '-3.2':2 'rel':1 | '3.2':3 'rel':2 'rel-3.2-a':1
(1 row)
```

See Also

CREATE TEXT SEARCH CONFIGURATION

ALTER TEXT SEARCH CONFIGURATION

F.53.3. Authors

Postgres Professional, Moscow, Russia

F.54. pg_variables

The pg_variables module provides functions for working with variables of various types. The created variables are only available in the current user session.

> **Note**
>
> This extension cannot be used while built-in connection pooling is enabled.

F.54.1. Installation

The pg_variables extension is included into Postgres Pro. Once you have Postgres Pro installed, you must execute the CREATE EXTENSION command to enable pg_variables, as follows:

```
CREATE EXTENSION pg_variables;
```

F.54.2. Usage

The pg_variables module provides several functions for creating, reading, and managing variables of scalar, record, and array types. See the following sections for function descriptions and syntax:

- Section F.54.3.1 describes functions for scalar variables.
- Section F.54.3.2 describes functions for collections of record variables.
- Section F.54.3.3 describes functions for array variables.
- Section F.54.3.4 describes functions for general collection variables.
- Section F.54.3.5 describes functions for using iterators to traverse collection variables.
- Section F.54.3.6 lists functions you can use to manage all variables in your current session.

For detailed usage examples, see Section F.54.5.

F.54.2.1. Using Transactional Variables

By default, the created variables are non-transactional. Once successfully set, a variable exists for the whole session, regardless of rollbacks, if any. For example:

```
SELECT pgv_set('vars', 'int1', 101);
BEGIN;
SELECT pgv_set('vars', 'int2', 102);
ROLLBACK;

SELECT * FROM pgv_list() order by package, name;
 package | name | is_transactional
---------+------+------------------
 vars    | int1 | f
 vars    | int2 | f
```

If you would like to use variables that support transactions and savepoints, pass the optional is_transactional flag as the last parameter when creating this variable:

```
BEGIN;
SELECT pgv_set('vars', 'trans_int', 101, true);
SAVEPOINT sp1;
SELECT pgv_set('vars', 'trans_int', 102, true);
ROLLBACK TO sp1;
```

```
COMMIT;
SELECT pgv_get('vars', 'trans_int', NULL::int);
 pgv_get
---------
     101
```

You must use the `is_transactional` flag every time you change the value of a transactional variable using `pgv_set()` or `pgv_insert()` functions. Otherwise, an error occurs. Other functions do not require this flag.

```
SELECT pgv_insert('pack', 'var_record', row(123::int, 'text'::text), true);

SELECT pgv_insert('pack', 'var_record', row(456::int, 'another text'::text));
ERROR:  variable "var_record" already created as TRANSACTIONAL

SELECT pgv_delete('pack', 'var_record', 123::int);
```

If the `pgv_free()` or `pgv_remove()` function calls are rolled back, the affected transactional variables will be restored, unlike non-transactional variables, which are removed permanently. For example:

```
SELECT pgv_set('pack', 'var_reg', 123);
SELECT pgv_set('pack', 'var_trans', 456, true);
BEGIN;
SELECT pgv_free();
ROLLBACK;
SELECT * FROM pgv_list();
 package |   name    | is_transactional
---------+-----------+------------------
 pack    | var_trans | t
```

F.54.3. Functions

F.54.3.1. Scalar Variables

The following functions support scalar variables:

Function	Returns
`pgv_set(package text, name text, value anynonarray, is_transactional bool default false)`	`void`
`pgv_get(package text, name text, var_type anynonarray, strict bool default true)`	`anynonarray`

To use the `pgv_get()` function, you must first create a package and a variable using the `pgv_set()` function. If the specified package or variable does not exist, an error occurs:

```
SELECT pgv_get('vars', 'int1', NULL::int);
ERROR:  unrecognized package "vars"

SELECT pgv_get('vars', 'int1', NULL::int);
ERROR:  unrecognized variable "int1"
```

`pgv_get()` function checks the variable type. If the specified type does not match the type of the variable, an error is raised:

```
SELECT pgv_get('vars', 'int1', NULL::text);
ERROR:  variable "int1" requires "integer" value
```

F.54.3.2. Collections of Records

The following functions support collections of record variables:

Function	Returns	Description
`pgv_insert(package text, name text, r record, is_transactional bool default false)`	`void`	Inserts a record into a collection variable for the specified package. If the package or variable does not exist, it is created automatically. The first column of `r` is the primary key. If a record with the same primary key already exists or this collection variable has a different structure, an error is raised.
`pgv_update(package text, name text, r record)`	`boolean`	Updates a record with the corresponding primary key (the first column of `r` is the primary key). Returns `true` if the record was found. If this collection variable has a different structure, an error is raised.
`pgv_delete(package text, name text, value anynonarray)`	`boolean`	Deletes a record with the corresponding primary key (the first column of `r` is the primary key). Returns `true` if the record was found and `false` otherwise.
`pgv_select(package text, name text)`	`set of records`	Returns the collection variable records.
`pgv_select(package text, name text, value anynonarray)`	`record`	Returns the record with the corresponding primary key (the first column of `r` is a primary key).
`pgv_select(package text, name text, value anyarray)`	`set of records`	Returns the collection variable records with the corresponding primary keys (the first column of `r` is a primary key).

To use `pgv_update()`, `pgv_delete()` and `pgv_select()` functions, you must first create a package and a variable using the `pgv_insert()` function. The variable type and the record type must be the same; otherwise, an error occurs.

F.54.3.3. Arrays

The following functions support array variables:

Function	Returns
`pgv_set(package text, name text, value anyarray, is_transactional bool default false)`	`void`
`pgv_get(package text, name text, var_type anyarray, strict bool default true)`	`anyarray`

Usage instructions for these functions are the same as those provided in Section F.54.3.1 for scalar variables.

F.54.3.4. General Collections

The following functions support general collection variables:

Function	Returns	Description

`pgv_set_elem(package text, name text, key int, value anyelement, is_transactional bool default false)`
 	
`pgv_set_elem(package text, name text, key text, value anyelement, is_transactional bool default false)`
	`void`	Sets a value for the element with the key `key` of the collection variable `name` in the package `package`. If the package or variable does not exist, it is created automatically. Inside one collection, only keys of the same type are allowed. The `key` argument can have either `int` or `text` type. If an element with the specified key already exists, its value is set to the new one. `is_transactional` shows whether the new variable is transactional and equals `false` by default. So if the variable already exists, it must be transactional/non-transactional as indicated by `is_transactional`, otherwise an error is raised. If the collection already exists and its value type does not match the type of the new value, an error is also raised.

`pgv_get_elem(package text, name text, key int, val_type anyelement)`
 	
`pgv_get_elem(package text, name text, key text, val_type anyelement)`
	`anyelement`	Returns the value of the element with the key `key` of the collection variable `name` in the package `package`. If there is no element with the specified key in this collection, returns NULL. The `key` argument can have either `int` or `text` type. If the package or variable does not exist, an error is raised. If the specified variable is not a collection, an error is also raised. The `val_type` argument is required to properly determine the return type.

`pgv_exists_elem(package text, name text, key int)`
 	
`pgv_exists_elem(package text, name text, key text)`
	`bool`	Returns `true` if an element with the key `key` exists in the collection variable `name` in the package `package` and `false` otherwise. If the package or variable does not exist, also returns `false`. The `key` argument can have either `int` or `text` type. If the specified variable is not a collection, an error is raised.

`pgv_remove_elem(package text, name text, key int)`	`void`	Removes the element with the key `key` from the collection variable `name` in the package `package`. If there is no element with

Function	Returns	Description
pgv_remove_elem(package text, name text, key text)		the specified key in this collection, does nothing. The key argument can have either int or text type. If the package or variable does not exist, an error is raised. If the specified variable is not a collection, an error is also raised.

Important

Collections initialized with pgv_set_elem() and with pgv_insert() are not considered compatible.

F.54.3.5. Iterators

The following functions are provided to use iterators to traverse collection variables. These functions work with collections initialized with both pgv_set_elem() and pgv_insert().

Function	Returns	Description
pgv_first(package text, name text, key_type anyelement)	anyelement	Returns the first key from the collection variable. Collections are sorted by the key in ascending order. key_type is required to determine the return value. If the name passed is the name of a non-collection variable, an error is raised.
pgv_last(package text, name text, key_type anyelement)	anyelement	Returns the last key from the collection variable. Collections are sorted by the key in ascending order. key_type is required to determine the return value. If the name passed is the name of a non-collection variable, an error is raised.
pgv_next(package text, name text, key anyelement)	anyelement	Returns the next key from the collection variable. The key passed may not exist in the collection. Returns NULL if used for the last key in the collection. Collections are sorted by the key in ascending order. If the name passed is the name of a non-collection variable, an error is raised.
pgv_prior(package text, name text, key anyelement)	anyelement	Returns the previous key from the collection variable. The key passed may not exist in the collection. Returns NULL if used for the first key in the collection. Collections are sorted by the key in ascending order. If the name passed is the name of a

Function	Returns	Description
		non-collection variable, an error is raised.
pgv_count(package text, name text)	integer	Returns the number of elements in the collection. If the name passed is the name of a non-collection variable, an error is raised.

F.54.3.6. Miscellaneous Functions

Function	Returns	Description
pgv_exists(package text, name text)	bool	Returns true if the specified package and variable exist and false otherwise.
pgv_exists(package text)	bool	Returns true if the specified package exists and false otherwise.
pgv_remove(package text, name text)	void	Removes the variable with the specified name. The specified package and variable must exist; otherwise, an error is raised.
pgv_remove(package text)	void	Removes the specified package and all the corresponding variables. The specified package must exist; otherwise, an error is raised.
pgv_free()	void	Removes all packages and variables.
pgv_list()	table(package text, name text, is_transactional bool)	Displays all the available variables and the corresponding packages, as well as whether each variable is transactional.
pgv_stats()	table(package text, allocated_memory bigint)	Returns the list of assigned packages and the amount of memory used by variables, in bytes. If you are using transactional variables, this list also includes all deleted packages that still may be restored by a ROLLBACK. This function only supports Postgres Pro 9.6 or higher.

F.54.3.7. Deprecated Functions

F.54.3.7.1. Integer Variables

The following functions are deprecated. Use generic functions for scalar variables instead.

Function	Returns
pgv_set_int(package text, name text, value int, is_transactional bool default false)	void

Function	Returns
pgv_get_int(package text, name text, strict bool default true)	int

F.54.3.7.2. Text Variables

The following functions are deprecated. Use generic functions for scalar variables instead.

Function	Returns
pgv_set_text(package text, name text, value text, is_transactional bool default false)	void
pgv_get_text(package text, name text, strict bool default true)	text

F.54.3.7.3. Numeric Variables

The following functions are deprecated. Use generic functions for scalar variables instead.

Function	Returns
pgv_set_numeric(package text, name text, value numeric, is_transactional bool default false)	void
pgv_get_numeric(package text, name text, strict bool default true)	numeric

F.54.3.7.4. Timestamp Variables

The following functions are deprecated. Use generic functions for scalar variables instead.

Function	Returns
pgv_set_timestamp(package text, name text, value timestamp, is_transactional bool default false)	void
pgv_get_timestamp(package text, name text, strict bool default true)	timestamp

F.54.3.7.5. Timestamp with timezone Variables

The following functions are deprecated. Use generic functions for scalar variables instead.

Function	Returns
pgv_set_timestamptz(package text, name text, value timestamptz, is_transactional bool default false)	void
pgv_get_timestamptz(package text, name text, strict bool default true)	timestamptz

F.54.3.7.6. Date Variables

The following functions are deprecated. Use generic functions for scalar variables instead.

Function	Returns
pgv_set_date(package text, name text, value date, is_transactional bool default false)	void

Function	Returns
pgv_get_date(package text, name text, strict bool default true)	date

F.54.3.7.7. Jsonb Variables

The following functions are deprecated. Use generic functions for scalar variables instead.

Function	Returns
pgv_set_jsonb(package text, name text, value jsonb, is_transactional bool default false)	void
pgv_get_jsonb(package text, name text, strict bool default true)	jsonb

F.54.4. Important Notes

F.54.4.1. Collations in Collections

Collections are stored in ascending order. In the case of `text` keys, you need a collation to determine the order of elements. If no collation is specified when inserting the first element of a collection, the default collation is used. Otherwise, the specified collation is used.

F.54.4.2. Cursors for Set-Returning Functions

All set-returning functions except `pgv_select(package, variable)` fix their return results at first `FETCH` from the cursor and are not affected by further data manipulation.

The results of `pgv_select(package, variable)` are received dynamically and are affected by transactions/changes in the collection. For `pgv_select()` called for a transactional collection, cursors look at the snapshot of the collection when the first `FETCH` was executed, but consider changes that were made in that transaction and in committed subtransactions.

F.54.5. Examples

Define scalar variables using the `pgv_set()` function, and then return their values using the `pgv_get()` function:

```
SELECT pgv_set('vars', 'int1', 101);
SELECT pgv_set('vars', 'int2', 102);
SELECT pgv_set('vars', 'text1', 'text variable'::text);

SELECT pgv_get('vars', 'int1', NULL::int);
 pgv_get
-------------
         101

SELECT pgv_get('vars', 'int2', NULL::int);
 pgv_get
-------------
         102

SELECT pgv_get('vars', 'text1', NULL::text);
 pgv_get
---------------
 text variable
```

Let's assume we have the `tab` table and examine several examples of using record variables:

```
CREATE TABLE tab (id int, t varchar);
INSERT INTO tab VALUES (0, 'str00'), (1, 'str11');
```

You can use the following functions to work with record variables:

```
SELECT pgv_insert('vars', 'r1', tab) FROM tab;

SELECT pgv_select('vars', 'r1');
 pgv_select
------------
 (1,str11)
 (0,str00)

SELECT pgv_select('vars', 'r1', 1);
 pgv_select
------------
 (1,str11)

SELECT pgv_select('vars', 'r1', 0);
 pgv_select
------------
 (0,str00)

SELECT pgv_select('vars', 'r1', ARRAY[1, 0]);
 pgv_select
------------
 (1,str11)
 (0,str00)

SELECT pgv_delete('vars', 'r1', 1);

SELECT pgv_select('vars', 'r1');
 pgv_select
------------
 (0,str00)
```

Consider the behavior of a transactional variable `var_text` when changed before and after savepoints:

```
SELECT pgv_set('pack', 'var_text', 'before transaction block'::text, true);
BEGIN;
SELECT pgv_set('pack', 'var_text', 'before savepoint'::text, true);
SAVEPOINT sp1;
SELECT pgv_set('pack', 'var_text', 'savepoint sp1'::text, true);
SAVEPOINT sp2;
SELECT pgv_set('pack', 'var_text', 'savepoint sp2'::text, true);
RELEASE sp2;
SELECT pgv_get('pack', 'var_text', NULL::text);
    pgv_get
---------------
 savepoint sp2

ROLLBACK TO sp1;
SELECT pgv_get('pack', 'var_text', NULL::text);
     pgv_get
------------------
 before savepoint

ROLLBACK;
SELECT pgv_get('pack', 'var_text', NULL::text);
```

```
         pgv_get
-------------------------
 before transaction block
```

If you create a variable after `BEGIN` or `SAVEPOINT` statements and than rollback to the previous state, the transactional variable is removed:

```
BEGIN;
SAVEPOINT sp1;
SAVEPOINT sp2;
SELECT pgv_set('pack', 'var_int', 122, true);
RELEASE SAVEPOINT sp2;
SELECT pgv_get('pack', 'var_int', NULL::int);
pgv_get
---------
     122

ROLLBACK TO sp1;
SELECT pgv_get('pack','var_int', NULL::int);
ERROR:  unrecognized variable "var_int"
COMMIT;
```

List the available packages and variables:

```
SELECT * FROM pgv_list() ORDER BY package, name;
 package |   name   | is_transactional
---------+----------+------------------
 pack    | var_text | t
 vars    | int1     | f
 vars    | int2     | f
 vars    | r1       | f
 vars    | text1    | f
```

Get the amount of memory used by variables, in bytes:

```
SELECT * FROM pgv_stats() ORDER BY package;
 package | allocated_memory
---------+------------------
 pack    |            16384
 vars    |            32768
```

Delete the specified variables or packages:

```
SELECT pgv_remove('vars', 'int1');
SELECT pgv_remove('vars');
```

Delete all packages and variables:

```
SELECT pgv_free();
```

These examples show usage of collection variables and iterator functions:

```
sql
SELECT pgv_set_elem('pack', 'var', 1, 1);
SELECT pgv_set_elem('pack', 'var', 5, 5);
SELECT pgv_set_elem('pack', 'var', 10, 10);

SELECT pgv_first('pack', 'var', NULL::int);
 pgv_first
-----------
         1
```

```
SELECT pgv_last('pack', 'var', NULL::int);
 pgv_last
----------
       10

SELECT pgv_next('pack', 'var', pgv_first('pack', 'var', NULL::int));
 pgv_next
----------
        5

SELECT pgv_prior('pack', 'var', pgv_last('pack', 'var', NULL::int));
 pgv_prior
-----------
         5

SELECT pgv_prior('pack', 'var', pgv_first('pack', 'var', NULL::int));
 pgv_prior
-----------

SELECT pgv_next('pack', 'var', pgv_last('pack', 'var', NULL::int));
 pgv_prior
-----------

SELECT pgv_next('pack', 'var', 3);
 pgv_next
----------
        5

SELECT pgv_prior('pack', 'var', 3);
 pgv_prior
-----------
         1

SELECT pgv_get_elem('pack', 'var', pgv_last('pack', 'var', NULL::int), NULL::int);
 pgv_get_elem
--------------
           10

SELECT pgv_remove_elem('pack', 'var', pgv_last('pack', 'var', NULL::int));
 pgv_remove_elem
-----------------


SELECT pgv_get_elem('pack', 'var', pgv_last('pack', 'var', NULL::int), NULL::int);
 pgv_get_elem
--------------
           5
(1 row)
```

These examples show how the collation affects the order of elements in a collection. They also show how to iterate over a whole collection with PL/pgSQL loops:

```
sql
SELECT pgv_set_elem('pack', 'var1', 'a' COLLATE "ru_RU", 'a'::text);
SELECT pgv_set_elem('pack', 'var1', 'д' COLLATE "ru_RU", 'д'::text);
SELECT pgv_set_elem('pack', 'var1', 'e' COLLATE "ru_RU", 'e'::text);
SELECT pgv_set_elem('pack', 'var1', 'ё' COLLATE "ru_RU", 'ё'::text);
SELECT pgv_set_elem('pack', 'var1', 'ж' COLLATE "ru_RU", 'ж'::text);
SELECT pgv_set_elem('pack', 'var1', 'я' COLLATE "ru_RU", 'я'::text);
```

```
DO
$$
DECLARE
        iter text;
BEGIN
        iter := pgv_first('pack', 'var1', NULL::text);
        WHILE iter IS NOT NULL LOOP
          RAISE NOTICE '%', pgv_get_elem('pack', 'var1', iter, NULL::text);
          iter := pgv_next('pack', 'var1', iter);
        END LOOP;
END;
$$;
NOTICE:  a
NOTICE:  д
NOTICE:  e
NOTICE:  ё
NOTICE:  ж
NOTICE:  я

SELECT pgv_set_elem('pack', 'var2', 'a' COLLATE "C", 'a'::text);
SELECT pgv_set_elem('pack', 'var2', 'д' COLLATE "C", 'д'::text);
SELECT pgv_set_elem('pack', 'var2', 'e' COLLATE "C", 'e'::text);
SELECT pgv_set_elem('pack', 'var2', 'ё' COLLATE "C", 'ё'::text);
SELECT pgv_set_elem('pack', 'var2', 'ж' COLLATE "C", 'ж'::text);
SELECT pgv_set_elem('pack', 'var2', 'я' COLLATE "C", 'я'::text);
DO
$$
DECLARE
        iter text;
BEGIN
        iter := pgv_first('pack', 'var2', NULL::text);
        WHILE iter IS NOT NULL LOOP
          RAISE NOTICE '%', pgv_get_elem('pack', 'var2', iter, NULL::text);
          iter := pgv_next('pack', 'var2', iter);
        END LOOP;
END;
$$;
NOTICE:  a
NOTICE:  д
NOTICE:  e
NOTICE:  ж
NOTICE:  я
NOTICE:  ё
```

F.54.6. Authors

Postgres Professional, Moscow, Russia

F.55. pg_visibility

The `pg_visibility` module provides a means for examining the visibility map (VM) and page-level visibility information of a table. It also provides functions to check the integrity of a visibility map and to force it to be rebuilt.

Three different bits are used to store information about page-level visibility. The all-visible bit in the visibility map indicates that every tuple in the corresponding page of the relation is visible to every current and future transaction. The all-frozen bit in the visibility map indicates that every tuple in the page is frozen; that is, no future vacuum will need to modify the page until such time as a tuple is inserted, updated, deleted, or locked on that page. The page header's `PD_ALL_VISIBLE` bit has the same

meaning as the all-visible bit in the visibility map, but is stored within the data page itself rather than in a separate data structure. These two bits will normally agree, but the page's all-visible bit can sometimes be set while the visibility map bit is clear after a crash recovery. The reported values can also disagree because of a change that occurs after `pg_visibility` examines the visibility map and before it examines the data page. Any event that causes data corruption can also cause these bits to disagree.

Functions that display information about `PD_ALL_VISIBLE` bits are much more costly than those that only consult the visibility map, because they must read the relation's data blocks rather than only the (much smaller) visibility map. Functions that check the relation's data blocks are similarly expensive.

F.55.1. Functions

`pg_visibility_map(relation regclass, blkno bigint, all_visible OUT boolean, all_frozen OUT boolean) returns record`

Returns the all-visible and all-frozen bits in the visibility map for the given block of the given relation.

`pg_visibility(relation regclass, blkno bigint, all_visible OUT boolean, all_frozen OUT boolean, pd_all_visible OUT boolean) returns record`

Returns the all-visible and all-frozen bits in the visibility map for the given block of the given relation, plus the `PD_ALL_VISIBLE` bit of that block.

`pg_visibility_map(relation regclass, blkno OUT bigint, all_visible OUT boolean, all_frozen OUT boolean) returns setof record`

Returns the all-visible and all-frozen bits in the visibility map for each block of the given relation.

`pg_visibility(relation regclass, blkno OUT bigint, all_visible OUT boolean, all_frozen OUT boolean, pd_all_visible OUT boolean) returns setof record`

Returns the all-visible and all-frozen bits in the visibility map for each block of the given relation, plus the `PD_ALL_VISIBLE` bit of each block.

`pg_visibility_map_summary(relation regclass, all_visible OUT bigint, all_frozen OUT bigint) returns record`

Returns the number of all-visible pages and the number of all-frozen pages in the relation according to the visibility map.

`pg_check_frozen(relation regclass, t_ctid OUT tid) returns setof tid`

Returns the TIDs of non-frozen tuples stored in pages marked all-frozen in the visibility map. If this function returns a non-empty set of TIDs, the visibility map is corrupt.

`pg_check_visible(relation regclass, t_ctid OUT tid) returns setof tid`

Returns the TIDs of non-all-visible tuples stored in pages marked all-visible in the visibility map. If this function returns a non-empty set of TIDs, the visibility map is corrupt.

`pg_truncate_visibility_map(relation regclass) returns void`

Truncates the visibility map for the given relation. This function is useful if you believe that the visibility map for the relation is corrupt and wish to force rebuilding it. The first `VACUUM` executed on the given relation after this function is executed will scan every page in the relation and rebuild the visibility map. (Until that is done, queries will treat the visibility map as containing all zeroes.)

By default, these functions are executable only by superusers and members of the `pg_stat_scan_tables` role, with the exception of `pg_truncate_visibility_map(relation regclass)` which can only be executed by superusers.

F.55.2. Author

Robert Haas `<rhaas@postgresql.org>`

F.56. pg_wait_sampling

pg_wait_sampling is a Postgres Pro extension for collecting sampling-based statistics on wait events.

Starting from the 9.6 version, Postgres Pro Enterprise provides information about the current wait events for particular processes. However, to get descriptive statistics of the server activity, you have to sample wait events multiple times. The pg_wait_sampling extension automates wait events sampling by launching a special background worker. With pg_wait_sampling enabled, you can get the following sampling-based data:

- *Waits history* — the list of wait events for recent processes, with timestamps.
- *Waits profile* — the number of wait event samples for all processes over time (per wait event type).
- Current wait events for all processes, including background workers.

Using pg_wait_sampling, you can troubleshoot dependencies for queries that process longer than expected. You can see what a particular process is waiting for at each moment of time, and analyze wait events statistics. For the list of possible wait events, see Table 27.4.

In combination with pg_stat_statements, this extension can also provide per query statistics.

See Also

Viewing Statistics on Wait Events

Reference

F.56.1. Installation

The pg_wait_sampling extension is included into Postgres Pro Enterprise and requires no special prerequisites.

To enable pg_wait_sampling, do the following:

1. Add pg_wait_sampling to the shared_preload_libraries variable in the postgresql.conf file:

   ```
   shared_preload_libraries = 'pg_wait_sampling'
   ```

   Important

   When using the pg_wait_sampling with the pg_stat_statements extension, place pg_stat_statements before pg_wait_sampling in the shared_preload_libraries variable. This ensures that the pg_stat_statements extension does not overwrite query IDs that are used by pg_wait_sampling.

2. Create the pg_wait_sampling extension using the following query:

   ```
   CREATE EXTENSION pg_wait_sampling;
   ```

3. Restart the server. Since pg_wait_sampling requires additional shared memory and launches a background worker, you must restart the server after adding or removing pg_wait_sampling.

Once the extension is created, pg_wait_sampling starts collecting statistics on wait events for each process. Optionally, you can change the sampling frequency and configure statistics collection modes using GUC variables.

If you want to stop collecting statistics, drop the pg_wait_sampling extension, remove the pg_wait_sampling from the shared_preload_libraries variable, and restart the server again.

F.56.2. Usage

F.56.2.1. Viewing Statistics on Wait Events

When pg_wait_sampling is enabled, wait events are sampled each 10ms by default. You can access the collected statistics through a set of functions and views. If some of your queries appear stalled or take longer than expected, you can review all the current wait events in the pg_wait_sampling_current view:

```
SELECT * FROM pg_wait_sampling_current;
```

The returned statistics covers all the active processes, including background workers. To filter the view for a single process, run pg_wait_sampling_get_current() function specifying the process ID:

```
SELECT * FROM pg_wait_sampling_get_current(pid);
```

To better understand the dynamics of the recent wait events, you can access the pg_wait_sampling_history view that provides the wait events history for the latest processes:

```
SELECT * FROM pg_wait_sampling_history;
```

The returned view displays wait samples per process, with event timestamps. Waits history is implemented as an in-memory ring buffer. By default, the history size is limited to 5000 samples. To save history for a longer period of time, you can modify the pg_wait_sampling.history_size variable, or connect a client application to periodically read waits history and dump it to a local storage.

To monitor wait events in your database over time, use the pg_wait_sampling_profile view:

```
SELECT * FROM pg_wait_sampling_profile;
```

Waits profile is stored as an in-memory hash table that accumulates samples per each process and each wait event. You can reset waits profile by calling the pg_wait_sampling_reset_profile() function. If you connect a client to your database that periodically dumps the wait events data and resets the profile, you can save and compare statistics of wait events intensity over time.

> **Important**
>
> Since wait sampling statistics is stored in RAM, make sure to reset the waits profile from time to time to avoid memory overflow.

If you are not interested in the distribution of wait events between processes, you can set the pg_wait_sampling.profile_pid variable to false. In this case, the pid value for each process is set to zero, and wait samples for all the processes are stored together.

F.56.3. Reference

F.56.3.1. GUC Variables

The pg_wait_sampling extension is configured with GUC variables. They are stored in the local memory and can be changed in the postgresql.conf file or using the ALTER SYSTEM command. For the changes to take effect, reload the server configuration. You can do it, for example, by calling the pg_reload_conf() function or executing the pg_ctl reload command.

pg_wait_sampling.history_size (int4)

Size of in-memory ring buffer for history sampling, in the number of samples.

Default: 5000

pg_wait_sampling.history_period (int4)

Time interval for history sampling, in milliseconds.

Default: 10

`pg_wait_sampling.profile_period` (`int4`)

Time interval for waits profile sampling, in milliseconds.

Default: 10

`pg_wait_sampling.profile_pid` (`bool`)

Sampling mode for waits profile. If set to `true`, waits profile is collected per process. If you set `pg_wait_sampling.profile_pid` to `false`, waits profile is collected for all processes together. In this case, the `pid` value for each process is set to zero, and the corresponding row contains wait samples for all the processes.

Default: `true`

`pg_wait_sampling.profile_queries` (`enum`)

Sampling mode for the waits profile. If `pg_wait_sampling.profile_queries` is set to `none`, the `queryid` field in views will be zero. If it is set to `top`, query IDs of only the top level statements are recorded. If it is set to `all`, query IDs of nested statements are recorded. To collect the waits profile per query, ensure that the pg_stat_statements extension is configured and set `pg_wait_sampling.profile_queries` to `top`. For version 14 or higher, you can compute query IDs by configuring the `compute_query_id` parameter and set the `pg_wait_sampling.profile_queries` value to `top` or `all`. For details, see Section 19.9.2.

Default: `top`

`pg_wait_sampling.sample_cpu` (`bool`)

The sampling mode that determines whether to perform sampling of on-CPU backends. If `pg_wait_sampling.sample_cpu` is set to `true`, then sampling also includes processes that are not waiting for anything. The wait event columns for such processes will have a `NULL` value.

Default: `true`

F.56.3.2. pg_wait_sampling Views

F.56.3.2.1. pg_wait_sampling_current View

The `pg_wait_sampling_current` view provides the information about the current wait events for all processes, including background workers.

Table F.44. pg_wait_sampling_current View

Column Name	Column Type	Description
`pid`	`int4`	Process ID
`event_type`	`text`	Name of wait event type
`event`	`text`	Name of wait event
`queryid`	`int8`	Query ID

F.56.3.2.2. pg_wait_sampling_history View

The `pg_wait_sampling_history` view provides the history of wait events. This data is stored as an in-memory ring buffer.

Table F.45. pg_wait_sampling_history View

Column Name	Column Type	Description
`pid`	`int4`	Process ID
`ts`	`timestamptz`	Sample timestamp

Column Name	Column Type	Description
event_type	text	Name of wait event type
event	text	Name of wait event
queryid	int8	Query ID

F.56.3.2.3. pg_wait_sampling_profile View

The pg_wait_sampling_profile view provides the profile of wait events. This data is stored as an in-memory hash table.

Table F.46. pg_wait_sampling_profile View

Column Name	Column Type	Description
pid	int4	Process ID
event_type	text	Name of wait event type
event	text	Name of wait event
queryid	int8	Query ID
count	int8	Number of samples

F.56.3.3. Functions

pg_wait_sampling_get_current(*pid* int4)

Returns the pg_wait_sampling_current view with the list of current wait events. If you set the *pid* argument, the view is filtered for the process with this *pid*.

Arguments:

- *pid* — Optional. The process ID for which to display the current wait events.

pg_wait_sampling_reset_profile()

Resets the waits profile and clears the memory.

F.56.4. Authors

- Alexander Korotkov
- Ildus Kurbangaliev <i.kurbangaliev@gmail.com>

F.57. plantuner

The plantuner module provides hints for the planner that can disable or enable indexes for query execution.

F.57.1. Motivation

In some cases, it may be required to control the planner by providing hints that make the optimizer ignore some parts of its algorithm. There are many situations when a developer may want to temporarily disable specific index(es), without dropping them, or to instruct the planner to use a specific index.

This version of plantuner provides a possibility to hide the specified indexes from Postgres Pro planner, so it will not use them. For some workloads, Postgres Pro could be too pessimistic about newly created tables and assume that there are much more rows in a table than it actually has. If the plantuner.fix_empty_table GUC variable is set to true, plantuner sets to zero the number of pages/tuples of the table that has no blocks in a file.

F.57.2. GUC Variables

plantuner.disable_index — list of indexes invisible to planner.

`plantuner.enable_index` — list of indexes visible to planner even if they are hidden by `plantuner.disable_index`.

F.57.3. Example

To enable the module, you can either load `plantuner` shared library in a `psql` session or specify `shared_preload_libraries` option in `postgresql.conf`.

```
=# LOAD 'plantuner';
=# create table test(id int);
=# create index id_idx on test(id);
=# create index id_idx2 on test(id);
=# \d test
     Table "public.test"
 Column |  Type   | Modifiers
--------+---------+-----------
 id     | integer |
Indexes:
    "id_idx" btree (id)
    "id_idx2" btree (id)
=# explain select id from test where id=1;
                              QUERY PLAN
-----------------------------------------------------------------------
 Bitmap Heap Scan on test  (cost=4.34..15.03 rows=12 width=4)
   Recheck Cond: (id = 1)
   ->  Bitmap Index Scan on id_idx2  (cost=0.00..4.34 rows=12 width=0)
         Index Cond: (id = 1)
(4 rows)
=# set enable_seqscan=off;
=# set plantuner.disable_index='id_idx2';
=# explain select id from test where id=1;
                              QUERY PLAN
-----------------------------------------------------------------------
 Bitmap Heap Scan on test  (cost=4.34..15.03 rows=12 width=4)
   Recheck Cond: (id = 1)
   ->  Bitmap Index Scan on id_idx  (cost=0.00..4.34 rows=12 width=0)
         Index Cond: (id = 1)
(4 rows)
=# set plantuner.disable_index='id_idx2,id_idx';
=# explain select id from test where id=1;
                               QUERY PLAN
-------------------------------------------------------------------------
 Seq Scan on test  (cost=10000000000.00..10000000040.00 rows=12 width=4)
   Filter: (id = 1)
(2 rows)
=# set plantuner.enable_index='id_idx';
=# explain select id from test where id=1;
                              QUERY PLAN
-----------------------------------------------------------------------
 Bitmap Heap Scan on test  (cost=4.34..15.03 rows=12 width=4)
   Recheck Cond: (id = 1)
   ->  Bitmap Index Scan on id_idx  (cost=0.00..4.34 rows=12 width=0)
         Index Cond: (id = 1)
(4 rows)
```

F.57.4. Authors

All work was done by Teodor Sigaev (teodor@sigaev.ru) and Oleg Bartunov (oleg@sai.msu.su).

The work sponsored by Nomao project (http://www.nomao.com).

F.58. postgres_fdw

The postgres_fdw module provides the foreign-data wrapper postgres_fdw, which can be used to access data stored in external Postgres Pro servers.

The functionality provided by this module overlaps substantially with the functionality of the older dblink module. But postgres_fdw provides more transparent and standards-compliant syntax for accessing remote tables, and can give better performance in many cases.

To prepare for remote access using postgres_fdw:

1. Install the postgres_fdw extension using CREATE EXTENSION.
2. Create a foreign server object, using CREATE SERVER, to represent each remote database you want to connect to. Specify connection information, except user and password, as options of the server object.
3. Create a user mapping, using CREATE USER MAPPING, for each database user you want to allow to access each foreign server. Specify the remote user name and password to use as user and password options of the user mapping.
4. Create a foreign table, using CREATE FOREIGN TABLE or IMPORT FOREIGN SCHEMA, for each remote table you want to access. The columns of the foreign table must match the referenced remote table. You can, however, use table and/or column names different from the remote table's, if you specify the correct remote names as options of the foreign table object.

Now you need only SELECT from a foreign table to access the data stored in its underlying remote table. You can also modify the remote table using INSERT, UPDATE, DELETE, COPY, or TRUNCATE. (Of course, the remote user you have specified in your user mapping must have privileges to do these things.)

Note that the ONLY option specified in SELECT, UPDATE, DELETE or TRUNCATE has no effect when accessing or modifying the remote table.

Note that postgres_fdw currently lacks support for INSERT statements with an ON CONFLICT DO UPDATE clause. However, the ON CONFLICT DO NOTHING clause is supported, provided a unique index inference specification is omitted. Note also that postgres_fdw supports row movement invoked by UPDATE statements executed on partitioned tables, but it currently does not handle the case where a remote partition chosen to insert a moved row into is also an UPDATE target partition that will be updated elsewhere in the same command.

It is generally recommended that the columns of a foreign table be declared with exactly the same data types, and collations if applicable, as the referenced columns of the remote table. Although postgres_fdw is currently rather forgiving about performing data type conversions at need, surprising semantic anomalies may arise when types or collations do not match, due to the remote server interpreting query conditions differently from the local server.

Note that a foreign table can be declared with fewer columns, or with a different column order, than its underlying remote table has. Matching of columns to the remote table is by name, not position.

F.58.1. FDW Options of postgres_fdw

F.58.1.1. Connection Options

A foreign server using the postgres_fdw foreign data wrapper can have the same options that libpq accepts in connection strings, as described in Section 36.1.2, except that these options are not allowed or have special handling:

- user, password and sslpassword (specify these in a user mapping, instead, or use a service file)
- client_encoding (this is automatically set from the local server encoding)
- fallback_application_name (always set to postgres_fdw)

- `sslkey` and `sslcert` - these may appear in *either or both* a connection and a user mapping. If both are present, the user mapping setting overrides the connection setting.

Only superusers may create or modify user mappings with the `sslcert` or `sslkey` settings.

Only superusers may connect to foreign servers without password authentication, so always specify the `password` option for user mappings belonging to non-superusers.

A superuser may override this check on a per-user-mapping basis by setting the user mapping option `password_required 'false'`, e.g.,

```
ALTER USER MAPPING FOR some_non_superuser SERVER loopback_nopw
OPTIONS (ADD password_required 'false');
```

To prevent unprivileged users from exploiting the authentication rights of the unix user the postgres server is running as to escalate to superuser rights, only the superuser may set this option on a user mapping.

Care is required to ensure that this does not allow the mapped user the ability to connect as superuser to the mapped database per CVE-2007-3278 and CVE-2007-6601. Don't set `password_required=false` on the `public` role. Keep in mind that the mapped user can potentially use any client certificates, `.pgpass`, `.pg_service.conf` etc in the unix home directory of the system user the postgres server runs as. They can also use any trust relationship granted by authentication modes like `peer` or `ident` authentication.

F.58.1.2. Object Name Options

These options can be used to control the names used in SQL statements sent to the remote Postgres Pro server. These options are needed when a foreign table is created with names different from the underlying remote table's names.

`schema_name`

This option, which can be specified for a foreign table, gives the schema name to use for the foreign table on the remote server. If this option is omitted, the name of the foreign table's schema is used.

`table_name`

This option, which can be specified for a foreign table, gives the table name to use for the foreign table on the remote server. If this option is omitted, the foreign table's name is used.

`column_name`

This option, which can be specified for a column of a foreign table, gives the column name to use for the column on the remote server. If this option is omitted, the column's name is used.

F.58.1.3. Cost Estimation Options

`postgres_fdw` retrieves remote data by executing queries against remote servers, so ideally the estimated cost of scanning a foreign table should be whatever it costs to be done on the remote server, plus some overhead for communication. The most reliable way to get such an estimate is to ask the remote server and then add something for overhead — but for simple queries, it may not be worth the cost of an additional remote query to get a cost estimate. So `postgres_fdw` provides the following options to control how cost estimation is done:

`use_remote_estimate`

This option, which can be specified for a foreign table or a foreign server, controls whether `postgres_fdw` issues remote `EXPLAIN` commands to obtain cost estimates. A setting for a foreign table overrides any setting for its server, but only for that table. The default is `false`.

`fdw_startup_cost`

This option, which can be specified for a foreign server, is a floating point value that is added to the estimated startup cost of any foreign-table scan on that server. This represents the additional

overhead of establishing a connection, parsing and planning the query on the remote side, etc. The default value is 100.

fdw_tuple_cost

This option, which can be specified for a foreign server, is a floating point value that is used as extra cost per-tuple for foreign-table scans on that server. This represents the additional overhead of data transfer between servers. You might increase or decrease this number to reflect higher or lower network delay to the remote server. The default value is 0.01.

When use_remote_estimate is true, postgres_fdw obtains row count and cost estimates from the remote server and then adds fdw_startup_cost and fdw_tuple_cost to the cost estimates. When use_remote_estimate is false, postgres_fdw performs local row count and cost estimation and then adds fdw_startup_cost and fdw_tuple_cost to the cost estimates. This local estimation is unlikely to be very accurate unless local copies of the remote table's statistics are available. Running ANALYZE on the foreign table is the way to update the local statistics; this will perform a scan of the remote table and then calculate and store statistics just as though the table were local. Keeping local statistics can be a useful way to reduce per-query planning overhead for a remote table — but if the remote table is frequently updated, the local statistics will soon be obsolete.

F.58.1.4. Remote Execution Options

By default, only WHERE clauses using built-in operators and functions will be considered for execution on the remote server. Clauses involving non-built-in functions are checked locally after rows are fetched. If such functions are available on the remote server and can be relied on to produce the same results as they do locally, performance can be improved by sending such WHERE clauses for remote execution. This behavior can be controlled using the following option:

extensions

This option is a comma-separated list of names of Postgres Pro extensions that are installed, in compatible versions, on both the local and remote servers. Functions and operators that are immutable and belong to a listed extension will be considered shippable to the remote server. This option can only be specified for foreign servers, not per-table.

When using the extensions option, *it is the user's responsibility* that the listed extensions exist and behave identically on both the local and remote servers. Otherwise, remote queries may fail or behave unexpectedly.

fetch_size

This option specifies the number of rows postgres_fdw should get in each fetch operation. It can be specified for a foreign table or a foreign server. The option specified on a table overrides an option specified for the server. The default is 100.

batch_size

This option specifies the number of rows postgres_fdw should insert in each insert operation. It can be specified for a foreign table or a foreign server. The option specified on a table overrides an option specified for the server. The default is 1.

Note the actual number of rows postgres_fdw inserts at once depends on the number of columns and the provided batch_size value. The batch is executed as a single query, and the libpq protocol (which postgres_fdw uses to connect to a remote server) limits the number of parameters in a single query to 65535. When the number of columns * batch_size exceeds the limit, the batch_size will be adjusted to avoid an error.

F.58.1.5. Asynchronous Execution Options

postgres_fdw supports asynchronous execution, which runs multiple parts of an Append node concurrently rather than serially to improve performance. This execution can be controlled using the following option:

async_capable

This option controls whether postgres_fdw allows foreign tables to be scanned concurrently for asynchronous execution. It can be specified for a foreign table or a foreign server. A table-level option overrides a server-level option. The default is false.

In order to ensure that the data being returned from a foreign server is consistent, postgres_fdw will only open one connection for a given foreign server and will run all queries against that server sequentially even if there are multiple foreign tables involved, unless those tables are subject to different user mappings. In such a case, it may be more performant to disable this option to eliminate the overhead associated with running queries asynchronously.

Asynchronous execution is applied even when an Append node contains subplan(s) executed synchronously as well as subplan(s) executed asynchronously. In such a case, if the asynchronous subplans are ones processed using postgres_fdw, tuples from the asynchronous subplans are not returned until after at least one synchronous subplan returns all tuples, as that subplan is executed while the asynchronous subplans are waiting for the results of asynchronous queries sent to foreign servers. This behavior might change in a future release.

F.58.1.6. Updatability Options

By default all foreign tables using postgres_fdw are assumed to be updatable. This may be overridden using the following option:

updatable

This option controls whether postgres_fdw allows foreign tables to be modified using INSERT, UPDATE and DELETE commands. It can be specified for a foreign table or a foreign server. A table-level option overrides a server-level option. The default is true.

Of course, if the remote table is not in fact updatable, an error would occur anyway. Use of this option primarily allows the error to be thrown locally without querying the remote server. Note however that the information_schema views will report a postgres_fdw foreign table to be updatable (or not) according to the setting of this option, without any check of the remote server.

F.58.1.7. Truncatability Options

By default all foreign tables using postgres_fdw are assumed to be truncatable. This may be overridden using the following option:

truncatable

This option controls whether postgres_fdw allows foreign tables to be truncated using the TRUNCATE command. It can be specified for a foreign table or a foreign server. A table-level option overrides a server-level option. The default is true.

Of course, if the remote table is not in fact truncatable, an error would occur anyway. Use of this option primarily allows the error to be thrown locally without querying the remote server.

F.58.1.8. Importing Options

postgres_fdw is able to import foreign table definitions using IMPORT FOREIGN SCHEMA. This command creates foreign table definitions on the local server that match tables or views present on the remote server. If the remote tables to be imported have columns of user-defined data types, the local server must have compatible types of the same names.

Importing behavior can be customized with the following options (given in the IMPORT FOREIGN SCHEMA command):

import_collate

This option controls whether column COLLATE options are included in the definitions of foreign tables imported from a foreign server. The default is true. You might need to turn this off if the remote

server has a different set of collation names than the local server does, which is likely to be the case if it's running on a different operating system. If you do so, however, there is a very severe risk that the imported table columns' collations will not match the underlying data, resulting in anomalous query behavior.

Even when this parameter is set to `true`, importing columns whose collation is the remote server's default can be risky. They will be imported with `COLLATE "default"`, which will select the local server's default collation, which could be different.

`import_default`

This option controls whether column `DEFAULT` expressions are included in the definitions of foreign tables imported from a foreign server. The default is `false`. If you enable this option, be wary of defaults that might get computed differently on the local server than they would be on the remote server; `nextval()` is a common source of problems. The `IMPORT` will fail altogether if an imported default expression uses a function or operator that does not exist locally.

`import_generated`

This option controls whether column `GENERATED` expressions are included in the definitions of foreign tables imported from a foreign server. The default is `true`. The `IMPORT` will fail altogether if an imported generated expression uses a function or operator that does not exist locally.

`import_not_null`

This option controls whether column `NOT NULL` constraints are included in the definitions of foreign tables imported from a foreign server. The default is `true`.

Note that constraints other than `NOT NULL` will never be imported from the remote tables. Although Postgres Pro does support check constraints on foreign tables, there is no provision for importing them automatically, because of the risk that a constraint expression could evaluate differently on the local and remote servers. Any such inconsistency in the behavior of a check constraint could lead to hard-to-detect errors in query optimization. So if you wish to import check constraints, you must do so manually, and you should verify the semantics of each one carefully. For more detail about the treatment of check constraints on foreign tables, see CREATE FOREIGN TABLE.

Tables or foreign tables which are partitions of some other table are imported only when they are explicitly specified in `LIMIT TO` clause. Otherwise they are automatically excluded from IMPORT FOREIGN SCHEMA. Since all data can be accessed through the partitioned table which is the root of the partitioning hierarchy, importing only partitioned tables should allow access to all the data without creating extra objects.

F.58.1.9. Connection Management Options

By default, all connections that `postgres_fdw` establishes to foreign servers are kept open in the local session for re-use.

`keep_connections`

This option controls whether `postgres_fdw` keeps the connections to the foreign server open so that subsequent queries can re-use them. It can only be specified for a foreign server. The default is `on`. If set to `off`, all connections to this foreign server will be discarded at the end of each transaction.

F.58.2. Functions

`postgres_fdw_get_connections(OUT server_name text, OUT valid boolean) returns setof record`

This function returns the foreign server names of all the open connections that `postgres_fdw` established from the local session to the foreign servers. It also returns whether each connection is valid or not. `false` is returned if the foreign server connection is used in the current local transaction

but its foreign server or user mapping is changed or dropped (Note that server name of an invalid connection will be NULL if the server is dropped), and then such invalid connection will be closed at the end of that transaction. true is returned otherwise. If there are no open connections, no record is returned. Example usage of the function:

```
postgres=# SELECT * FROM postgres_fdw_get_connections() ORDER BY 1;
 server_name | valid
-------------+-------
 loopback1   | t
 loopback2   | f
```

postgres_fdw_disconnect(server_name text) returns boolean

This function discards the open connections that are established by postgres_fdw from the local session to the foreign server with the given name. Note that there can be multiple connections to the given server using different user mappings. If the connections are used in the current local transaction, they are not disconnected and warning messages are reported. This function returns true if it disconnects at least one connection, otherwise false. If no foreign server with the given name is found, an error is reported. Example usage of the function:

```
postgres=# SELECT postgres_fdw_disconnect('loopback1');
 postgres_fdw_disconnect
-------------------------
 t
```

postgres_fdw_disconnect_all() returns boolean

This function discards all the open connections that are established by postgres_fdw from the local session to foreign servers. If the connections are used in the current local transaction, they are not disconnected and warning messages are reported. This function returns true if it disconnects at least one connection, otherwise false. Example usage of the function:

```
postgres=# SELECT postgres_fdw_disconnect_all();
 postgres_fdw_disconnect_all
-----------------------------
 t
```

F.58.3. Connection Management

postgres_fdw establishes a connection to a foreign server during the first query that uses a foreign table associated with the foreign server. By default this connection is kept and re-used for subsequent queries in the same session. This behavior can be controlled using keep_connections option for a foreign server. If multiple user identities (user mappings) are used to access the foreign server, a connection is established for each user mapping.

When changing the definition of or removing a foreign server or a user mapping, the associated connections are closed. But note that if any connections are in use in the current local transaction, they are kept until the end of the transaction. Closed connections will be re-established when they are necessary by future queries using a foreign table.

Once a connection to a foreign server has been established, it's by default kept until the local or corresponding remote session exits. To disconnect a connection explicitly, keep_connections option for a foreign server may be disabled, or postgres_fdw_disconnect and postgres_fdw_disconnect_all functions may be used. For example, these are useful to close connections that are no longer necessary, thereby releasing connections on the foreign server.

F.58.4. Transaction Management

During a query that references any remote tables on a foreign server, postgres_fdw opens a transaction on the remote server if one is not already open corresponding to the current local transaction. The

remote transaction is committed or aborted when the local transaction commits or aborts. Savepoints are similarly managed by creating corresponding remote savepoints.

The remote transaction uses SERIALIZABLE isolation level when the local transaction has SERIALIZABLE isolation level; otherwise it uses REPEATABLE READ isolation level. This choice ensures that if a query performs multiple table scans on the remote server, it will get snapshot-consistent results for all the scans. A consequence is that successive queries within a single transaction will see the same data from the remote server, even if concurrent updates are occurring on the remote server due to other activities. That behavior would be expected anyway if the local transaction uses SERIALIZABLE or REPEATABLE READ isolation level, but it might be surprising for a READ COMMITTED local transaction. A future Postgres Pro release might modify these rules.

Note that it is currently not supported by postgres_fdw to prepare the remote transaction for two-phase commit.

F.58.5. Remote Query Optimization

postgres_fdw attempts to optimize remote queries to reduce the amount of data transferred from foreign servers. This is done by sending query WHERE clauses to the remote server for execution, and by not retrieving table columns that are not needed for the current query. To reduce the risk of misexecution of queries, WHERE clauses are not sent to the remote server unless they use only data types, operators, and functions that are built-in or belong to an extension that's listed in the foreign server's extensions option. Operators and functions in such clauses must be IMMUTABLE as well. For an UPDATE or DELETE query, postgres_fdw attempts to optimize the query execution by sending the whole query to the remote server if there are no query WHERE clauses that cannot be sent to the remote server, no local joins for the query, no row-level local BEFORE or AFTER triggers or stored generated columns on the target table, and no CHECK OPTION constraints from parent views. In UPDATE, expressions to assign to target columns must use only built-in data types, IMMUTABLE operators, or IMMUTABLE functions, to reduce the risk of misexecution of the query.

When postgres_fdw encounters a join between foreign tables on the same foreign server, it sends the entire join to the foreign server, unless for some reason it believes that it will be more efficient to fetch rows from each table individually, or unless the table references involved are subject to different user mappings. While sending the JOIN clauses, it takes the same precautions as mentioned above for the WHERE clauses.

The query that is actually sent to the remote server for execution can be examined using EXPLAIN VERBOSE.

F.58.6. Remote Query Execution Environment

In the remote sessions opened by postgres_fdw, the search_path parameter is set to just pg_catalog, so that only built-in objects are visible without schema qualification. This is not an issue for queries generated by postgres_fdw itself, because it always supplies such qualification. However, this can pose a hazard for functions that are executed on the remote server via triggers or rules on remote tables. For example, if a remote table is actually a view, any functions used in that view will be executed with the restricted search path. It is recommended to schema-qualify all names in such functions, or else attach SET search_path options (see CREATE FUNCTION) to such functions to establish their expected search path environment.

postgres_fdw likewise establishes remote session settings for various parameters:

- TimeZone is set to UTC
- DateStyle is set to ISO
- IntervalStyle is set to postgres
- extra_float_digits is set to 3 for remote servers 9.0 and newer and is set to 2 for older versions

These are less likely to be problematic than search_path, but can be handled with function SET options if the need arises.

It is *not* recommended that you override this behavior by changing the session-level settings of these parameters; that is likely to cause postgres_fdw to malfunction.

F.58.7. Cross-Version Compatibility

postgres_fdw can be used with remote servers dating back to PostgreSQL 8.3. Read-only capability is available back to 8.1. A limitation however is that postgres_fdw generally assumes that immutable built-in functions and operators are safe to send to the remote server for execution, if they appear in a WHERE clause for a foreign table. Thus, a built-in function that was added since the remote server's release might be sent to it for execution, resulting in "function does not exist" or a similar error. This type of failure can be worked around by rewriting the query, for example by embedding the foreign table reference in a sub-SELECT with OFFSET 0 as an optimization fence, and placing the problematic function or operator outside the sub-SELECT.

F.58.8. Examples

Here is an example of creating a foreign table with postgres_fdw. First install the extension:

```
CREATE EXTENSION postgres_fdw;
```

Then create a foreign server using CREATE SERVER. In this example we wish to connect to a Postgres Pro server on host 192.83.123.89 listening on port 5432. The database to which the connection is made is named foreign_db on the remote server:

```
CREATE SERVER foreign_server
        FOREIGN DATA WRAPPER postgres_fdw
        OPTIONS (host '192.83.123.89', port '5432', dbname 'foreign_db');
```

A user mapping, defined with CREATE USER MAPPING, is needed as well to identify the role that will be used on the remote server:

```
CREATE USER MAPPING FOR local_user
        SERVER foreign_server
        OPTIONS (user 'foreign_user', password 'password');
```

Now it is possible to create a foreign table with CREATE FOREIGN TABLE. In this example we wish to access the table named some_schema.some_table on the remote server. The local name for it will be foreign_table:

```
CREATE FOREIGN TABLE foreign_table (
        id integer NOT NULL,
        data text
)
        SERVER foreign_server
        OPTIONS (schema_name 'some_schema', table_name 'some_table');
```

It's essential that the data types and other properties of the columns declared in CREATE FOREIGN TABLE match the actual remote table. Column names must match as well, unless you attach column_name options to the individual columns to show how they are named in the remote table. In many cases, use of IMPORT FOREIGN SCHEMA is preferable to constructing foreign table definitions manually.

F.58.9. Author

Shigeru Hanada <shigeru.hanada@gmail.com>

F.59. ptrack

PTRACK is a block-level incremental backup engine for Postgres Pro. If PTRACK is enabled, backup tools like pg_probackup can use its API to get information on the changed blocks on the fly when taking incremental backups. Copying only those blocks that have changed since the previous backup can significantly speed up the creation and minimize the size of backups.

PTRACK is designed to allow false positives, but to never allow false negatives: it means that all changes within the data directory except hint bits are guaranteed to be marked in the PTRACK map file, although some unchanged blocks might be included as well.

F.59.1. Setting up PTRACK

Once you complete Postgres Pro Enterprise installation, do the following:

1. Add `ptrack` to the shared_preload_libraries parameter in the `postgresql.conf` file:

   ```
   shared_preload_libraries = 'ptrack'
   ```

2. Set ptrack.map_size parameter to a positive integer.

   For optimal performance, it is recommended to set `ptrack.map_size` to *`N / 1024`*, where *`N`* is the size of the Postgres Pro cluster, in `MB`. If you set this parameter to a lower value, PTRACK is more likely to map several blocks together, which leads to false-positive results when tracking changed blocks and increases the incremental backup size as unchanged blocks can also be copied into the incremental backup.

   Setting `ptrack.map_size` to a higher value does not affect PTRACK operation, but keep in mind that you need up to `ptrack.map_size * 3 MB` of additional disk space since PTRACK uses two additional temporary files to ensure durability. It is not recommended to set this parameter to a value higher than 1024. Even for Postgres Pro clusters with *`N`* > 1 `TB`, it makes sense to use a higher value only if the efficiency and sizes of backups are more critical than the potential overhead of maintaining a large PTRACK map.

3. Check the wal_level setting. When using PTRACK, it is required to set the wal_level parameter to `replica` or higher. Otherwise, you can lose some tracked changes if crash-recovery occurs: some commands do not write WAL at all if `wal_level` is `minimal`, and PTRACK map files are flushed to disk only at checkpoint time.

4. Restart the Postgres Pro Enterprise instance for the changes to take effect, and then create the PTRACK extension:

   ```
   CREATE EXTENSION ptrack;
   ```

   As a result, several PTRACK functions are created, which are required for accessing PTRACK data.

Once this setup is complete, PTRACK starts tracking all the page changes in the Postgres Pro cluster and creates a `ptrack.map` file that stores the latest LSN values for these pages.

> **Note**
>
> The `ptrack.map_size` parameter can only be set at server start. If you change this parameter, the previously created PTRACK map file is cleared, and tracking newly changed blocks starts from scratch. To avoid losing recent changes, it is recommended to retake a full backup after modifying this setting.

F.59.2. PTRACK Configuration Parameters

`ptrack.map_size` (`integer`)

Specifies the size of a PTRACK map file and the amount of shared memory allocated for this file, in `MB`. The PTRACK map file stores the latest LSN values for all pages of the Postgres Pro cluster that have changed since PTRACK was enabled. It is not recommended to set this parameter to a value higher than 1GB. The 0 value disables PTRACK and cleans up all the related service files.

The `ptrack.map_size` parameter can only be set at server start. If you change this parameter, the previously created PTRACK map file is cleared, and tracking newly changed blocks starts from

scratch. To avoid losing recent changes, it is recommended to retake a full backup after modifying this setting.

Default: 0

F.59.3. PTRACK Functions

`ptrack_init_lsn() returns pg_lsn`

Returns the LSN of the last PTRACK map initialization.

`ptrack_get_pagemapset(start_lsn pg_lsn) returns setof record`

Returns a list of data files changed since the specified *start_lsn* with the number and bitmap of changed pages for each file.

For example:

```
postgres=# SELECT * FROM ptrack_get_pagemapset('0/185C8C0');
        path         | pagecount |                 pagemap
---------------------+-----------+----------------------------------------
 base/16384/1255     |         3 | \x00100000000050000000000000
 base/16384/2674     |         3 | \x00000009000100000000000000000000
 base/16384/2691     |         1 | \x00004000000000000000000000
 base/16384/2608     |         1 | \x00000000000000004000000000000000000000
 base/16384/2690     |         1 | \x00040000000000000000000000
```

`ptrack_get_change_stat(start_lsn pg_lsn) returns record`

Returns the statistics of changes (number of files, number of changed pages and their total size in `MB`) since the specified *start_lsn*.

For example:

```
postgres=# SELECT * FROM ptrack_get_change_stat('0/285C8C8');
 files | pages |        size, MB
-------+-------+------------------------
    20 |    25 | 0.19531250000000000000
```

`ptrack_version() returns text`

Returns PTRACK version.

F.60. referee

`referee` is a Postgres Pro Enterprise extension for managing quorum settings in clusters with an even number of nodes configured with multimaster. Installed on a separate system, the `referee` extension provides a voting node to assign the quorum status to a subset of nodes if only half of the cluster nodes remain connected to each other.

If a multi-master cluster is split into equal parts, or half of the cluster nodes fail, each subset of nodes that equals half of the cluster tries to access the referee. The first subset that gets connected to the referee wins the voting and continues working, while all the other nodes are excluded from the cluster to avoid split-brain problems.

The referee node does not store any cluster data, so it is very lightweight and can be located on systems with limited resources. For details on how to set up and use a referee node with `multimaster`, see Section F.32.3.3.

F.60.1. Authors

Postgres Professional, Moscow, Russia

F.61. rum

F.61.1. Introduction

The **rum** module provides access method to work with the RUM indexes. It is based on the GIN access method code.

GIN index allows you to perform fast full-text search using tsvector and tsquery types. However, full-text search with GIN index has some performance issues because positional and other additional information is not stored.

RUM solves these issues by storing additional information in a posting tree. As compared to GIN, RUM index has the following benefits:

- Faster ranking. Ranking requires positional information. And after the index scan we do not need an additional heap scan to retrieve lexeme positions because RUM index stores them.
- Faster phrase search. This improvement is related to the previous one as phrase search also needs positional information.
- Faster ordering by timestamp. RUM index stores additional information together with lexemes, so it is not necessary to perform a heap scan.
- A possibility to perform depth-first search and therefore return first results immediately.

The drawback of RUM is that it has slower build and insert time as compared to GIN because RUM stores additional information together with keys and uses generic WAL records.

F.61.2. Installation

rum is a Postgres Pro Enterprise extension and it has no special prerequisites.

Install extension as follows:

```
$ psql dbname -c "CREATE EXTENSION rum"
```

F.61.3. Common Operators

The operators provided by the rum module are shown in Table F.47:

Table F.47. rum Operators

Operator	Returns	Description
tsvector <=> tsquery	float4	Returns distance between tsvector and tsquery values.
timestamp <=> timestamp	float8	Returns distance between two timestamp values.
timestamp <=| timestamp	float8	Returns distance only for ascending timestamp values.
timestamp |=> timestamp	float8	Returns distance only for descending timestamp values.

> **Note**
>
> rum introduces its own ranking function that is executed inside the <=> operator. It calculates the score (inverted distance) using the specified normalization method. This function is a combination of ts_rank and ts_rank_cd (see Section 9.13 for details). While ts_rank does not support logical

operators and ts_rank_cd works poorly with OR queries, the rum-specific ranking function overcomes these drawbacks.

F.61.4. Operator Classes

The rum extension provides the following operator classes:

rum_tsvector_ops

Stores tsvector lexemes with positional information. Supports ordering by <=> operator and prefix search.

rum_tsvector_hash_ops

Stores hash of tsvector lexemes with positional information. Supports ordering by <=> operator, but does not support prefix search.

rum_tsvector_addon_ops

Stores tsvector lexemes with additional data of any type supported by RUM.

> **Note**
>
> To use the rum_tsvector_addon_ops operator class, when creating the RUM index with CREATE INDEX, specify the attach and to storage parameters in the WITH clause.

rum_tsvector_hash_addon_ops

Stores tsvector lexemes with additional data of any type supported by RUM. Does not support prefix search.

rum_tsquery_ops

Stores branches of query tree in additional information.

rum_anyarray_ops

Stores anyarray elements with length of the array. Supports ordering by <=> operator.

Indexable operators: && @> <@ = %

rum_anyarray_addon_ops

Stores anyarray elements with additional data of any type supported by RUM.

rum_*type*_ops

Stores lexemes of the corresponding type with positional information. The *type* placeholder in the class name must be substituted by one of the following type names: int2, int4, int8, float4, float8, money, oid, timestamp, timestamptz, time, timetz, date, interval, macaddr, inet, cidr, text, varchar, char, bytea, bit, varbit, numeric.

rum_*type*_ops supports ordering by <=>, <=|, and |=> operators. This operator class can be used together with rum_tsvector_addon_ops, rum_tsvector_hash_addon_ops, and rum_anyarray_addon_ops operator classes.

Supported indexable operators depend on the data type:

- < <= = >= > <=> <=| |=> are supported for int2, int4, int8, float4, float8, money, oid, timestamp, timestamptz.

- `< <= = >= >` are supported for `time`, `timetz`, `date`, `interval`, `macaddr`, `inet`, `cidr`, `text`, `varchar`, `char`, `bytea`, `bit`, `varbit`, `numeric`.

> **Note**
>
> The following operator classes are now deprecated: `rum_tsvector_timestamp_ops`, `rum_tsvector_timestamptz_ops`, `rum_tsvector_hash_timestamp_ops`, `rum_tsvector_hash_timestamptz_ops`.

F.61.5. Examples

F.61.5.1. rum_tsvector_ops Example

Let's assume we have the following table:

```
CREATE TABLE test_rum(t text, a tsvector);

CREATE TRIGGER tsvectorupdate
BEFORE UPDATE OR INSERT ON test_rum
FOR EACH ROW EXECUTE PROCEDURE tsvector_update_trigger('a', 'pg_catalog.english', 't');

INSERT INTO test_rum(t) VALUES ('The situation is most beautiful');
INSERT INTO test_rum(t) VALUES ('It is a beautiful');
INSERT INTO test_rum(t) VALUES ('It looks like a beautiful place');
```

Then we can create a new index:

```
CREATE INDEX rumidx ON test_rum USING rum (a rum_tsvector_ops);
```

And we can execute the following queries:

```
SELECT t, a <=> to_tsquery('english', 'beautiful | place') AS rank
    FROM test_rum
    WHERE a @@ to_tsquery('english', 'beautiful | place')
    ORDER BY a <=> to_tsquery('english', 'beautiful | place');
               t                |   rank
--------------------------------+-----------
 The situation is most beautiful | 0.0303964
 It is a beautiful               | 0.0303964
 It looks like a beautiful place | 0.0607927
(3 rows)

SELECT t, a <=> to_tsquery('english', 'place | situation') AS rank
    FROM test_rum
    WHERE a @@ to_tsquery('english', 'place | situation')
    ORDER BY a <=> to_tsquery('english', 'place | situation');
               t                |   rank
--------------------------------+-----------
 The situation is most beautiful | 0.0303964
 It looks like a beautiful place | 0.0303964
(2 rows)
```

F.61.5.2. rum_tsvector_addon_ops Example

Let's assume we have the following table:

```
CREATE TABLE tsts (id int, t tsvector, d timestamp);
```

```
\copy tsts from 'rum/data/tsts.data'

CREATE INDEX tsts_idx ON tsts USING rum (t rum_tsvector_addon_ops, d)
    WITH (attach = 'd', to = 't');
```

Now we can execute the following queries:

```
EXPLAIN (costs off)
    SELECT id, d, d <=> '2016-05-16 14:21:25' FROM tsts WHERE t @@ 'wr&qh' ORDER BY d
 <=> '2016-05-16 14:21:25' LIMIT 5;
                                  QUERY PLAN
-------------------------------------------------------------------------------------
 Limit
   ->  Index Scan using tsts_idx on tsts
         Index Cond: (t @@ '''wr'' & ''qh'''::tsquery)
         Order By: (d <=> 'Mon May 16 14:21:25 2016'::timestamp without time zone)
(4 rows)

SELECT id, d, d <=> '2016-05-16 14:21:25' FROM tsts WHERE t @@ 'wr&qh' ORDER BY d <=>
 '2016-05-16 14:21:25' LIMIT 5;
 id  |                d                |   ?column?
-----+---------------------------------+---------------
 355 | Mon May 16 14:21:22.326724 2016 |      2.673276
 354 | Mon May 16 13:21:22.326724 2016 |   3602.673276
 371 | Tue May 17 06:21:22.326724 2016 |  57597.326724
 406 | Wed May 18 17:21:22.326724 2016 | 183597.326724
 415 | Thu May 19 02:21:22.326724 2016 | 215997.326724
(5 rows)
```

F.61.5.3. rum_tsquery_ops Example

Suppose we have the table:

```
CREATE TABLE query (q tsquery, tag text);

INSERT INTO query VALUES ('supernova & star', 'sn'),
    ('black', 'color'),
    ('big & bang & black & hole', 'bang'),
    ('spiral & galaxy', 'shape'),
    ('black & hole', 'color');

CREATE INDEX query_idx ON query USING rum(q);
```

We can execute the following fast query:

```
SELECT * FROM query
    WHERE to_tsvector('black holes never exists before we think about them') @@ q;
        q         |  tag
------------------+-------
 'black'          | color
 'black' & 'hole' | color
(2 rows)
```

F.61.5.4. rum_anyarray_ops Example

Let's assume we have the following table:

```
CREATE TABLE test_array (i int2[]);

INSERT INTO test_array VALUES ('{}'), ('{0}'), ('{1,2,3,4}'), ('{1,2,3}'), ('{1,2}'),
 ('{1}');
```

```
CREATE INDEX idx_array ON test_array USING rum (i rum_anyarray_ops);
```

Now we can execute the following query using index scan:

```
SET enable_seqscan TO off;

EXPLAIN (COSTS OFF) SELECT * FROM test_array WHERE i && '{1}' ORDER BY i <=> '{1}' ASC;
                QUERY PLAN
------------------------------------------
 Index Scan using idx_array on test_array
   Index Cond: (i && '{1}'::smallint[])
   Order By: (i <=> '{1}'::smallint[])
(3 rows)

SELECT * FROM test_array WHERE i && '{1}' ORDER BY i <=> '{1}' ASC;
     i
-----------
 {1}
 {1,2}
 {1,2,3}
 {1,2,3,4}
(4 rows)
```

F.61.6. Authors

Alexander Korotkov

Oleg Bartunov

Teodor Sigaev

F.62. seg

This module implements a data type `seg` for representing line segments, or floating point intervals. `seg` can represent uncertainty in the interval endpoints, making it especially useful for representing laboratory measurements.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.62.1. Rationale

The geometry of measurements is usually more complex than that of a point in a numeric continuum. A measurement is usually a segment of that continuum with somewhat fuzzy limits. The measurements come out as intervals because of uncertainty and randomness, as well as because the value being measured may naturally be an interval indicating some condition, such as the temperature range of stability of a protein.

Using just common sense, it appears more convenient to store such data as intervals, rather than pairs of numbers. In practice, it even turns out more efficient in most applications.

Further along the line of common sense, the fuzziness of the limits suggests that the use of traditional numeric data types leads to a certain loss of information. Consider this: your instrument reads 6.50, and you input this reading into the database. What do you get when you fetch it? Watch:

```
test=> select 6.50 :: float8 as "pH";
 pH
---
6.5
```

```
(1 row)
```

In the world of measurements, 6.50 is not the same as 6.5. It may sometimes be critically different. The experimenters usually write down (and publish) the digits they trust. 6.50 is actually a fuzzy interval contained within a bigger and even fuzzier interval, 6.5, with their center points being (probably) the only common feature they share. We definitely do not want such different data items to appear the same.

Conclusion? It is nice to have a special data type that can record the limits of an interval with arbitrarily variable precision. Variable in the sense that each data element records its own precision.

Check this out:

```
test=> select '6.25 .. 6.50'::seg as "pH";
          pH
------------
6.25 .. 6.50
(1 row)
```

F.62.2. Syntax

The external representation of an interval is formed using one or two floating-point numbers joined by the range operator (`..` or `...`). Alternatively, it can be specified as a center point plus or minus a deviation. Optional certainty indicators (<, > or ~) can be stored as well. (Certainty indicators are ignored by all the built-in operators, however.) Table F.48 gives an overview of allowed representations; Table F.49 shows some examples.

In Table F.48, *x*, *y*, and *delta* denote floating-point numbers. *x* and *y*, but not *delta*, can be preceded by a certainty indicator.

Table F.48. `seg` External Representations

x	Single value (zero-length interval)
x `..` *y*	Interval from *x* to *y*
x `(+-)` *delta*	Interval from *x* - *delta* to *x* + *delta*
x `..`	Open interval with lower bound *x*
`..` *x*	Open interval with upper bound *x*

Table F.49. Examples of Valid `seg` Input

`5.0`	Creates a zero-length segment (a point, if you will)
`~5.0`	Creates a zero-length segment and records ~ in the data. ~ is ignored by `seg` operations, but is preserved as a comment.
`<5.0`	Creates a point at 5.0. < is ignored but is preserved as a comment.
`>5.0`	Creates a point at 5.0. > is ignored but is preserved as a comment.
`5(+-)0.3`	Creates an interval `4.7 .. 5.3`. Note that the `(+-)` notation isn't preserved.
`50 ..`	Everything that is greater than or equal to 50
`.. 0`	Everything that is less than or equal to 0
`1.5e-2 .. 2E-2`	Creates an interval `0.015 .. 0.02`
`1 ... 2`	The same as `1...2`, or `1 .. 2`, or `1..2` (spaces around the range operator are ignored)

Because the `...` operator is widely used in data sources, it is allowed as an alternative spelling of the `..` operator. Unfortunately, this creates a parsing ambiguity: it is not clear whether the upper bound

in `0...23` is meant to be `23` or `0.23`. This is resolved by requiring at least one digit before the decimal point in all numbers in `seg` input.

As a sanity check, `seg` rejects intervals with the lower bound greater than the upper, for example `5 .. 2`.

F.62.3. Precision

`seg` values are stored internally as pairs of 32-bit floating point numbers. This means that numbers with more than 7 significant digits will be truncated.

Numbers with 7 or fewer significant digits retain their original precision. That is, if your query returns 0.00, you will be sure that the trailing zeroes are not the artifacts of formatting: they reflect the precision of the original data. The number of leading zeroes does not affect precision: the value 0.0067 is considered to have just 2 significant digits.

F.62.4. Usage

The `seg` module includes a GiST index operator class for `seg` values. The operators supported by the GiST operator class are shown in Table F.50.

Table F.50. Seg GiST Operators

Operator Description
`seg << seg → boolean` Is the first `seg` entirely to the left of the second? [a, b] << [c, d] is true if b < c.
`seg >> seg → boolean` Is the first `seg` entirely to the right of the second? [a, b] >> [c, d] is true if a > d.
`seg &< seg → boolean` Does the first `seg` not extend to the right of the second? [a, b] &< [c, d] is true if b <= d.
`seg &> seg → boolean` Does the first `seg` not extend to the left of the second? [a, b] &> [c, d] is true if a >= c.
`seg = seg → boolean` Are the two `seg`s equal?
`seg && seg → boolean` Do the two `seg`s overlap?
`seg @> seg → boolean` Does the first `seg` contain the second?
`seg <@ seg → boolean` Is the first `seg` contained in the second?

In addition to the above operators, the usual comparison operators shown in Table 9.1 are available for type `seg`. These operators first compare (a) to (c), and if these are equal, compare (b) to (d). That results in reasonably good sorting in most cases, which is useful if you want to use ORDER BY with this type.

F.62.5. Notes

For examples of usage, see the regression test `sql/seg.sql`.

The mechanism that converts `(+-)` to regular ranges isn't completely accurate in determining the number of significant digits for the boundaries. For example, it adds an extra digit to the lower boundary if the resulting interval includes a power of ten:

```
postgres=> select '10(+-)1'::seg as seg;
```

```
      seg
---------
9.0 .. 11               -- should be: 9 .. 11
```

The performance of an R-tree index can largely depend on the initial order of input values. It may be very helpful to sort the input table on the `seg` column; see the script `sort-segments.pl` for an example.

F.62.6. Credits

Original author: Gene Selkov, Jr. <selkovjr@mcs.anl.gov>, Mathematics and Computer Science Division, Argonne National Laboratory.

My thanks are primarily to Prof. Joe Hellerstein (*https://dsf.berkeley.edu/jmh/*) for elucidating the gist of the GiST (*http://gist.cs.berkeley.edu/*). I am also grateful to all Postgres developers, present and past, for enabling myself to create my own world and live undisturbed in it. And I would like to acknowledge my gratitude to Argonne Lab and to the U.S. Department of Energy for the years of faithful support of my database research.

F.63. shared_ispell

The `shared_ispell` module provides a shared ispell dictionary, i.e. a dictionary that's stored in shared segment. The traditional ispell implementation means that each session initializes and stores the dictionary on it's own, which means a lot of CPU/RAM is wasted.

This extension allocates an area in shared segment (you have to choose the size in advance) and then loads the dictionary into it when it's used for the first time.

F.63.1. Functions

The functions provided by the `shared_ispell` module are shown in Table F.51.

Table F.51. `shared_ispell` Functions

Function	Returns	Description
`shared_ispell_reset()`	`void`	Resets the dictionaries (e.g. so that you can reload the updated files from disk). The sessions that already use the dictionaries will be forced to reinitialize them.
`shared_ispell_mem_used()`	`int`	Returns a value of used memory of the shared segment by loaded shared dictionaries in bytes.
`shared_ispell_mem_available()`	`int`	Returns a value of available memory of the shared segment.
`shared_ispell_dicts()`	`setof(dict_name varchar, affix_name varchar, words int, affixes int, bytes int)`	Returns a list of dictionaries loaded in the shared segment.
`shared_ispell_stoplists()`	`setof(stop_name varchar, words int, bytes int)`	Returns a list of stopwords loaded in the shared segment.

F.63.2. GUC Parameters

`shared_ispell.max_size` (`int`)

Defines the maximum size of the shared segment. This is a hard limit, the shared segment is not extensible and you need to set it so that all the dictionaries fit into it and not much memory is wasted.

F.63.3. Using the dictionary

The module needs to allocate space in the shared memory segment. So add this to the config file (or update the current values):

```
# libraries to load
shared_preload_libraries = 'shared_ispell'

# config of the shared memory
shared_ispell.max_size = 32MB
```

To find out how much memory you actually need, use a large value (e.g. 200MB) and load all the dictionaries you want to use. Then use the `shared_ispell_mem_used()` function to find out how much memory was actually used (and set the `shared_ispell.max_size` GUC variable accordingly).

Don't set it exactly to that value, leave there some free space, so that you can reload the dictionaries without changing the GUC max_size limit (which requires a restart of the DB). Something like 512kB should be just fine.

The extension defines a `shared_ispell` template that you may use to define custom dictionaries. E.g. you may do this:

```
CREATE TEXT SEARCH DICTIONARY english_shared (
    TEMPLATE = shared_ispell,
    DictFile = en_us,
    AffFile = en_us,
    StopWords = english
);

CREATE TEXT SEARCH CONFIGURATION public.english_shared
    ( COPY = pg_catalog.simple );

ALTER TEXT SEARCH CONFIGURATION english_shared
    ALTER MAPPING FOR asciiword, asciihword, hword_asciipart,
                      word, hword, hword_part
    WITH english_shared, english_stem;
```

We can test created configuration:

```
SELECT * FROM ts_debug('english_shared', 'abilities');
   alias   |   description   |   token   |         dictionaries          |   dictionary
   |  lexemes
-----------+-----------------+-----------+-------------------------------
+----------------+-----------
 asciiword | Word, all ASCII | abilities | {english_shared,english_stem} |
 english_shared | {ability}
(1 row)
```

Or you can update your own text search configuration. For example, you have the `public.english` dictionary. You can update it to use the `shared_ispell` template:

```
ALTER TEXT SEARCH CONFIGURATION public.english
    ALTER MAPPING FOR asciiword, asciihword, hword_asciipart,
                      word, hword, hword_part
    WITH english_shared, english_stem;
```

F.63.4. Author

Tomas Vondra <tomas.vondra@2ndquadrant.com>, Prague, Czech Republic

F.64. spi

The spi module provides several workable examples of using the Server Programming Interface (SPI) and triggers. While these functions are of some value in their own right, they are even more useful as examples to modify for your own purposes. The functions are general enough to be used with any table, but you have to specify table and field names (as described below) while creating a trigger.

Each of the groups of functions described below is provided as a separately-installable extension.

F.64.1. refint — Functions for Implementing Referential Integrity

`check_primary_key()` and `check_foreign_key()` are used to check foreign key constraints. (This functionality is long since superseded by the built-in foreign key mechanism, of course, but the module is still useful as an example.)

`check_primary_key()` checks the referencing table. To use, create a `BEFORE INSERT OR UPDATE` trigger using this function on a table referencing another table. Specify as the trigger arguments: the referencing table's column name(s) which form the foreign key, the referenced table name, and the column names in the referenced table which form the primary/unique key. To handle multiple foreign keys, create a trigger for each reference.

`check_foreign_key()` checks the referenced table. To use, create a `BEFORE DELETE OR UPDATE` trigger using this function on a table referenced by other table(s). Specify as the trigger arguments: the number of referencing tables for which the function has to perform checking, the action if a referencing key is found (`cascade` — to delete the referencing row, `restrict` — to abort transaction if referencing keys exist, `setnull` — to set referencing key fields to null), the triggered table's column names which form the primary/unique key, then the referencing table name and column names (repeated for as many referencing tables as were specified by first argument). Note that the primary/unique key columns should be marked NOT NULL and should have a unique index.

There are examples in `refint.example`.

F.64.2. autoinc — Functions for Autoincrementing Fields

`autoinc()` is a trigger that stores the next value of a sequence into an integer field. This has some overlap with the built-in "serial column" feature, but it is not the same: `autoinc()` will override attempts to substitute a different field value during inserts, and optionally it can be used to increment the field during updates, too.

To use, create a `BEFORE INSERT` (or optionally `BEFORE INSERT OR UPDATE`) trigger using this function. Specify two trigger arguments: the name of the integer column to be modified, and the name of the sequence object that will supply values. (Actually, you can specify any number of pairs of such names, if you'd like to update more than one autoincrementing column.)

There is an example in `autoinc.example`.

F.64.3. insert_username — Functions for Tracking Who Changed a Table

`insert_username()` is a trigger that stores the current user's name into a text field. This can be useful for tracking who last modified a particular row within a table.

To use, create a `BEFORE INSERT` and/or `UPDATE` trigger using this function. Specify a single trigger argument: the name of the text column to be modified.

There is an example in `insert_username.example`.

F.64.4. moddatetime — Functions for Tracking Last Modification Time

`moddatetime()` is a trigger that stores the current time into a `timestamp` field. This can be useful for tracking the last modification time of a particular row within a table.

To use, create a `BEFORE UPDATE` trigger using this function. Specify a single trigger argument: the name of the column to be modified. The column must be of type `timestamp` or `timestamp with time zone`.

There is an example in `moddatetime.example`.

F.65. sslinfo

The `sslinfo` module provides information about the SSL certificate that the current client provided when connecting to Postgres Pro. The module is useless (most functions will return NULL) if the current connection does not use SSL.

Some of the information available through this module can also be obtained using the built-in system view `pg_stat_ssl`.

This extension won't build at all unless the installation was configured with `--with-ssl=openssl`.

F.65.1. Functions Provided

`ssl_is_used() returns boolean`

Returns true if current connection to server uses SSL, and false otherwise.

`ssl_version() returns text`

Returns the name of the protocol used for the SSL connection (e.g., TLSv1.0, TLSv1.1, TLSv1.2 or TLSv1.3).

`ssl_cipher() returns text`

Returns the name of the cipher used for the SSL connection (e.g., DHE-RSA-AES256-SHA).

`ssl_client_cert_present() returns boolean`

Returns true if current client has presented a valid SSL client certificate to the server, and false otherwise. (The server might or might not be configured to require a client certificate.)

`ssl_client_serial() returns numeric`

Returns serial number of current client certificate. The combination of certificate serial number and certificate issuer is guaranteed to uniquely identify a certificate (but not its owner — the owner ought to regularly change their keys, and get new certificates from the issuer).

So, if you run your own CA and allow only certificates from this CA to be accepted by the server, the serial number is the most reliable (albeit not very mnemonic) means to identify a user.

`ssl_client_dn() returns text`

Returns the full subject of the current client certificate, converting character data into the current database encoding. It is assumed that if you use non-ASCII characters in the certificate names, your database is able to represent these characters, too. If your database uses the SQL_ASCII encoding, non-ASCII characters in the name will be represented as UTF-8 sequences.

The result looks like `/CN=Somebody /C=Some country/O=Some organization`.

`ssl_issuer_dn() returns text`

Returns the full issuer name of the current client certificate, converting character data into the current database encoding. Encoding conversions are handled the same as for `ssl_client_dn`.

The combination of the return value of this function with the certificate serial number uniquely identifies the certificate.

This function is really useful only if you have more than one trusted CA certificate in your server's certificate authority file, or if this CA has issued some intermediate certificate authority certificates.

`ssl_client_dn_field(fieldname text) returns text`

This function returns the value of the specified field in the certificate subject, or NULL if the field is not present. Field names are string constants that are converted into ASN1 object identifiers using the OpenSSL object database. The following values are acceptable:

```
commonName (alias CN)
surname (alias SN)
name
givenName (alias GN)
countryName (alias C)
localityName (alias L)
stateOrProvinceName (alias ST)
organizationName (alias O)
organizationalUnitName (alias OU)
title
description
initials
postalCode
streetAddress
generationQualifier
description
dnQualifier
x500UniqueIdentifier
pseudonym
role
emailAddress
```

All of these fields are optional, except `commonName`. It depends entirely on your CA's policy which of them would be included and which wouldn't. The meaning of these fields, however, is strictly defined by the X.500 and X.509 standards, so you cannot just assign arbitrary meaning to them.

`ssl_issuer_field(fieldname text) returns text`

Same as `ssl_client_dn_field`, but for the certificate issuer rather than the certificate subject.

`ssl_extension_info() returns setof record`

Provide information about extensions of client certificate: extension name, extension value, and if it is a critical extension.

F.65.2. Author

Victor Wagner `<vitus@cryptocom.ru>`, Cryptocom LTD

Dmitry Voronin `<carriingfate92@yandex.ru>`

E-Mail of Cryptocom OpenSSL development group: `<openssl@cryptocom.ru>`

F.66. tablefunc

The `tablefunc` module includes various functions that return tables (that is, multiple rows). These functions are useful both in their own right and as examples of how to write C functions that return multiple rows.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.66.1. Functions Provided

Table F.52 summarizes the functions provided by the `tablefunc` module.

Table F.52. `tablefunc` Functions

Function Description
`normal_rand ( numvals integer, mean float8, stddev float8 ) → setof float8` Produces a set of normally distributed random values.
`crosstab ( sql text ) → setof record` Produces a "pivot table" containing row names plus *N* value columns, where *N* is determined by the row type specified in the calling query.
`crosstabN ( sql text ) → setof table_crosstab_ N` Produces a "pivot table" containing row names plus *N* value columns. `crosstab2`, `crosstab3`, and `crosstab4` are predefined, but you can create additional `crosstabN` functions as described below.
`crosstab ( source_sql text, category_sql text ) → setof record` Produces a "pivot table" with the value columns specified by a second query.
`crosstab ( sql text, N integer ) → setof record` Obsolete version of `crosstab(text)`. The parameter *N* is now ignored, since the number of value columns is always determined by the calling query.
`connectby ( relname text, keyid_fld text, parent_keyid_fld text [, orderby_fld text ], start_with text, max_depth integer [, branch_delim text ] ) → setof record` Produces a representation of a hierarchical tree structure.

F.66.1.1. `normal_rand`

```
normal_rand(int numvals, float8 mean, float8 stddev) returns setof float8
```

`normal_rand` produces a set of normally distributed random values (Gaussian distribution).

numvals is the number of values to be returned from the function. *mean* is the mean of the normal distribution of values and *stddev* is the standard deviation of the normal distribution of values.

For example, this call requests 1000 values with a mean of 5 and a standard deviation of 3:

```
test=# SELECT * FROM normal_rand(1000, 5, 3);
     normal_rand
----------------------
     1.56556322244898
     9.10040991424657
     5.36957140345079
    -0.369151492880995
     0.283600703686639
        .
        .
        .
     4.82992125404908
     9.71308014517282
     2.49639286969028
(1000 rows)
```

F.66.1.2. `crosstab(text)`

```
crosstab(text sql)
```

```
crosstab(text sql, int N)
```

The `crosstab` function is used to produce "pivot" displays, wherein data is listed across the page rather than down. For example, we might have data like

```
row1    val11
row1    val12
row1    val13
...
row2    val21
row2    val22
row2    val23
...
```

which we wish to display like

```
row1    val11   val12   val13   ...
row2    val21   val22   val23   ...
...
```

The `crosstab` function takes a text parameter that is an SQL query producing raw data formatted in the first way, and produces a table formatted in the second way.

The *`sql`* parameter is an SQL statement that produces the source set of data. This statement must return one `row_name` column, one `category` column, and one `value` column. *`N`* is an obsolete parameter, ignored if supplied (formerly this had to match the number of output value columns, but now that is determined by the calling query).

For example, the provided query might produce a set something like:

```
 row_name    cat    value
----------+-------+-------
  row1      cat1    val1
  row1      cat2    val2
  row1      cat3    val3
  row1      cat4    val4
  row2      cat1    val5
  row2      cat2    val6
  row2      cat3    val7
  row2      cat4    val8
```

The `crosstab` function is declared to return `setof record`, so the actual names and types of the output columns must be defined in the `FROM` clause of the calling `SELECT` statement, for example:

```
SELECT * FROM crosstab('...') AS ct(row_name text, category_1 text, category_2 text);
```

This example produces a set something like:

```
           <== value  columns  ==>
 row_name   category_1   category_2
----------+------------+------------
  row1        val1         val2
  row2        val5         val6
```

The `FROM` clause must define the output as one `row_name` column (of the same data type as the first result column of the SQL query) followed by N `value` columns (all of the same data type as the third result column of the SQL query). You can set up as many output value columns as you wish. The names of the output columns are up to you.

The `crosstab` function produces one output row for each consecutive group of input rows with the same `row_name` value. It fills the output `value` columns, left to right, with the `value` fields from these rows.

If there are fewer rows in a group than there are output `value` columns, the extra output columns are filled with nulls; if there are more rows, the extra input rows are skipped.

In practice the SQL query should always specify `ORDER BY 1,2` to ensure that the input rows are properly ordered, that is, values with the same `row_name` are brought together and correctly ordered within the row. Notice that `crosstab` itself does not pay any attention to the second column of the query result; it's just there to be ordered by, to control the order in which the third-column values appear across the page.

Here is a complete example:

```
CREATE TABLE ct(id SERIAL, rowid TEXT, attribute TEXT, value TEXT);
INSERT INTO ct(rowid, attribute, value) VALUES('test1','att1','val1');
INSERT INTO ct(rowid, attribute, value) VALUES('test1','att2','val2');
INSERT INTO ct(rowid, attribute, value) VALUES('test1','att3','val3');
INSERT INTO ct(rowid, attribute, value) VALUES('test1','att4','val4');
INSERT INTO ct(rowid, attribute, value) VALUES('test2','att1','val5');
INSERT INTO ct(rowid, attribute, value) VALUES('test2','att2','val6');
INSERT INTO ct(rowid, attribute, value) VALUES('test2','att3','val7');
INSERT INTO ct(rowid, attribute, value) VALUES('test2','att4','val8');

SELECT *
FROM crosstab(
  'select rowid, attribute, value
   from ct
   where attribute = ''att2'' or attribute = ''att3''
   order by 1,2')
AS ct(row_name text, category_1 text, category_2 text, category_3 text);

 row_name | category_1 | category_2 | category_3
----------+------------+------------+------------
 test1    | val2       | val3       |
 test2    | val6       | val7       |
(2 rows)
```

You can avoid always having to write out a `FROM` clause to define the output columns, by setting up a custom crosstab function that has the desired output row type wired into its definition. This is described in the next section. Another possibility is to embed the required `FROM` clause in a view definition.

> **Note**
>
> See also the `\crosstabview` command in psql, which provides functionality similar to `crosstab()`.

F.66.1.3. `crosstabN(text)`

```
crosstabN(text sql)
```

The `crosstabN` functions are examples of how to set up custom wrappers for the general `crosstab` function, so that you need not write out column names and types in the calling `SELECT` query. The `tablefunc` module includes `crosstab2`, `crosstab3`, and `crosstab4`, whose output row types are defined as

```
CREATE TYPE tablefunc_crosstab_N AS (
    row_name TEXT,
    category_1 TEXT,
    category_2 TEXT,
        .
        .
        .
    category_N TEXT
);
```

Thus, these functions can be used directly when the input query produces `row_name` and `value` columns of type `text`, and you want 2, 3, or 4 output values columns. In all other ways they behave exactly as described above for the general `crosstab` function.

For instance, the example given in the previous section would also work as

```
SELECT *
FROM crosstab3(
  'select rowid, attribute, value
   from ct
   where attribute = ''att2'' or attribute = ''att3''
   order by 1,2');
```

These functions are provided mostly for illustration purposes. You can create your own return types and functions based on the underlying `crosstab()` function. There are two ways to do it:

- Create a composite type describing the desired output columns, similar to the examples in `contrib/tablefunc/tablefunc--1.0.sql`. Then define a unique function name accepting one `text` parameter and returning `setof your_type_name`, but linking to the same underlying `crosstab` C function. For example, if your source data produces row names that are `text`, and values that are `float8`, and you want 5 value columns:

  ```
  CREATE TYPE my_crosstab_float8_5_cols AS (
      my_row_name text,
      my_category_1 float8,
      my_category_2 float8,
      my_category_3 float8,
      my_category_4 float8,
      my_category_5 float8
  );

  CREATE OR REPLACE FUNCTION crosstab_float8_5_cols(text)
      RETURNS setof my_crosstab_float8_5_cols
      AS '$libdir/tablefunc','crosstab' LANGUAGE C STABLE STRICT;
  ```

- Use `OUT` parameters to define the return type implicitly. The same example could also be done this way:

  ```
  CREATE OR REPLACE FUNCTION crosstab_float8_5_cols(
      IN text,
      OUT my_row_name text,
      OUT my_category_1 float8,
      OUT my_category_2 float8,
      OUT my_category_3 float8,
      OUT my_category_4 float8,
      OUT my_category_5 float8)
    RETURNS setof record
    AS '$libdir/tablefunc','crosstab' LANGUAGE C STABLE STRICT;
  ```

F.66.1.4. crosstab(text, text)

```
crosstab(text source_sql, text category_sql)
```

The main limitation of the single-parameter form of `crosstab` is that it treats all values in a group alike, inserting each value into the first available column. If you want the value columns to correspond to specific categories of data, and some groups might not have data for some of the categories, that doesn't work well. The two-parameter form of `crosstab` handles this case by providing an explicit list of the categories corresponding to the output columns.

`source_sql` is an SQL statement that produces the source set of data. This statement must return one `row_name` column, one `category` column, and one `value` column. It may also have one or more “extra”

columns. The `row_name` column must be first. The `category` and `value` columns must be the last two columns, in that order. Any columns between `row_name` and `category` are treated as “extra”. The “extra” columns are expected to be the same for all rows with the same `row_name` value.

For example, *`source_sql`* might produce a set something like:

```
SELECT row_name, extra_col, cat, value FROM foo ORDER BY 1;

 row_name    extra_col   cat    value
----------+------------+-----+---------
  row1         extra1    cat1    val1
  row1         extra1    cat2    val2
  row1         extra1    cat4    val4
  row2         extra2    cat1    val5
  row2         extra2    cat2    val6
  row2         extra2    cat3    val7
  row2         extra2    cat4    val8
```

`category_sql` is an SQL statement that produces the set of categories. This statement must return only one column. It must produce at least one row, or an error will be generated. Also, it must not produce duplicate values, or an error will be generated. *`category_sql`* might be something like:

```
SELECT DISTINCT cat FROM foo ORDER BY 1;
    cat
  -------
    cat1
    cat2
    cat3
    cat4
```

The `crosstab` function is declared to return `setof record`, so the actual names and types of the output columns must be defined in the `FROM` clause of the calling `SELECT` statement, for example:

```
SELECT * FROM crosstab('...', '...')
    AS ct(row_name text, extra text, cat1 text, cat2 text, cat3 text, cat4 text);
```

This will produce a result something like:

```
                  <==  value  columns   ==>
row_name   extra   cat1   cat2   cat3   cat4
---------+-------+------+------+------+------
  row1     extra1  val1   val2          val4
  row2     extra2  val5   val6   val7   val8
```

The `FROM` clause must define the proper number of output columns of the proper data types. If there are *`N`* columns in the *`source_sql`* query's result, the first *`N`*-2 of them must match up with the first *`N`*-2 output columns. The remaining output columns must have the type of the last column of the *`source_sql`* query's result, and there must be exactly as many of them as there are rows in the *`category_sql`* query's result.

The `crosstab` function produces one output row for each consecutive group of input rows with the same `row_name` value. The output `row_name` column, plus any “extra” columns, are copied from the first row of the group. The output `value` columns are filled with the `value` fields from rows having matching `category` values. If a row's `category` does not match any output of the *`category_sql`* query, its `value` is ignored. Output columns whose matching category is not present in any input row of the group are filled with nulls.

In practice the *`source_sql`* query should always specify `ORDER BY 1` to ensure that values with the same `row_name` are brought together. However, ordering of the categories within a group is not important. Also, it is essential to be sure that the order of the *`category_sql`* query's output matches the specified output column order.

Here are two complete examples:

```
create table sales(year int, month int, qty int);
insert into sales values(2007, 1, 1000);
insert into sales values(2007, 2, 1500);
insert into sales values(2007, 7, 500);
insert into sales values(2007, 11, 1500);
insert into sales values(2007, 12, 2000);
insert into sales values(2008, 1, 1000);

select * from crosstab(
  'select year, month, qty from sales order by 1',
  'select m from generate_series(1,12) m'
) as (
  year int,
  "Jan" int,
  "Feb" int,
  "Mar" int,
  "Apr" int,
  "May" int,
  "Jun" int,
  "Jul" int,
  "Aug" int,
  "Sep" int,
  "Oct" int,
  "Nov" int,
  "Dec" int
);
 year | Jan  | Feb  | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov  | Dec
------+------+------+-----+-----+-----+-----+-----+-----+-----+-----+------+------
 2007 | 1000 | 1500 |     |     |     |     | 500 |     |     |     | 1500 | 2000
 2008 | 1000 |      |     |     |     |     |     |     |     |     |      |
(2 rows)
```

```
CREATE TABLE cth(rowid text, rowdt timestamp, attribute text, val text);
INSERT INTO cth VALUES('test1','01 March 2003','temperature','42');
INSERT INTO cth VALUES('test1','01 March 2003','test_result','PASS');
INSERT INTO cth VALUES('test1','01 March 2003','volts','2.6987');
INSERT INTO cth VALUES('test2','02 March 2003','temperature','53');
INSERT INTO cth VALUES('test2','02 March 2003','test_result','FAIL');
INSERT INTO cth VALUES('test2','02 March 2003','test_startdate','01 March 2003');
INSERT INTO cth VALUES('test2','02 March 2003','volts','3.1234');

SELECT * FROM crosstab
(
  'SELECT rowid, rowdt, attribute, val FROM cth ORDER BY 1',
  'SELECT DISTINCT attribute FROM cth ORDER BY 1'
)
AS
(
       rowid text,
       rowdt timestamp,
       temperature int4,
       test_result text,
       test_startdate timestamp,
       volts float8
);
 rowid |          rowdt           | temperature | test_result |      test_startdate
  | volts
```

```
-------+-------------------------+-------------+-------------
+-------------------------+--------
 test1 | Sat Mar 01 00:00:00 2003 |          42 | PASS        |
  | 2.6987
 test2 | Sun Mar 02 00:00:00 2003 |          53 | FAIL        | Sat Mar 01 00:00:00
 2003 | 3.1234
(2 rows)
```

You can create predefined functions to avoid having to write out the result column names and types in each query. See the examples in the previous section. The underlying C function for this form of `crosstab` is named `crosstab_hash`.

F.66.1.5. `connectby`

```
connectby(text relname, text keyid_fld, text parent_keyid_fld
          [, text orderby_fld ], text start_with, int max_depth
          [, text branch_delim ])
```

The `connectby` function produces a display of hierarchical data that is stored in a table. The table must have a key field that uniquely identifies rows, and a parent-key field that references the parent (if any) of each row. `connectby` can display the sub-tree descending from any row.

Table F.53 explains the parameters.

Table F.53. `connectby` Parameters

Parameter	Description
`relname`	Name of the source relation
`keyid_fld`	Name of the key field
`parent_keyid_fld`	Name of the parent-key field
`orderby_fld`	Name of the field to order siblings by (optional)
`start_with`	Key value of the row to start at
`max_depth`	Maximum depth to descend to, or zero for unlimited depth
`branch_delim`	String to separate keys with in branch output (optional)

The key and parent-key fields can be any data type, but they must be the same type. Note that the *`start_with`* value must be entered as a text string, regardless of the type of the key field.

The `connectby` function is declared to return `setof record`, so the actual names and types of the output columns must be defined in the `FROM` clause of the calling `SELECT` statement, for example:

```
SELECT * FROM connectby('connectby_tree', 'keyid', 'parent_keyid', 'pos', 'row2', 0,
 '~')
    AS t(keyid text, parent_keyid text, level int, branch text, pos int);
```

The first two output columns are used for the current row's key and its parent row's key; they must match the type of the table's key field. The third output column is the depth in the tree and must be of type `integer`. If a *`branch_delim`* parameter was given, the next output column is the branch display and must be of type `text`. Finally, if an *`orderby_fld`* parameter was given, the last output column is a serial number, and must be of type `integer`.

The “branch” output column shows the path of keys taken to reach the current row. The keys are separated by the specified *`branch_delim`* string. If no branch display is wanted, omit both the *`branch_delim`* parameter and the branch column in the output column list.

If the ordering of siblings of the same parent is important, include the *orderby_fld* parameter to specify which field to order siblings by. This field can be of any sortable data type. The output column list must include a final integer serial-number column, if and only if *orderby_fld* is specified.

The parameters representing table and field names are copied as-is into the SQL queries that connectby generates internally. Therefore, include double quotes if the names are mixed-case or contain special characters. You may also need to schema-qualify the table name.

In large tables, performance will be poor unless there is an index on the parent-key field.

It is important that the *branch_delim* string not appear in any key values, else connectby may incorrectly report an infinite-recursion error. Note that if *branch_delim* is not provided, a default value of ~ is used for recursion detection purposes.

Here is an example:

```
CREATE TABLE connectby_tree(keyid text, parent_keyid text, pos int);

INSERT INTO connectby_tree VALUES('row1',NULL, 0);
INSERT INTO connectby_tree VALUES('row2','row1', 0);
INSERT INTO connectby_tree VALUES('row3','row1', 0);
INSERT INTO connectby_tree VALUES('row4','row2', 1);
INSERT INTO connectby_tree VALUES('row5','row2', 0);
INSERT INTO connectby_tree VALUES('row6','row4', 0);
INSERT INTO connectby_tree VALUES('row7','row3', 0);
INSERT INTO connectby_tree VALUES('row8','row6', 0);
INSERT INTO connectby_tree VALUES('row9','row5', 0);

-- with branch, without orderby_fld (order of results is not guaranteed)
SELECT * FROM connectby('connectby_tree', 'keyid', 'parent_keyid', 'row2', 0, '~')
 AS t(keyid text, parent_keyid text, level int, branch text);
 keyid | parent_keyid | level |       branch
-------+--------------+-------+--------------------
 row2  |              |     0 | row2
 row4  | row2         |     1 | row2~row4
 row6  | row4         |     2 | row2~row4~row6
 row8  | row6         |     3 | row2~row4~row6~row8
 row5  | row2         |     1 | row2~row5
 row9  | row5         |     2 | row2~row5~row9
(6 rows)

-- without branch, without orderby_fld (order of results is not guaranteed)
SELECT * FROM connectby('connectby_tree', 'keyid', 'parent_keyid', 'row2', 0)
 AS t(keyid text, parent_keyid text, level int);
 keyid | parent_keyid | level
-------+--------------+-------
 row2  |              |     0
 row4  | row2         |     1
 row6  | row4         |     2
 row8  | row6         |     3
 row5  | row2         |     1
 row9  | row5         |     2
(6 rows)

-- with branch, with orderby_fld (notice that row5 comes before row4)
SELECT * FROM connectby('connectby_tree', 'keyid', 'parent_keyid', 'pos', 'row2', 0,
 '~')
 AS t(keyid text, parent_keyid text, level int, branch text, pos int);
 keyid | parent_keyid | level |       branch        | pos
```

```
-------+--------------+-------+---------------------+-----
 row2  |              |     0 | row2                |   1
 row5  | row2         |     1 | row2~row5           |   2
 row9  | row5         |     2 | row2~row5~row9      |   3
 row4  | row2         |     1 | row2~row4           |   4
 row6  | row4         |     2 | row2~row4~row6      |   5
 row8  | row6         |     3 | row2~row4~row6~row8 |   6
(6 rows)

-- without branch, with orderby_fld (notice that row5 comes before row4)
SELECT * FROM connectby('connectby_tree', 'keyid', 'parent_keyid', 'pos', 'row2', 0)
 AS t(keyid text, parent_keyid text, level int, pos int);
 keyid | parent_keyid | level | pos
-------+--------------+-------+-----
 row2  |              |     0 |   1
 row5  | row2         |     1 |   2
 row9  | row5         |     2 |   3
 row4  | row2         |     1 |   4
 row6  | row4         |     2 |   5
 row8  | row6         |     3 |   6
(6 rows)
```

F.66.2. Author

Joe Conway

F.67. tcn

The `tcn` module provides a trigger function that notifies listeners of changes to any table on which it is attached. It must be used as an `AFTER` trigger `FOR EACH ROW`.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

Only one parameter may be supplied to the function in a `CREATE TRIGGER` statement, and that is optional. If supplied it will be used for the channel name for the notifications. If omitted `tcn` will be used for the channel name.

The payload of the notifications consists of the table name, a letter to indicate which type of operation was performed, and column name/value pairs for primary key columns. Each part is separated from the next by a comma. For ease of parsing using regular expressions, table and column names are always wrapped in double quotes, and data values are always wrapped in single quotes. Embedded quotes are doubled.

A brief example of using the extension follows.

```
test=# create table tcndata
test-#   (
test(#     a int not null,
test(#     b date not null,
test(#     c text,
test(#     primary key (a, b)
test(#   );
CREATE TABLE
test=# create trigger tcndata_tcn_trigger
test-#   after insert or update or delete on tcndata
test-#   for each row execute function triggered_change_notification();
CREATE TRIGGER
test=# listen tcn;
LISTEN
```

```
test=# insert into tcndata values (1, date '2012-12-22', 'one'),
test-#                            (1, date '2012-12-23', 'another'),
test-#                            (2, date '2012-12-23', 'two');
INSERT 0 3
Asynchronous notification "tcn" with payload ""tcndata",I,"a"='1',"b"='2012-12-22'"
 received from server process with PID 22770.
Asynchronous notification "tcn" with payload ""tcndata",I,"a"='1',"b"='2012-12-23'"
 received from server process with PID 22770.
Asynchronous notification "tcn" with payload ""tcndata",I,"a"='2',"b"='2012-12-23'"
 received from server process with PID 22770.
test=# update tcndata set c = 'uno' where a = 1;
UPDATE 2
Asynchronous notification "tcn" with payload ""tcndata",U,"a"='1',"b"='2012-12-22'"
 received from server process with PID 22770.
Asynchronous notification "tcn" with payload ""tcndata",U,"a"='1',"b"='2012-12-23'"
 received from server process with PID 22770.
test=# delete from tcndata where a = 1 and b = date '2012-12-22';
DELETE 1
Asynchronous notification "tcn" with payload ""tcndata",D,"a"='1',"b"='2012-12-22'"
 received from server process with PID 22770.
```

F.68. test_decoding

`test_decoding` is an example of a logical decoding output plugin. It doesn't do anything especially useful, but can serve as a starting point for developing your own output plugin.

`test_decoding` receives WAL through the logical decoding mechanism and decodes it into text representations of the operations performed.

Typical output from this plugin, used over the SQL logical decoding interface, might be:

```
postgres=# SELECT * FROM pg_logical_slot_get_changes('test_slot', NULL, NULL, 'include-
xids', '0');
 location  | xid |                       data
-----------+-----+------------------------------------------------
 0/16D30F8 | 691 | BEGIN
 0/16D32A0 | 691 | table public.data: INSERT: id[int4]:2 data[text]:'arg'
 0/16D32A0 | 691 | table public.data: INSERT: id[int4]:3 data[text]:'demo'
 0/16D32A0 | 691 | COMMIT
 0/16D32D8 | 692 | BEGIN
 0/16D3398 | 692 | table public.data: DELETE: id[int4]:2
 0/16D3398 | 692 | table public.data: DELETE: id[int4]:3
 0/16D3398 | 692 | COMMIT
(8 rows)
```

We can also get the changes of the in-progress transaction, and the typical output might be:

```
postgres[33712]=#* SELECT * FROM pg_logical_slot_get_changes('test_slot', NULL, NULL,
 'stream-changes', '1');
    lsn    | xid |                       data
-----------+-----+------------------------------------------------
 0/16B21F8 | 503 | opening a streamed block for transaction TXN 503
 0/16B21F8 | 503 | streaming change for TXN 503
 0/16B2300 | 503 | streaming change for TXN 503
 0/16B2408 | 503 | streaming change for TXN 503
 0/16BEBA0 | 503 | closing a streamed block for transaction TXN 503
 0/16B21F8 | 503 | opening a streamed block for transaction TXN 503
 0/16BECA8 | 503 | streaming change for TXN 503
 0/16BEDB0 | 503 | streaming change for TXN 503
 0/16BEEB8 | 503 | streaming change for TXN 503
```

```
 0/16BEBA0 | 503 | closing a streamed block for transaction TXN 503
(10 rows)
```

F.69. tsm_system_rows

The tsm_system_rows module provides the table sampling method SYSTEM_ROWS, which can be used in the TABLESAMPLE clause of a SELECT command.

This table sampling method accepts a single integer argument that is the maximum number of rows to read. The resulting sample will always contain exactly that many rows, unless the table does not contain enough rows, in which case the whole table is selected.

Like the built-in SYSTEM sampling method, SYSTEM_ROWS performs block-level sampling, so that the sample is not completely random but may be subject to clustering effects, especially if only a small number of rows are requested.

SYSTEM_ROWS does not support the REPEATABLE clause.

This module is considered "trusted", that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.69.1. Examples

Here is an example of selecting a sample of a table with SYSTEM_ROWS. First install the extension:

```
CREATE EXTENSION tsm_system_rows;
```

Then you can use it in a SELECT command, for instance:

```
SELECT * FROM my_table TABLESAMPLE SYSTEM_ROWS(100);
```

This command will return a sample of 100 rows from the table my_table (unless the table does not have 100 visible rows, in which case all its rows are returned).

F.70. tsm_system_time

The tsm_system_time module provides the table sampling method SYSTEM_TIME, which can be used in the TABLESAMPLE clause of a SELECT command.

This table sampling method accepts a single floating-point argument that is the maximum number of milliseconds to spend reading the table. This gives you direct control over how long the query takes, at the price that the size of the sample becomes hard to predict. The resulting sample will contain as many rows as could be read in the specified time, unless the whole table has been read first.

Like the built-in SYSTEM sampling method, SYSTEM_TIME performs block-level sampling, so that the sample is not completely random but may be subject to clustering effects, especially if only a small number of rows are selected.

SYSTEM_TIME does not support the REPEATABLE clause.

This module is considered "trusted", that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.70.1. Examples

Here is an example of selecting a sample of a table with SYSTEM_TIME. First install the extension:

```
CREATE EXTENSION tsm_system_time;
```

Then you can use it in a SELECT command, for instance:

```
SELECT * FROM my_table TABLESAMPLE SYSTEM_TIME(1000);
```

This command will return as large a sample of my_table as it can read in 1 second (1000 milliseconds). Of course, if the whole table can be read in under 1 second, all its rows will be returned.

F.71. unaccent

unaccent is a text search dictionary that removes accents (diacritic signs) from lexemes. It's a filtering dictionary, which means its output is always passed to the next dictionary (if any), unlike the normal behavior of dictionaries. This allows accent-insensitive processing for full text search.

The current implementation of unaccent cannot be used as a normalizing dictionary for the thesaurus dictionary.

This module is considered “trusted”, that is, it can be installed by non-superusers who have CREATE privilege on the current database.

F.71.1. Configuration

An unaccent dictionary accepts the following options:

- RULES is the base name of the file containing the list of translation rules. This file must be stored in $SHAREDIR/tsearch_data/ (where $SHAREDIR means the Postgres Pro installation's shared-data directory). Its name must end in .rules (which is not to be included in the RULES parameter).

The rules file has the following format:

- Each line represents one translation rule, consisting of a character with accent followed by a character without accent. The first is translated into the second. For example,

  ```
  À       A
  Á       A
  Â       A
  Ã       A
  Ä       A
  Å       A
  Æ       AE
  ```

  The two characters must be separated by whitespace, and any leading or trailing whitespace on a line is ignored.
- Alternatively, if only one character is given on a line, instances of that character are deleted; this is useful in languages where accents are represented by separate characters.
- Actually, each “character” can be any string not containing whitespace, so unaccent dictionaries could be used for other sorts of substring substitutions besides diacritic removal.
- As with other Postgres Pro text search configuration files, the rules file must be stored in UTF-8 encoding. The data is automatically translated into the current database's encoding when loaded. Any lines containing untranslatable characters are silently ignored, so that rules files can contain rules that are not applicable in the current encoding.

A more complete example, which is directly useful for most European languages, can be found in unaccent.rules, which is installed in $SHAREDIR/tsearch_data/ when the unaccent module is installed. This rules file translates characters with accents to the same characters without accents, and it also expands ligatures into the equivalent series of simple characters (for example, Æ to AE).

F.71.2. Usage

Installing the unaccent extension creates a text search template unaccent and a dictionary unaccent based on it. The unaccent dictionary has the default parameter setting RULES='unaccent', which makes it immediately usable with the standard unaccent.rules file. If you wish, you can alter the parameter, for example

```
mydb=# ALTER TEXT SEARCH DICTIONARY unaccent (RULES='my_rules');
```

or create new dictionaries based on the template.

To test the dictionary, you can try:

```
mydb=# select ts_lexize('unaccent','Hôtel');
 ts_lexize
-----------
 {Hotel}
(1 row)
```

Here is an example showing how to insert the `unaccent` dictionary into a text search configuration:

```
mydb=# CREATE TEXT SEARCH CONFIGURATION fr ( COPY = french );
mydb=# ALTER TEXT SEARCH CONFIGURATION fr
        ALTER MAPPING FOR hword, hword_part, word
        WITH unaccent, french_stem;
mydb=# select to_tsvector('fr','Hôtels de la Mer');
    to_tsvector
-------------------
 'hotel':1 'mer':4
(1 row)

mydb=# select to_tsvector('fr','Hôtel de la Mer') @@ to_tsquery('fr','Hotels');
 ?column?
----------
 t
(1 row)

mydb=# select ts_headline('fr','Hôtel de la Mer',to_tsquery('fr','Hotels'));
      ts_headline
------------------------
 <b>Hôtel</b> de la Mer
(1 row)
```

F.71.3. Functions

The `unaccent()` function removes accents (diacritic signs) from a given string. Basically, it's a wrapper around `unaccent`-type dictionaries, but it can be used outside normal text search contexts.

`unaccent([`*`dictionary`* `regdictionary, ] `*`string`* `text) returns text`

If the *`dictionary`* argument is omitted, the text search dictionary named `unaccent` and appearing in the same schema as the `unaccent()` function itself is used.

For example:

```
SELECT unaccent('unaccent', 'Hôtel');
SELECT unaccent('Hôtel');
```

F.72. uuid-ossp

The `uuid-ossp` module provides functions to generate universally unique identifiers (UUIDs) using one of several standard algorithms. There are also functions to produce certain special UUID constants. This module is only necessary for special requirements beyond what is available in core PostgreSQL. See Section 9.14 for built-in ways to generate UUIDs.

This module is considered “trusted”, that is, it can be installed by non-superusers who have `CREATE` privilege on the current database.

F.72.1. `uuid-ossp` Functions

Table F.54 shows the functions available to generate UUIDs. The relevant standards ITU-T Rec. X.667, ISO/IEC 9834-8:2005, and *RFC 4122* specify four algorithms for generating UUIDs, identified by the version numbers 1, 3, 4, and 5. (There is no version 2 algorithm.) Each of these algorithms could be suitable for a different set of applications.

Table F.54. Functions for UUID Generation

Function Description
`uuid_generate_v1` () → `uuid` Generates a version 1 UUID. This involves the MAC address of the computer and a time stamp. Note that UUIDs of this kind reveal the identity of the computer that created the identifier and the time at which it did so, which might make it unsuitable for certain security-sensitive applications.
`uuid_generate_v1mc` () → `uuid` Generates a version 1 UUID, but uses a random multicast MAC address instead of the real MAC address of the computer.

`uuid_generate_v3` (*namespace* `uuid`, *name* `text`) → `uuid`
Generates a version 3 UUID in the given namespace using the specified input name. The namespace should be one of the special constants produced by the `uuid_ns_*()` functions shown in Table F.55. (It could be any UUID in theory.) The name is an identifier in the selected namespace.
For example:
`SELECT uuid_generate_v3(uuid_ns_url(), 'http://www.postgresql.org');`
The name parameter will be MD5-hashed, so the cleartext cannot be derived from the generated UUID. The generation of UUIDs by this method has no random or environment-dependent element and is therefore reproducible.

`uuid_generate_v4` () → `uuid` Generates a version 4 UUID, which is derived entirely from random numbers.
`uuid_generate_v5` (*namespace* `uuid`, *name* `text`) → `uuid` Generates a version 5 UUID, which works like a version 3 UUID except that SHA-1 is used as a hashing method. Version 5 should be preferred over version 3 because SHA-1 is thought to be more secure than MD5.

Table F.55. Functions Returning UUID Constants

Function Description
`uuid_nil` () → `uuid` Returns a “nil” UUID constant, which does not occur as a real UUID.
`uuid_ns_dns` () → `uuid` Returns a constant designating the DNS namespace for UUIDs.
`uuid_ns_url` () → `uuid` Returns a constant designating the URL namespace for UUIDs.
`uuid_ns_oid` () → `uuid` Returns a constant designating the ISO object identifier (OID) namespace for UUIDs. (This pertains to ASN.1 OIDs, which are unrelated to the OIDs used in Postgres Pro.)
`uuid_ns_x500` () → `uuid` Returns a constant designating the X.500 distinguished name (DN) namespace for UUIDs.

F.72.2. Building `uuid-ossp`

Historically this module depended on the OSSP UUID library, which accounts for the module's name. While the OSSP UUID library can still be found at *http://www.ossp.org/pkg/lib/uuid/*, it is not well maintained, and is becoming increasingly difficult to port to newer platforms. `uuid-ossp` can now be built without the OSSP library on some platforms. On FreeBSD and some other BSD-derived platforms, suitable UUID creation functions are included in the core `libc` library. On Linux, macOS, and some other

platforms, suitable functions are provided in the libuuid library, which originally came from the e2fsprogs project (though on modern Linux it is considered part of util-linux-ng). When invoking configure, specify --with-uuid=bsd to use the BSD functions, or --with-uuid=e2fs to use e2fsprogs' libuuid, or --with-uuid=ossp to use the OSSP UUID library. More than one of these libraries might be available on a particular machine, so configure does not automatically choose one.

F.72.3. Author

Peter Eisentraut <peter_e@gmx.net>

F.73. vops

> **Important**
>
> The vops extension is considered deprecated. It is not recommended to use it.

The vops module is an experimental Postgres Pro Enterprise extension that provides support for vector operations, which allows to speed up OLAP queries with filtering and aggregation more than 10 times. Performance improvements are achieved by implementing a vertical data model that allows storing data in *tiles*, or groups of column values. Such a storage format is also called *Parquet* in some analytical databases. Reducing the overhead of unpacking tuples, vertical data model allows to speed up query execution without any radical changes in Postgres Pro planner and executor.

vops provides its own set of vector functions that can be used inside predicates and aggregate expressions. To avoid learning new syntax, you can use postgres_fdw as an abstraction layer and run regular SQL queries on vectorized data. For query types other than filtering and aggregation, vops can also use postgres_fdw to present vectorized data as a regular table with scalar column types and process this data as regular tuples. For ease of use, vops also provides an automated way of generating and accessing vectorized data, as explained in Section F.73.5.5.

F.73.1. Limitations

- Tile-based tables only allow INSERT and APPEND operations. Once imported, vectorized data cannot be updated.
- Vector operations are only available for filtering and aggregation. Other query types are supported via postgres_fdw.
- Aggregate expressions must be of the same type.
- JOIN operations are not supported for vector types. You have to use postgres_fdw to transform vectorized data back to regular tuples to run such queries.
- Since postgres_fdw does not support parallel query execution, you can only run parallel queries when using vector operators directly.

F.73.2. Installation and Setup

The vops extension is included into Postgres Pro Enterprise. Once you have Postgres Pro Enterprise installed, complete the following steps to enable vops:

1. Add vops to the shared_preload_libraries parameter in the postgresql.conf file:

```
shared_preload_libraries = 'vops'
```

> **Note**
>
> If the extension library is not added to the shared_preload_libraries list, it will be loaded on demand after the first function invocation of this extension. In this case, the first time you execute a vectorized query, it will not be processed correctly and can return a wrong result.

2. Restart the Postgres Pro Enterprise instance for the changes to take effect.
3. Create `vops` extension:

```
CREATE EXTENSION vops;
```

Once `vops` is enabled, you can create vectorized tables and query data using vector operations in your database.

If you would like to use regular SQL syntax for vector types, you must also enable postgres_fdw.

F.73.3. Motivation

For OLTP workloads, Postgres Pro looks very competitive as compared to other mainstream databases. However, for OLAP queries, which require processing larger volumes of data, analytics-oriented database management systems can provide a much better speed. There are several main factors that limit Postgres Pro performance:

- Tuple unpacking overhead. To access column values, Postgres Pro needs to unpack the tuple. As tables can have columns of variable-length data types, to extract the N-th column, the preceding N-1 columns need to be unpacked. Thus, deforming a tuple is quite an expensive operation, especially for tables with a large number of attributes. Besides, values can be compressed or stored in another page (TOAST). In queries like Query 6 of the *TPC-H benchmark*, deforming tuples takes about 40% of the total query execution time.
- Interpretation overhead. Postgres Pro planner and optimizer build a tree representing the query execution plan. Query executor recursively calls functions that evaluate the nodes of this tree. Some nodes may also contain switches used to select the requested action. Thus, query plan is interpreted by Postgres Pro query executor rather than directly executed. The interpreter is usually about 10 times slower than the native code. If you eliminate interpretation overhead, you can increase query speed several times, especially for queries with complex predicates that have high evaluation costs.
- Abstraction penalty. Support for abstract (user-defined) types and operations is one of the key features of Postgres Pro. However, the price of such flexibility is that each operation requires a separate function call. Instead of adding two integers directly, Postgres Pro executor invokes a function that performs addition. In this case, function call overhead is much higher than the cost the operation itself. Function call overhead is also increased because Postgres Pro requires passing parameter values through memory.
- Pull model overhead. In Postgres Pro, operators pull the operand values. This approach simplifies the implementation of operators and the executor, but has a negative impact on performance. In this model, leaf nodes that fetch a tuple from the heap or index pages have to do a lot of extra work while saving and restoring their context.
- MVCC overhead. Postgres Pro provides multi-version concurrency control, which allows multiple transactions to work with the same record in parallel without blocking each other. It is good for frequently updated data (OLTP), but for read-only or append-only data in OLAP scenarios it only adds both space overhead (about 20 extra bytes per tuple) and CPU overhead (checking visibility of each tuple).

Vector operations can address most of these issues without radical changes in the Postgres Pro executor, as explained in Section F.73.4.

F.73.4. Architecture

The `vops` extension implements a *vertical data model* for Postgres Pro. In this model, vertical columns are used as a data storing unit, with the values of the corresponding table attribute forming a vector.

The vertical data model used by `vops` has the following advantages:

- Reduces the size of fetched data: only the columns used in the query need to be fetched.
- Achieves higher compression rates: storing all values of the same attribute together makes it possible to compress them much better and faster. For example, you can use delta encoding.
- Minimizes interpretation overhead: a set of values can be processed by a single operation instead of running separate operations for each value.

- Uses CPU vector instructions (SIMD) to process data.

A traditional Postgres Pro query executor deals with a single row of data at each moment of time. For example, to evaluate an expression `(x+y)`, it first fetches the value of `x`, then fetches the value of `y`, performs the addition, and returns the result value to the upper node. In contrast, a vectorized executor can process multiple values within a single operation. In this case, `x` and `y` represent vectors of values instead of single scalars. The returned result is also a vector. In vector execution model, interpretation and function call overhead is divided by the vector size. The price of performing a function call is the same, but as the function processes N values instead of a single one, this overhead becomes less critical. The larger the vector, the smaller the per-row overhead.

However, performing an operation on the whole column may also turn out to be ineffective. Working with large vectors prevents efficient utilization of CPU cache levels. If the table is very large, the vector may not fit in memory at all. To avoid these issues, `vops` splits the columns into relatively small chunks, or *tiles*. The size of a tile is currently set to 64 elements. It allows to keep all operands of vector operations in cache, even for complex expressions.

The `vops` extension implements special vector types to be used instead of scalar types for table columns. The available types are listed in Section F.73.6.1. To use `vops`, you have to create vectorized projections of original tables, with at least some attributes using these tile types, as explained in Section F.73.5.1.

The original table can be treated as a write-optimized storage: if it has no indexes, Postgres Pro can provide a very fast insertion speed, comparable to raw disk write speed. Vectorized projection can be treated as a read-optimized storage, which is most efficient for running OLAP queries.

Once all the data is in the tile-based format, you can run vectorized queries on this data. `vops` provides a set of vector operators to work with vector types. Using these operators, you can write queries for filtering and aggregation, similar to SQL queries. For details, see Section F.73.5.2.

For other query types, `vops` allows to work with vectorized data via `postgres_fdw`. You can add vectorized data to your database cluster as a foreign table and use regular SQL for running any types of queries on this data. Using the implicit type casts and post-parse `ANALYZE` hook, the `vops` extension either transforms the query to use vector operators for filtering and aggregation, or processes the data using scalar operators for other query types. For details, see Section F.73.5.3.

F.73.5. Usage

F.73.5.1. Converting Data into Vectorized Format

To start using vector operations, you have to convert your data into a vectorized format, as explained below.

1. **Create an empty vectorized table.**

   To use vector operations, you need to load data into a tile-based vectorized table, which can be treated as a *projection* of the original table. It can map all columns of the original table, or include some of the most frequently used columns only. To create a vectorized table, you can use the regular CREATE TABLE syntax, but at least some of the columns must be of vector types.

   For example, suppose you have the following table from the TPC-H benchmark:

```
CREATE TABLE lineitem(
   l_orderkey integer,
   l_partkey integer,
   l_suppkey integer,
   l_linenumber integer,
   l_quantity double precision,
   l_extendedprice double precision,
   l_discount double precision,
   l_tax double precision,
   l_returnflag "char",
```

```
    l_linestatus "char",
    l_shipdate date,
    l_commitdate date,
    l_receiptdate date,
    l_shipinstruct char(25),
    l_shipmode char(10),
    l_comment char(44));
```

To create a vectorized projection that includes only a subset of the original columns, you can run:

```
CREATE TABLE vops_lineitem(
    l_shipdate vops_date not null,
    l_quantity vops_float8 not null,
    l_extendedprice vops_float8 not null,
    l_discount vops_float8 not null,
    l_tax vops_float8 not null,
    l_returnflag vops_char not null,
    l_linestatus vops_char not null
);
```

Alternatively, you can keep the scalar type for some of the columns. In this case, you can sort the data by these columns when loading the data. For example, let's create another vectorized projection where `l_returnflag` and `l_linestatus` fields remain scalar:

```
CREATE TABLE vops_lineitem_projection(
    l_shipdate vops_date not null,
    l_quantity vops_float8 not null,
    l_extendedprice vops_float8 not null,
    l_discount vops_float8 not null,
    l_tax vops_float8 not null,
    l_returnflag "char" not null,
    l_linestatus "char" not null
);
```

In this table, `l_returnflag` and `l_linestatus` fields are scalar, while all the other fields are of the vector types that can be used in vector operations.

2. **Load the data into the vectorized table.**

   - If the data to load is already stored in your database, use the populate() function to preprocess the data and unite attribute values of several rows inside a single tile. This function loads the data from the original table into its vectorized projection, using vector types instead of scalar types, as specified in the created empty table.

     For example:

     ```
     SELECT populate(destination := 'vops_lineitem'::regclass, source :=
      'lineitem'::regclass);
     ```

     Once the table is populated, you can start running queries performing sequential scan.

     Optionally, you can sort the data by one or more scalar columns when loading the data:

     ```
     SELECT populate(destination := 'vops_lineitem_projection'::regclass, source :=
      'lineitem'::regclass, sort := 'l_returnflag,l_linestatus');
     ```

     If you sort the original table by the scalar columns that have a lot of duplicates, `vops` can effectively collapse them and store the corresponding attribute values in tiles, which can reduce the occupied space, speed up queries, and facilitate index creation on these scalar columns.

   - If your data is not yet loaded into the database and you would like to avoid having two copies of the same dataset, you can import the data into a vectorized table directly from a CSV file using the import() function, bypassing creation of a regular table. For example:

```
SELECT import(destination := 'vops_lineitem'::regclass, csv_path := '/mnt/data/
lineitem.csv', separator := '|');
```

For detailed description and syntax of the `populate()` and `import()` functions, see Section F.73.6.4.

Once your data is in the tile-based format, you can run queries on this data using vector operators, as described in Section F.73.5.2. If you create a foreign vectorized table, you can also run regular SQL queries. See Section F.73.5.3 for details.

F.73.5.2. Running Queries on Vectorized Data

`vops` implements its own vector functions and operators for working with vectorized data. See Section F.73.6 for the full list of vector functions and operators and their usage specifics.

F.73.5.2.1. Aggregating Vectorized Data

OLAP queries often aggregate large volumes of data. To enable aggregate operations for vector types, `vops` implements the following aggregate functions for vectorized data: `count`, `min`, `max`, `avg`, `var_pop`, `var_sampl`, `variance`, `stddev_pop`, `stddev_samp`, `stddev`. Besides, `vops` provides the `wavg` aggregate function that calculates volume-weighted average price (VWAP).

The `vops` extension supports the following types of aggregates:

- grand aggregates calculated for the whole table
- aggregates for subsets of table rows defined by the `GROUP BY` clause

F.73.5.2.1.1. Calculating Grand Aggregates

To calculate grand aggregates, you can use the provided vector aggregate functions exactly like in regular SQL queries.

Examples:

To calculate volume-weighted average price, run the following query:

```
SELECT wavg(l_extendedprice,l_quantity) FROM vops_lineitem;
```

To calculate the company revenue for the year 1996 based on discounted prices of the shipped goods, run:

```
SELECT sum(l_extendedprice*l_discount) AS revenue
  FROM vops_lineitem
  WHERE filter(betwixt(l_shipdate, '1996-01-01', '1997-01-01')
        & betwixt(l_discount, 0.08, 0.1)
        & (l_quantity < 24));
```

F.73.5.2.1.2. Calculating Grouped Aggregates

To support grouped aggregates, `vops` provides `map()` and `reduce()` functions:

- The `map()` function collects aggregate states for all groups in a hash table. Its syntax is as follows:

  ```
  map(group_by_expression,
        aggregate_list, expr {,
        expr })
  ```

- The `reduce()` function iterates through the hash table constructed by `map` and returns the set. The `reduce` function is needed because the result of aggregation in Postgres Pro cannot be a set.

Consider the following example:

```
SELECT reduce(map(l_returnflag||l_linestatus, 'sum,sum,sum,sum,avg,avg,avg',
    l_quantity,
    l_extendedprice,
    l_extendedprice*(1-l_discount),
```

```
    l_extendedprice*(1-l_discount)*(1+l_tax),
    l_quantity,
    l_extendedprice,
    l_discount))
FROM vops_lineitem
WHERE filter(l_shipdate <= '1998-12-01'::date);
```

The concatenation operator `||` performs grouping by two columns. The `vops` extension supports grouping only by an integer type. The `map` function accepts aggregation arguments as a variadic array, so all elements of this array should have the same type. For example, you cannot calculate aggregates for `vops_float4` and `vops_int8` columns in a single operation.

An aggregate string in `map` function should contain the list of aggregate functions to call, in a comma-separated format. Standard lowercase names should be used: `count`, `sum`, `agg`, `min`, `max`. Count is executed for the particular column: `count(x)`. There is no need to explicitly specify `count(*)` because the number of records in each group is returned by `reduce` function in any case.

`reduce` function returns set of the `vops_aggregate` type. It contains three components: the value of the `GROUP BY` expression, the number of records in the group, and an array of floats with aggregate values. The values of all aggregates, including `count` and `min/max`, are returned as floats.

Alternatively, you can partition the vectorized table by the `GROUP BY` fields to calculate grouped aggregates. In this case, grouping keys are stored as regular scalar values, while other fields are stored inside tiles. Now Postgres Pro executor will execute vops aggregates for each group:

```
SELECT
    l_returnflag,
    l_linestatus,
    sum(l_quantity) as sum_qty,
    sum(l_extendedprice) AS sum_base_price,
    sum(l_extendedprice*(1-l_discount)) AS sum_disc_price,
    sum(l_extendedprice*(1-l_discount)*(1+l_tax)) AS sum_charge,
    avg(l_quantity) AS avg_qty,
    avg(l_extendedprice) AS avg_price,
    avg(l_discount) AS avg_disc,
    count(*) AS count_order
FROM
    vops_lineitem_projection
WHERE
    filter(l_shipdate <= '1998-12-01'::date)
GROUP BY
    l_returnflag,
    l_linestatus
ORDER BY
    l_returnflag,
    l_linestatus;
```

In this example, `l_returnflag` and `l_linestatus` fields of the `vops_lineitem_projection` table have the `char` type, while all the other used fields are of vector types. The query above is executed even faster than query with the `map()` and `reduce()` functions. The main problem with this approach is that you have to create a separate projection for each combination of the `GROUP BY` keys to be used in queries.

F.73.5.2.2. Using Vector Window Functions

The `vops` extension provides limited support for Postgres Pro window functions. It provides `mcount`, `msum`, `mmin`, `mmax`, `mavg`, and `lag` functions that correspond to the standard Postgres Pro window functions `count`, `sum`, `min`, `max`, `avg`, and `lag` functions, respectively.

Note the following important restrictions:

1. Filtering, grouping, and sorting can be done only by scalar attributes.

2. Vector window functions only support window frames specified with `ROWS BETWEEN UNBOUNDED PRECEDING AND CURRENT ROW`.

Examples:

```
SELECT vops_unnest(t.*)
  FROM (SELECT mcount(*) over w,mcount(x) over w,msum(x) over w,mavg(x) over w,mmin(x)
 over w,mmax(x) over w,x - lag(x) over w
  FROM v window w
  AS (rows between unbounded preceding and current row)) t;
```

F.73.5.2.3. Converting Results to Horizontal Format

A query from the `vops` projection returns a set of tiles. The output function of a tile type can print the tile contents. However, if you want to convert the result to the horizontal format where each tuple represents a single record, use the vops-unnest function. For example:

```
SELECT vops_unnest(l.*)
  FROM vops_lineitem l
  WHERE filter(l_shipdate >= '1998-12-01'::date);
```

F.73.5.3. Using Standard SQL for Vector Operations

Vector operators can efficiently execute only filtering and aggregation queries. For other query types, you have to run regular SQL queries. The `vops` extension offers the following options:

- Use the original table, if any.
- Enable a foreign data wrapper (FDW) using `postgres_fdw` to present a vectorized table to Postgres Pro as a regular table with scalar column types.

If you use `postgres_fdw` with the `vops` extension, vectorized data is not really foreign: it is stored inside the database in an alternative vectorized format. FDW allows to hide specifics of the vectorized format and provides the following opportunities for working with vectorized data:

1. Extract the data from a vectorized table and present it in the horizontal format, so that it can be processed by upper nodes in the query execution plan.
2. Push filtering and aggregation queries down to vector operations.
3. Get statistic for the underlying table by running `ANALYZE` for the foreign table. The collected statistic can be used by the query optimizer, so query execution plan should be almost the same as for regular tables.

Thus, by placing a vectorized projection under FDW, you can use standard SQL without any `vops`-specific functions to perform sequential scan and aggregation queries as if they are explicitly written for the `vops` table, and execute any other queries on this data at the same time, including `JOIN` operations, common table expressions (CTE), etc. The queries that can be efficiently executed by vector operations will be pushed by Postgres Pro query optimizer to `vops` FDW and will be executed using vector operators. For other queries, the data is fetched from vectorized tables as standard tuples. If it is determined that vector operations are required, `vops` uses a post-parse `ANALYZE` hook that replaces scalar boolean operations with vector boolean operations:

Original Expression	Transformed Expression
`NOT filter(o1)`	`filter(vops_bool_not(o1))`
`filter(o1) AND filter(o2)`	`filter(vops_bool_and(o1, o2))`
`filter(o1) OR filter(o2)`	`filter(vops_bool_or(o1, o2))`

There is only one difference between standard SQL and its vectorized extension. You still have to perform explicit type cast for string literals. For example, `l_shipdate <= '1998-12-01'` will not work for the `l_shipdate` column with vector type. Postgres Pro Enterprise has two overloaded versions of the **<=** operator to choose the appropriate scalar or vector type:

- `vops_date` **<=** `vops_date`

- vops_date **<=** date

The example below shows creation of a vectorized table via postgres_fdw and some queries on it:

```
CREATE FOREIGN TABLE lineitem_fdw (
   l_suppkey int4 not null,
   l_orderkey int4 not null,
   l_partkey int4 not null,
   l_shipdate date not null,
   l_quantity float8 not null,
   l_extendedprice float8 not null,
   l_discount float8 not null,
   l_tax      float8 not null,
   l_returnflag "char" not null,
   l_linestatus "char" not null
) SERVER vops_server OPTIONS (table_name 'vops_lineitem');

EXPLAIN SELECT
   sum(l_extendedprice*l_discount) AS revenue
FROM
   lineitem_fdw
WHERE
   l_shipdate BETWEEN '1996-01-01' AND '1997-01-01'
   AND l_discount BETWEEN 0.08 AND 0.1
   AND l_quantity < 24;
                       QUERY PLAN
-------------------------------------------------------
 Foreign Scan  (cost=1903.26..1664020.23 rows=1 width=4)
(1 row)

-- Filter was pushed down to FDW

EXPLAIN SELECT
    n_name,
    count(*),
    sum(l_extendedprice * (1-l_discount)) AS revenue
FROM
    customer_fdw JOIN orders_fdw ON c_custkey = o_custkey
    JOIN lineitem_fdw ON l_orderkey = o_orderkey
    JOIN supplier_fdw ON l_suppkey = s_suppkey
    JOIN nation ON c_nationkey = n_nationkey
    JOIN region ON n_regionkey = r_regionkey
WHERE
    c_nationkey = s_nationkey
    AND r_name = 'ASIA'
    AND o_orderdate >= '1996-01-01'
    AND o_orderdate < '1997-01-01'
GROUP BY
    n_name
ORDER BY
    revenue desc;
                                                                  QUERY PLAN

-------------------------------------------------------------------------------------------
 Sort  (cost=2337312.28..2337312.78 rows=200 width=48)
   Sort Key: (sum((lineitem_fdw.l_extendedprice * ('1'::double precision -
 lineitem_fdw.l_discount)))) DESC
   ->  GroupAggregate  (cost=2336881.54..2337304.64 rows=200 width=48)
         Group Key: nation.n_name
```

```
          ->  Sort  (cost=2336881.54..2336951.73 rows=28073 width=40)
                Sort Key: nation.n_name
                ->  Hash Join  (cost=396050.65..2334807.39 rows=28073 width=40)
                      Hash Cond: ((orders_fdw.o_custkey = customer_fdw.c_custkey) AND
(nation.n_nationkey = customer_fdw.c_nationkey))
                      ->  Hash Join  (cost=335084.53..2247223.46 rows=701672 width=52)
                            Hash Cond: (lineitem_fdw.l_orderkey = orders_fdw.o_orderkey)
                            ->  Hash Join  (cost=2887.07..1786058.18 rows=4607421
width=52)
                                  Hash Cond: (lineitem_fdw.l_suppkey =
supplier_fdw.s_suppkey)
                                  ->  Foreign Scan on lineitem_fdw
(cost=0.00..1512151.52 rows=59986176 width=16)
                                  ->  Hash  (cost=2790.80..2790.80 rows=7702 width=44)
                                        ->  Hash Join  (cost=40.97..2790.80 rows=7702
width=44)
                                              Hash Cond: (supplier_fdw.s_nationkey =
nation.n_nationkey)
                                              ->  Foreign Scan on supplier_fdw
(cost=0.00..2174.64 rows=100032 width=8)
                                              ->  Hash  (cost=40.79..40.79 rows=15
width=36)
                                                    ->  Hash Join  (cost=20.05..40.79
rows=15 width=36)
                                                          Hash Cond: (nation.n_regionkey
= region.r_regionkey)
                                                          ->  Seq Scan on nation
(cost=0.00..17.70 rows=770 width=40)
                                                          ->  Hash  (cost=20.00..20.00
rows=4 width=4)
                                                                ->  Seq Scan on region
(cost=0.00..20.00 rows=4 width=4)
                                                                      Filter:
((r_name)::text = 'ASIA'::text)
                            ->  Hash  (cost=294718.76..294718.76 rows=2284376 width=8)
                                  ->  Foreign Scan on orders_fdw  (cost=0.00..294718.76
rows=2284376 width=8)
                      ->  Hash  (cost=32605.64..32605.64 rows=1500032 width=8)
                            ->  Foreign Scan on customer_fdw  (cost=0.00..32605.64
rows=1500032 width=8)

-- filter on orders range is pushed to FDW
```

F.73.5.4. Building Indexes for Vectorized Tables

Analytic queries are usually performed on the data for which no indexes are defined. Vector operations on tiles are most effective in this case. However, you can still use indexes with vectorized data.

Since each tile represents multiple values, an index can be used only for some preliminary, non-precise filtering of data. The `vops` extension provides the following pairs of functions to obtain boundary values stored in the tile:

- `first()` and `last()` functions should be used for sorted dataset. In this case, the first and the last values in the tile are the smallest and the largest values in the tile, respectively.
- `high()` and `low()` functions should be used for unsorted data. These functions are more expensive because they need to inspect all tile values.

Using the returned values, you can construct functional indexes for vectorized data. The BRIN index seems to be the best choice:

```
CREATE INDEX low_boundary ON trades
USING brin(first(day)); -- trades table is ordered by day
CREATE INDEX high_boundary ON trades
USING brin(last(day)); -- trades table is ordered by day
```

Now you can use the created indexes in queries. However, you have to recheck the precise condition because such an index only gives an approximate result:

```
SELECT sum(price) FROM trades
WHERE first(day) >= '2015-01-01' AND last(day) <= '2016-01-01'
AND filter(betwixt(day, '2015-01-01', '2016-01-01'));
```

F.73.5.5. Automating Projection Usage

`vops` can automate most of the operations required to create and maintain vectorized data projections. In this case, you do not have to use postgres_fdw: `vops` can redirect regular SQL queries to projection tables automatically. However, these queries must satisfy the following criteria to get redirected:

- The query does not contain joins.
- The query performs aggregation of vector columns.
- All other expressions in the target list, as well as `ORDER BY` and `GROUP BY` clauses refer only to scalar columns.

To enable automatic query redirection to a vectorized projection of your data, do the following:

1. **Create a vectorized projection of the table using the create_projection() function.**

   For example, to create a projection for the `lineitem` table shown above, similar to the `vops_lineitem`, run:

   ```
   SELECT create_projection('auto_vops_lineitem','lineitem',

    array['l_shipdate','l_quantity','l_extendedprice','l_discount','l_tax'],
                            array['l_returnflag','l_linestatus']);
   ```

   In this example, the first two arguments specify the projection table and the original table, respectively, the first array defines all the vector columns to be included into the projection, and the second array specifies the scalar columns that will be used for grouping vectorized data into tiles.

   Additionally, you can provide an optional `order_by` parameter to speed up subsequent projection refresh operations. The `order_by` values should be unique. For example, to sort all table entries by `l_shipdate`, you can create a projection table as follows:

   ```
   SELECT create_projection('auto_vops_lineitem_ordered','lineitem',

    array['l_shipdate','l_quantity','l_extendedprice','l_discount','l_tax'],
                            array['l_returnflag','l_linestatus'],
                            'l_shipdate');
   ```

2. **Set the vops.auto_substitute_projections parameter to `on`.**

   Now all queries that `vops` can redirect to the `auto_vops_lineitem` projection table will be run on the vectorized data.

Projections are not updated automatically, so once the original table gets updated, implicitly redirected queries can start returning inaccurate results. To avoid this, you have to refresh the projections before running queries on the vectorized data. For this purpose, `vops` provides the *pname*`_refresh()` functions, where the *pname* prefix is the name of the projection you need to refresh. For example, to refresh the `auto_vops_lineitem` projection, run:

```
SELECT auto_vops_lineitem_refresh();
```

This function calls the `populate()` method to update all the fields present in the projection. If you have specified the optional `order_by` parameter when creating the projection, only the new data will be im-

ported from the original table, selecting only the rows with the `order_by` column value greater than the maximal value of this column in the projection. Otherwise, the whole table will be re-written. The `populate()` method also takes the grouping columns into account to efficiently group the imported data in tiles.

If you have specified the `order_by` attribute when creating a projection, `vops` also creates the following indexes:

- Two functional BRIN indexes on `first()` and `last()` functions of this attribute. Such indexes allow to efficiently select time slices. For example, if the original query contains predicates like `(l_shipdate between '01-01-2017' and '01-01-2018')`, `vops` adds the `(first(l_shipdate) >= '01-01-2017' and last(l_shipdate) >= '01-01-2018')` conjuncts when redirecting the query, so that Postgres Pro optimizer can quickly locate the affected pages using BRIN indexes.
- A BRIN index for scalar columns used for grouping. Such index allows to efficiently select groups and perform index joins.

F.73.6. Reference

F.73.6.1. Vector Types

The `vops` extension supports all basic Postgres Pro numeric types: 1-, 2-, 4-, 8-byte integers, as well as 4- and 8-byte floats. The `date` and `timestamp` types are using the same implementation as `int4` and `int8`, respectively. The table below illustrates the available vector types, as compared to the corresponding SQL and C types.

SQL Type	C Type	vops Vector Type
bool	bool	vops_bool
"char"	char	vops_char
date	DateADT	vops_date
int2	int16	vops_int2
int4	int32	vops_int4
int8	int64	vops_int8
float4	float4	vops_float4
float8	float8	vops_float8
timestamp	Timestamp	vops_timestamp
char(*N*), varchar(*N*)	text	vops_text(*N*)

> **Note**
>
> For performance reasons, using `vops_text` for single-character strings is not recommended. If you are using strings as identifiers, you can place them in a dictionary and use integer identifiers instead of the original strings.

F.73.6.2. Vector Operators

The `vops` extension provides a set of operators for vector types.

F.73.6.2.1. Mathematical Operators

For mathematical operations, `vops` overloads regular SQL operators, so they can take operands of both vector and scalar types.

Operator	Description
+	Addition

Operator	Description
-	Binary subtraction or unary negation
*	Multiplication
/	Division

||	Concatenation. This operator is only supported for `char`, `int2`, and `int4` types. It returns an integer type of a doubled size:
	`(char || char) -> int2`
	`(int2 || int2) -> int4`
	`(int4 || int4) -> int8`

F.73.6.2.2. Comparison Operators

For comparison operations, `vops` overloads regular SQL operators, so they can take operands of both vector and scalar types.

Operator	Description
=	Equals
<>	Not equals
<	Less than
<=	Less than or equals
>	Greater than
>=	Greater than or equals

F.73.6.2.3. Boolean Operators

Boolean operators `AND`, `OR`, and `NOT` cannot be overloaded, so `vops` provides its own implementation of boolean operators for vector types:

Operator	Description
&	Boolean AND
|	Boolean OR
!	Boolean NOT

Vector boolean operators have the following usage specifics:

- The precedence of vector boolean operators is different from `AND`, `OR`, and `NOT`, so you have to enclose the operands into parentheses. For example:

  ```
  (x=1) | (x=2)
  ```
- The result of vector boolean operations is `vops_bool`. Since Postgres Pro requires predicate expressions to have a regular boolean type, you have to convert the result to the `bool` type using the `filter()` function. Taking a vector boolean expression, this function calculates a `filter_mask` value that defines the result of this boolean operation for each vector element. If all mask bits are zero (the predicate is false for all vector elements), then `filter()` returns `false`, and Postgres Pro executor skips this record. Otherwise, `true` is returned, so vector operators will check the `filter_mask` value for the selected vector elements in subsequent operations.
- When using vector boolean operators, you have to use explicit cast of string constants to the required data type.

F.73.6.3. Comparison Functions

Function	Description
`bitwixt(x,low,high)`	Same as the *x* `BETWEEN` *low* `AND` *high* predicate.

Function	Description
is_null(x)	Same as the *expression* IS NULL predicate.
is_not_null(x)	Same as the *expression* IS NOT NULL predicate.
ifnull(x,subst)	Same as the COALESCE function.

F.73.6.4. Conversion Functions

create_projection(*projection_name* text, *source_table* regclass, *vector_columns* text[], *scalar_columns* text[] DEFAULT null, *order_by* text DEFAULT null)

Creates a projection table with specified name and attributes and updates the vops_projections table to include the information about this projection, so that the optimizer can automatically redirect queries from the original table to its projection. It also creates the pname_refresh() function that can update the projection.

Arguments:

- *projection_name* — the name of the projection table.
- *source_table* — the original Postgres Pro table for which to create a vectorized projection.
- *vector_columns* — an array of column names that will be stored as vops tiles.
- *scalar_columns* — an array of column names that will preserve its original scalar type. These columns will be used to group table rows into vops tiles. vops automatically builds a BRIN index over such columns.
- *order_by* — an optional vector column that can be used to sort data in the projection table. Sorting can be useful to incrementally update the projection after the original table updates using the pname_refresh() function. This column should contain unique timestamp values, such as trade dates. vops automatically builds a functional BRIN index for first() and last() functions of this column.

Examples:

```
SELECT
 create_projection('vops_lineitem','lineitem',array['l_shipdate','l_quantity','l_extended
```

*pname*_refresh()

Refreshes the *pname* projection table.

Examples:

Refresh the vops_lineitem projection:

```
SELECT vops_lineitem_refresh();
```

drop_projection(*projection_name* text)

Drops the specified projection and the corresponding refresh function, as well as removes the information about this projection from the vops_projections table.

Examples:

Drop the vops_lineitem projection:

```
SELECT drop_projection(vops_lineitem);
```

populate(*destination* regclass, *source* regclass, *predicate* cstring DEFAULT null, *sort* cstring DEFAULT null)

Copies the data from an existing table to its vectorized projection and returns the number of imported rows (bigint).

Arguments:

- *destination* — target table to copy the data into.

  Type: regclass

- *source* — source table to copy the data from.

  Type: regclass

- *predicate* — restricts the amount of imported data (optional). Using this argument, you can upload only the most recent records.

  Type: cstring

- *sort* — sorts the source data to define the order in which the data needs to be loaded (optional).

  Type: cstring

Examples:

```
SELECT populate(destination := 'vops_lineitem'::regclass, source :=
 'lineitem'::regclass);

SELECT populate(destination := 'vops_lineitem_projection'::regclass, source :=
 'lineitem_projection'::regclass, sort := 'l_returnflag,l_linestatus');
```

import(*destination* regclass, *csv_path* cstring, *separator* cstring DEFAULT ',' *skip* integer DEFAULT 0)

Loads the data into a vops table directly from a CSV file, bypassing creation of a regular table, and returns the number of imported rows (bigint). Use this function to avoid storing two copies of the same dataset.

Arguments:

- *destination* — target table to copy the data into.

  Type: regclass

- *csv_path* — the path to the CSV file to copy the data from.

  Type: cstring

- *separator* — specifies the field separator used in the CSV file (optional). By default, the comma is assumed to be the field separator.

  Type: cstring

- *skip* — specifies the number of rows in the CSV header that do not need to be imported (optional).

  Default: 0

  Type: cstring

Examples:

```
SELECT import(destination := 'vops_lineitem'::regclass, csv_path := '/mnt/data/
lineitem.csv', separator := '|');
```

vops_unnest(anyelement)

Scatters records with vops types into records with scalar types.

F.73.6.5. Configuration Parameters

`vops.auto_substitute_projections` (`boolean`)

Enables automatic query redirection to projection tables. For correct results, you have to ensure that the projection is synchronized with the original table.

Default: `off`

F.73.7. Authors

Postgres Professional, Moscow, Russia

F.74. xml2

The `xml2` module provides XPath querying and XSLT functionality.

F.74.1. Deprecation Notice

From PostgreSQL 8.3 on, there is XML-related functionality based on the SQL/XML standard in the core server. That functionality covers XML syntax checking and XPath queries, which is what this module does, and more, but the API is not at all compatible. It is planned that this module will be removed in a future version of Postgres Pro in favor of the newer standard API, so you are encouraged to try converting your applications. If you find that some of the functionality of this module is not available in an adequate form with the newer API, please explain your issue to `<pgsql-hackers@lists.postgresql.org>` so that the deficiency can be addressed.

F.74.2. Description of Functions

Table F.56 shows the functions provided by this module. These functions provide straightforward XML parsing and XPath queries.

Table F.56. `xml2` Functions

Function Description
`xml_valid` (*document* `text`) → `boolean` Parses the given document and returns true if the document is well-formed XML. (Note: this is an alias for the standard Postgres Pro function `xml_is_well_formed()`. The name `xml_valid()` is technically incorrect since validity and well-formedness have different meanings in XML.)
`xpath_string` (*document* `text`, *query* `text`) → `text` Evaluates the XPath query on the supplied document, and casts the result to `text`.
`xpath_number` (*document* `text`, *query* `text`) → `real` Evaluates the XPath query on the supplied document, and casts the result to `real`.
`xpath_bool` (*document* `text`, *query* `text`) → `boolean` Evaluates the XPath query on the supplied document, and casts the result to `boolean`.

`xpath_nodeset` (*document* `text`, *query* `text`, *toptag* `text`, *itemtag* `text`) → `text`
Evaluates the query on the document and wraps the result in XML tags. If the result is multi-valued, the output will look like:
`<toptag>`
`<itemtag>Value 1 which could be an XML fragment</itemtag>`
`<itemtag>Value 2....</itemtag>`
`</toptag>`
If either *toptag* or *itemtag* is an empty string, the relevant tag is omitted.

Function Description	
`xpath_nodeset ( document text, query text, itemtag text ) → text` Like `xpath_nodeset(document, query, toptag, itemtag)`	but result omits *toptag*.
`xpath_nodeset ( document text, query text ) → text` Like `xpath_nodeset(document, query, toptag, itemtag)`	but result omits both tags.
`xpath_list ( document text, query text, separator text ) → text` Evaluates the query on the document and returns multiple values separated by the specified separator, for example `Value 1,Value 2,Value 3` if *separator* is `,` .	
`xpath_list ( document text, query text ) → text` This is a wrapper for the above function that uses `,` as the separator.	

F.74.3. xpath_table

```
xpath_table(text key, text document, text relation, text xpaths, text criteria) returns
 setof record
```

`xpath_table` is a table function that evaluates a set of XPath queries on each of a set of documents and returns the results as a table. The primary key field from the original document table is returned as the first column of the result so that the result set can readily be used in joins. The parameters are described in Table F.57.

Table F.57. `xpath_table` Parameters

Parameter	Description
key	the name of the "key" field — this is just a field to be used as the first column of the output table, i.e., it identifies the record from which each output row came (see note below about multiple values)
document	the name of the field containing the XML document
relation	the name of the table or view containing the documents
xpaths	one or more XPath expressions, separated by `|`
criteria	the contents of the WHERE clause. This cannot be omitted, so use `true` or `1=1` if you want to process all the rows in the relation

These parameters (except the XPath strings) are just substituted into a plain SQL SELECT statement, so you have some flexibility — the statement is

```
SELECT <key>, <document> FROM <relation> WHERE <criteria>
```

so those parameters can be *anything* valid in those particular locations. The result from this SELECT needs to return exactly two columns (which it will unless you try to list multiple fields for key or document). Beware that this simplistic approach requires that you validate any user-supplied values to avoid SQL injection attacks.

The function has to be used in a `FROM` expression, with an `AS` clause to specify the output columns; for example

```
SELECT * FROM
xpath_table('article_id',
            'article_xml',
            'articles',
            '/article/author|/article/pages|/article/title',
            'date_entered > ''2003-01-01'' ')
AS t(article_id integer, author text, page_count integer, title text);
```

The AS clause defines the names and types of the columns in the output table. The first is the “key” field and the rest correspond to the XPath queries. If there are more XPath queries than result columns, the extra queries will be ignored. If there are more result columns than XPath queries, the extra columns will be NULL.

Notice that this example defines the page_count result column as an integer. The function deals internally with string representations, so when you say you want an integer in the output, it will take the string representation of the XPath result and use Postgres Pro input functions to transform it into an integer (or whatever type the AS clause requests). An error will result if it can't do this — for example if the result is empty — so you may wish to just stick to text as the column type if you think your data has any problems.

The calling SELECT statement doesn't necessarily have to be just SELECT * — it can reference the output columns by name or join them to other tables. The function produces a virtual table with which you can perform any operation you wish (e.g., aggregation, joining, sorting etc). So we could also have:

```
SELECT t.title, p.fullname, p.email
FROM xpath_table('article_id', 'article_xml', 'articles',
                 '/article/title|/article/author/@id',
                 'xpath_string(article_xml,''/article/@date'') > ''2003-03-20'' ')
       AS t(article_id integer, title text, author_id integer),
     tblPeopleInfo AS p
WHERE t.author_id = p.person_id;
```

as a more complicated example. Of course, you could wrap all of this in a view for convenience.

F.74.3.1. Multivalued Results

The xpath_table function assumes that the results of each XPath query might be multivalued, so the number of rows returned by the function may not be the same as the number of input documents. The first row returned contains the first result from each query, the second row the second result from each query. If one of the queries has fewer values than the others, null values will be returned instead.

In some cases, a user will know that a given XPath query will return only a single result (perhaps a unique document identifier) — if used alongside an XPath query returning multiple results, the single-valued result will appear only on the first row of the result. The solution to this is to use the key field as part of a join against a simpler XPath query. As an example:

```
CREATE TABLE test (
    id int PRIMARY KEY,
    xml text
);

INSERT INTO test VALUES (1, '<doc num="C1">
<line num="L1"><a>1</a><b>2</b><c>3</c></line>
<line num="L2"><a>11</a><b>22</b><c>33</c></line>
</doc>');

INSERT INTO test VALUES (2, '<doc num="C2">
<line num="L1"><a>111</a><b>222</b><c>333</c></line>
<line num="L2"><a>111</a><b>222</b><c>333</c></line>
</doc>');

SELECT * FROM
  xpath_table('id','xml','test',
              '/doc/@num|/doc/line/@num|/doc/line/a|/doc/line/b|/doc/line/c',
              'true')
  AS t(id int, doc_num varchar(10), line_num varchar(10), val1 int, val2 int, val3 int)
WHERE id = 1 ORDER BY doc_num, line_num
```

```
 id | doc_num | line_num | val1 | val2 | val3
----+---------+----------+------+------+------
  1 | C1      | L1       |    1 |    2 |    3
  1 |         | L2       |   11 |   22 |   33
```

To get `doc_num` on every line, the solution is to use two invocations of `xpath_table` and join the results:

```
SELECT t.*,i.doc_num FROM
  xpath_table('id', 'xml', 'test',
              '/doc/line/@num|/doc/line/a|/doc/line/b|/doc/line/c',
              'true')
    AS t(id int, line_num varchar(10), val1 int, val2 int, val3 int),
  xpath_table('id', 'xml', 'test', '/doc/@num', 'true')
    AS i(id int, doc_num varchar(10))
WHERE i.id=t.id AND i.id=1
ORDER BY doc_num, line_num;

 id | line_num | val1 | val2 | val3 | doc_num
----+----------+------+------+------+---------
  1 | L1       |    1 |    2 |    3 | C1
  1 | L2       |   11 |   22 |   33 | C1
(2 rows)
```

F.74.4. XSLT Functions

The following functions are available if libxslt is installed:

F.74.4.1. `xslt_process`

```
xslt_process(text document, text stylesheet, text paramlist) returns text
```

This function applies the XSL stylesheet to the document and returns the transformed result. The `paramlist` is a list of parameter assignments to be used in the transformation, specified in the form `a=1,b=2`. Note that the parameter parsing is very simple-minded: parameter values cannot contain commas!

There is also a two-parameter version of `xslt_process` which does not pass any parameters to the transformation.

F.74.5. Author

John Gray `<jgray@azuli.co.uk>`

Development of this module was sponsored by Torchbox Ltd. (www.torchbox.com). It has the same BSD license as Postgres Pro.

Appendix G. Postgres Pro Modules and Extensions Shipped as Individual Packages

This appendix contains Postgres Pro modules and extensions that are made available in Postgres Pro Enterprise as individual packages. These packages are listed in Section 17.1.4.1, and the documentation for each module explains which package to choose to install it. Appendix F covers more modules and extensions included in the Postgres Pro Enterprise distribution. The pg_portal_modify extension is also shipped as an individual package (see Section 17.1.4.1 for details).

G.1. pgpro_datactl — manage Postgres Pro Enterprise data files

G.1.1. Overview

The pgpro_datactl utility provides tools for managing Postgres Pro Enterprise data files, including a module for CFS (Compressed File Storage) operations. This module offers the following functionalities:

- Retrieving metadata from compressed files, including their compression algorithm and location.
- Unpacking CFS files for further analysis.

G.1.2. Installation

pgpro_datactl is provided with Postgres Pro Enterprise as a separate pre-built package `pgpro-datactl-ent-14` (for the detailed installation instructions, see Chapter 17).

G.1.3. Commands

pgpro_datactl supports the following commands:

- `unpack`
- `probe`
- `info`

G.1.3.1. unpack

```
pgpro_datactl unpack --source=source_path --target=target_path
[--calg=compression_algorithm] [-verbose] [--log-level=logging_level] [--help]
```

Unpacks CFS files.

`-s=source_path`
`--source=source_path`

Specifies the path to a compressed file or directory.

> **Note**
>
> The path must be in the directory named `PG_version_date` that contains the `pg_compression` file.

`-t=target_path`
`--target=target_path`

Specifies the path to a directory where the unpacked files will be placed.

If the source and target directories are the same, files are unpacked with a `.dec` extension.

`-c=`*`compression_algorithm`*
`--calg=`*`compression_algorithm`*

Specifies the compression algorithm used. If omitted, the `unpack` command will take this value from the `pg_compression` file.

`-v`
`--verbose`

Enables detailed logging.

`--log-level=`*`logging_level`*

Sets the logging level. Possible values: `info`, `warning`, `error`.

Example:

```
pgpro_datactl unpack -s /path/to/archive.cfs -t /path/to/destination -c zstd
```

In this example, `unpack` extracts `archive.cfs` compressed with the `zstd` algorithm into the directory `/path/to/destination`.

G.1.3.2. probe

`pgpro_datactl probe --source=`*`source_path`* `[--log-level=`*`logging_level`*`] [--help]`

Analyzes the specified file and identifies the following:

- Compression type: `zlib` or `zstd` compression algorithm.
- Fragmentation level: Analyzes the corresponding `*.cfm` file (if available) and reports the percentage of unused storage space in the physical file.
- Whether the file belongs to CFS: Checks the presence of an associated `*.cfm` file, which indicates whether the file belongs to a CFS archive.

`-s=`*`source_path`*
`--source=`*`source_path`*

Specifies the path to the target file.

`--log-level=`*`logging_level`*

Sets the logging level. Possible values: `info`, `warning`, `error`.

Example output:

```
Probing path: /data/sample.dat
Has cfm file: Yes
pg_compression: zstd
Actual compression: zstd
Fragmentation: 5%
```

In this example, the file is compressed with the `zstd` algorithm, is part of a CFS archive, and has a fragmentation level of five percent.

G.1.3.3. info

`pgpro_datactl info --source=`*`source_path`* `[--log-level=`*`logging_level`*`] [--help]`

Analyzes the file and displays the following information:

- The file physical size, virtual size, and utilized file space in bytes.
- Whether the garbage collector (`GC`) is active.

- Whether the `*.cfm` file is present and accessible.

`-s=`*`source_path`*
`--source=`*`source_path`*

Specifies the path to the target file.

`--log-level=`*`logging_level`*

Sets the logging level. Possible values: `info`, `warning`, `error`.

Example output:

```
Physical size: 10485760
Virtual size: 9437184
Used size: 7864320
GC active: Yes
```

G.2. pgpro_pwr — workload reports

The pgpro_pwr module is designed to discover most resource-intensive activities in your database. (PWR, pronounced like "power", is an abbreviation of Postgres Pro Workload Reporting.) This extension is based on Postgres Pro's Statistics Collector views and the pgpro_stats or pg_stat_statements extension.

> **Note**
>
> Although pgpro_pwr can work with the pg_stat_statements extension, it is recommended that you use the pgpro_stats extension since it provides statement plans, wait events sampling and load distribution statistics for databases, roles, client hosts and applications.

Below, use of pgpro_stats is assumed unless otherwise noted.

If you cannot use pgpro_stats for an observed database, but the *pg_stat_kcache* extension is available, pgpro_pwr can process pg_stat_kcache data, which also provides information about CPU resource usage of statements and filesystem load (*rusage*).

pgpro_pwr can obtain summary wait statistics from the pg_wait_sampling extension. When pg_wait_sampling is in use, pgpro_pwr will reset the wait sampling profile on every sample.

pgpro_pwr is based on cumulative statistics sampling. Each sample contains statistic increments for most active objects and queries since the time when the previous sample was taken, or more concisely, *since the previous sample*. This data is later used to generate reports.

pgpro_pwr provides functions to collect samples. Regular sampling allows building a report on the database workload in the past.

pgpro_pwr allows you to take explicit samples during batch processing, load testing, etc.

Any time a sample is taken, `pgpro_stats_statements_reset()` (see pgpro_stats for the function description) is called to ensure that statement statistics will not be lost when the statements count exceed `pgpro_stats.max` (see Section G.3.7.1). The report will also contain a section informing you of whether the count of captured statements in any sample reaches 90% of `pgpro_stats.max`.

pgpro_pwr installed on one Postgres Pro server can also collect statistics from other servers. This feature is useful for gathering workload statistics from hot standbys on the primary server. To benefit from it, make sure that all server names and connection strings are specified and that the pgpro_pwr server can connect to all databases on all servers.

G.2.1. pgpro_pwr Architecture

The extension consists of the following parts:

- *Historical repository* is a storage for sampling data. The repository is a set of extension tables.

> **Note**
>
> Among the rest, pgpro_pwr tables store query texts, which can contain sensitive information. So, for security reasons, restrict access to the repository as appropriate.

- *Sample management engine* comprises functions used to take samples and maintain the repository by removing obsolete sample data.
- *Report engine* comprises functions for generating reports based on data from the historical repository.
- *Administrative functions* allow you to create and manage servers and baselines.

G.2.2. Prerequisites

The prerequisites assume that pgpro_pwr, which is usually installed in a *target* cluster, i.e., the cluster that you will mainly track the workload for, the extension can also collect performance data from other clusters.

G.2.2.1. For the pgpro_pwr Database

The pgpro_pwr extension depends on PL/pgSQL and the dblink extension.

G.2.2.2. For the Target Server

The target server must allow connections to all databases from the server where pgpro_pwr is running. To connect to the target server, provide a connection string where a particular database on this server is specified. This database is of high importance for pgpro_pwr since the functionality of the pgpro_stats or pg_stat_statements extensions will be provided through this database. Note, however, that pgpro_pwr will also connect to all the other databases on this server.

Optionally, for completeness of gathered statistics:

- If statement statistics are needed in reports, pgpro_stats must be installed and configured in the aforementioned database. The following settings may affect the completeness and accuracy of gathered statistics:
  - `pgpro_stats.max`

    Low setting of this parameter may cause some statement statistics to be wiped out before the sample is taken. A report will warn you if the value of `pgpro_stats.max` seems undersized.
  - `pgpro_stats.track`

    Avoid changing the default value of '`top`' (note that the value of '`all`' will affect the accuracy of `%Total` fields for statements-related sections of a report).
- Set the parameters of the Postgres Pro's Statistics Collector as follows:

```
track_activities = on
track_counts = on
track_io_timing = on
track_wal_io_timing = on    # Since PostgreSQL 14
track_functions = all/pl
```

G.2.3. Installation and Setup

pgpro_pwr is provided with Postgres Pro Enterprise as a separate pre-built package `pgpro-pwr-ent-14` (for the detailed installation instructions, see Chapter 17).

> **Note**
>
> pgpro_pwr creates a bunch of database objects, so installation in a dedicated schema is recommended.

Although the use of pgpro_pwr with superuser privileges does not have any issues, superuser privileges are not necessary. So you can choose one of the following setup procedures depending on your configuration and security requirements or customize them to meet your needs:

G.2.3.1. Simple Setup

Use this setup procedure when pgpro_pwr is to be installed on the target cluster to only track its workload as superuser.

Create a schema for the pgpro_pwr installation and create the extension:

```
CREATE SCHEMA profile;
CREATE EXTENSION pgpro_pwr SCHEMA profile;
```

G.2.3.2. Complex Setup

Use this setup procedure when you intend to use pgpro_pwr for tracking workload on one or more servers and need to follow the principle of least privilege.

G.2.3.2.1. In the Target Server Database

Create a user for pgpro_pwr on the target server:

```
CREATE USER pwr_collector PASSWORD 'collector_pwd';
```

Make sure this user has permissions to connect to any database in the target cluster (by default, it is true) and that `pg_hba.conf` permits such a connection from the pgpro_pwr database host. Also, grant `pwr_collector` with membership in the `pg_read_all_stats` role and the `EXECUTE` privilege on the following functions:

```
GRANT pg_read_all_stats TO pwr_collector;
GRANT EXECUTE ON FUNCTION pgpro_stats_statements_reset TO pwr_collector;
GRANT EXECUTE ON FUNCTION pgpro_stats_totals_reset(text,bigint) TO pwr_collector;
```

Also ensure the `SELECT` privilege on the `pgpro_stats_archiver` view:

```
GRANT SELECT ON pgpro_stats_archiver TO pwr_collector;
```

G.2.3.2.2. In the pgpro_pwr Database

Create an unprivileged user:

```
CREATE USER pwr_user;
```

This user will be the owner of the extension schema and will collect samples.

Create a schema for the pgpro_pwr installation:

```
CREATE SCHEMA profile AUTHORIZATION pwr_user;
```

Grant the `USAGE` privilege on the schema where the dblink extension resides:

```
GRANT USAGE ON SCHEMA public TO pwr_user;
```

Create the extension using `pwr_user` account:

```
\c - pwr_user
CREATE EXTENSION pgpro_pwr SCHEMA profile;
```

Define the connection parameters of the target server for pgpro_pwr. For example:

```
SELECT profile.create_server('target_server_name','host=192.168.1.100 dbname=postgres
 port=5432');
```

The connection string provided will be used in the `dblink_connect()` call while executing the `take_sample()` function.

> **Note**
>
> Connection strings are stored in a pgpro_pwr table in clear-text form. Make sure no other database users can access tables of the pgpro_pwr extension.

G.2.3.3. Setting Up pgpro_pwr Roles

Up to three roles can be distinguished when pgpro_pwr is in operation:

- The *pgpro_pwr owner* role is the owner of the pgpro_pwr extension.
- The *collecting role* is used by pgpro_pwr to connect to databases and collect statistics.
- The *reporting role* is used to generate reports.

If all the actions with pgpro_pwr are performed by the superuser role `postgres`, you can skip most of the setup explained below.

G.2.3.3.1. The pgpro_pwr Owner

This role can be used to perform all actions related to pgpro_pwr. This role will have access to server connection strings, which may contain passwords. You should use this role to call the `take_sample()` function. The dblink extension is needed for this user.

Consider an example assuming each extension in its own schema:

```
\c postgres postgres
CREATE SCHEMA dblink;
CREATE EXTENSION dblink SCHEMA dblink;
CREATE USER pwr_usr with password 'pwr_pwd';
GRANT USAGE ON SCHEMA dblink TO pwr_usr;
CREATE SCHEMA profile AUTHORIZATION pwr_usr;
\c postgres pwr_usr
CREATE EXTENSION pgpro_pwr SCHEMA profile;
```

G.2.3.3.2. The Collecting Role

This role should be used by pgpro_pwr to connect to databases and collect statistics. Unprivileged users cannot open connections using dblink without a password, so you need to provide the password in the connection string for each server. This role should have access to all supported statistics extensions. It should also be able to perform a reset of statistics extensions.

Consider an example. If you use pgpro_stats to collect statistics, set up the collecting role as follows:

```
\c postgres postgres
CREATE SCHEMA pgps;
CREATE EXTENSION pgpro_stats SCHEMA pgps;
CREATE USER pwr_collector with password 'collector_pwd';
GRANT pg_read_all_stats TO pwr_collector;
GRANT USAGE ON SCHEMA pgps TO pwr_collector;
GRANT EXECUTE ON FUNCTION pgps.pgpro_stats_statements_reset TO pwr_collector;
```

If you use pg_stat_statements to collect statistics, set up the collecting role as follows:

```
\c postgres postgres
CREATE SCHEMA pgss;
CREATE SCHEMA pgsk;
```

```
CREATE SCHEMA pgws;
CREATE EXTENSION pg_stat_statements SCHEMA pgss;
CREATE EXTENSION pg_stat_kcache SCHEMA pgsk;
CREATE EXTENSION pg_wait_sampling SCHEMA pgws;
CREATE USER pwr_collector with password 'collector_pwd';
GRANT pg_read_all_stats TO pwr_collector;
GRANT USAGE ON SCHEMA pgss TO pwr_collector;
GRANT USAGE ON SCHEMA pgsk TO pwr_collector;
GRANT USAGE ON SCHEMA pgws TO pwr_collector;
GRANT EXECUTE ON FUNCTION pgss.pg_stat_statements_reset TO pwr_collector;
GRANT EXECUTE ON FUNCTION pgsk.pg_stat_kcache_reset TO pwr_collector;
GRANT EXECUTE ON FUNCTION pgws.pg_wait_sampling_reset_profile TO pwr_collector;
```

Now you should set up a connection string pointing to the database with statistics extensions installed:

```
\c postgres pwr_usr
SELECT profile.set_server_connstr('local','dbname=postgres port=5432 host=localhost
user=pwr_collector password=collector_pwd');
```

Password authentication must be configured in the `pg_hba.conf` file for the `pwr_collector` user.

Obviously, the collecting role should be properly configured on all servers observed by pgpro_pwr.

Now you should be able to call `take_sample()` using the `pwr_usr` role:

```
\c postgres pwr_usr
SELECT * FROM take_sample();
```

And now it's time to configure the scheduler (in our example, the `crontab` command of the `postgres` user):

```
*/30 * * * *   psql -U pwr_usr -d postgres -c 'SELECT profile.take_sample()' > /dev/
null 2>&1
```

Note that you can use the Postgres Pro password file to store passwords.

G.2.3.3.3. The Reporting Role

Any user can build a pgpro_pwr report. The minimal privileges needed to generate pgpro_pwr reports are granted to the `public` role. However a full report, with query texts, is only available to the member of the `pg_read_all_stats` role. Anyway, the reporting role cannot access server connection strings, so it cannot get the passwords of servers.

G.2.3.4. Setting Extension Parameters

In `postgresql.conf`, you can define the following pgpro_pwr parameters:

`pgpro_pwr.max` (`integer`)

Number of top objects (statements, relations, etc.) to be reported in each sorted report table. This parameter affects the size of a sample.

The default value is `20`.

`pgpro_pwr.max_sample_age` (`integer`)

Retention time of the sample, in days. Samples aged `pgpro_pwr.max_sample_age` days and older are automatically deleted on the next `take_sample()` call.

The default value is `7` days.

`pgpro_pwr.max_query_length` (`integer`)

Maximum query length allowed in reports. All queries in a report will be truncated to `pgpro_pwr.max_query_length` characters.

The default value is `20 000` characters.

`pgpro_pwr.track_sample_timings` (`boolean`)

Enables collecting detailed timing statistics of pgpro_pwr's own sampling procedures. Set this parameter to diagnose why sampling functions run slowly. Collected timing statistics will be available in the `v_sample_timings` view.

The default value is `off`.

`pgpro_pwr.statements_reset` (`boolean`)

Controls the pgpro_stats/pg_stat_statements statistics reset during taking a sample. Allows you not to reset the statistics during taking a sample due to new techniques employed. When disabled, pgpro_pwr will track statement evictions using the value of the `calls` field. However this method does not completly prevent statistics loss. pg_stat_statements v1.11 and pgpro_stats v1.8 contain time tracking abilities that can reduce the possible data loss. When this setting is disabled, you can temporarily enable it in a session if you want to sometimes perform a reset of pgpro_stats/pg_stat_statements.

The default value is `on`.

`pgpro_pwr.relsize_collect_mode` (`text`)

Defines the mode of collecting relation sizes. Possible values:

- `off` — collection of relation sizes is based on `pg_class`. Although the relation sizes collected this way are rough, their collection consumes almost no resources.
- `on` — accurate relation sizes are collected for each sample using the `pg_relation_size()` function, which requires a lock on the table and is pretty resource intensive.
- `schedule` — accurate relation sizes are collected in the size-collection window, defined for each server.

The default value is `off`.

G.2.4. Managing Servers

Once installed, pgpro_pwr creates one enabled `local` server for the current cluster. If a server is *enabled*, pgpro_pwr includes it in sampling when no server is explicitly specified (see `take_sample()` for details). A server that is not enabled is referred to as *disabled*.

The default connection string for a local node contains only `dbname` and `port` parameters. The values of these parameters are taken from the connection used to create the extension. You can change the server connection string using the `set_server_connstr()` function when needed.

G.2.4.1. Server Management Functions

Use the following pgpro_pwr functions for server management:

`create_server(`*`server`* `name, `*`connstr`* `text, `*`enabled`* `boolean DEFAULT TRUE, `*`max_sample_age`* `integer DEFAULT NULL `*`description`* `text DEFAULT NULL)`

Creates a server definition.

Arguments:

- *`server`* — server name. Must be unique.
- *`connstr`* — connection string. Must contain all the necessary settings to connect from pgpro_pwr server to the target server database.
- *`enabled`* — set to include the server in sampling by the `take_sample()` function without arguments.

- *max_sample_age* — retention time of the sample. Overrides the global pgpro_pwr.max_sample_age setting for this server.
- *description* — server description text, to be included in reports.

Here is an example of how to create a server definition:

```
SELECT profile.create_server('omega','host=192.168.1.100 dbname=postgres
 port=5432');
```

drop_server(*server* name)

Drops a server and all its samples.

set_server_description(*server* name *description* text)

Sets a new server description.

set_server_subsampling(*server* name, *subsample_enabled* boolean, *min_query_duration* interval, *min_xact_duration* interval, *min_xact_age* integer, *min_idle_xact_dur* interval hour to second)

Defines subsample settings for a server.

Arguments:

- *server* — server name.
- *subsample_enabled* — defines whether subsampling is enabled for the server, that is, whether take_subsample() function should actually take a subsample.
- *min_query_duration* — the query duration threshold.
- *min_xact_duration* — the transaction duration threshold.
- *min_xact_age* — the transaction age threshold.
- *min_idle_xact_dur_age* — the idle transaction threshold.

enable_server(*server* name)

Includes a server in sampling by the take_sample() function without arguments.

disable_server(*server* name)

Excludes a server from sampling by the take_sample() function without arguments.

rename_server(*server* name, *new_name* name)

Renames a server.

set_server_max_sample_age(*server* name, *max_sample_age* integer)

Sets the retention period for a server (in days). To reset the server retention, set the value of *max_sample_age* to NULL.

set_server_db_exclude(*server* name, *exclude_db* name[])

Excludes a list of databases on a server from sampling. Use when pgpro_pwr is unable to connect to some databases in a cluster (for example, in Amazon RDS instances).

set_server_connstr(*server* name, *server_connstr* text)

Sets the connection string for a server.

set_server_setting(*server* name, *setting* text, *value* jsonb)

Fine-tunes settings of the server statistics collection. collect* settings control which statistics should be collected, and *value* for these settings accepts bollean values, with the default equal to true. Available settings:

- `collect_pg_stat_statement` — collect statement statistics using pg_stat_statements and pg_stat_kcache extensions.
- `collect_pg_wait_sampling` — collect wait event statistics using the pg_wait_sampling extension.
- `collect_objects` — collect all the schema object statistics, that is, tables, indexes, and functions, from `pg_stat_*` views.
- `collect_relations` — collect statistics on tables and indexes from `pg_stat_*` views.
- `collect_functions` — collect statistics on user functions from the `pg_stat_user_functions` view.
- `collect_vacuum_stats` — collect the extended vacuum statistics.

`show_server_settings(`*`server`* `name)`

Returns the statistics collection settings for the specified server.

`show_servers()`

Displays the list of configured servers.

G.2.5. Managing Samples

A *sample* contains the database workload statistics since the previous sample

G.2.5.1. Sampling Functions

The following pgpro_pwr functions relate to sampling:

`take_sample()`
`take_sample(`*`server`* `name [,` *`skip_sizes`* `boolean])`

Takes samples.

If the parameter is omitted, the function takes a sample on each enabled server. Servers are accessed for sampling sequentially, one by one. The function returns a table with the following columns:

- `server` — server name.
- `result` — result of taking the sample. Can be `OK` if the sample was taken successfully or contain the error trace text in case of exception.
- `elapsed` — time elapsed while the sample was taken.

If called with the parameter, the function takes a sample on the specified server even if this server is disabled. Use when you need different sampling frequencies on specific servers. Returns `0` on success.

Arguments:

- *`server`* — server name.
- *`skip_sizes`* — if omitted or set to null, the size-collection policy applies; if `false`, relation sizes are collected; if `true`, the collection of relation sizes is skipped.

`take_sample_subset([`*`sets_cnt`* `integer,` *`current_set`* `integer])`

Takes a sample on each server in a subset of servers. Use to take samples on servers in parallel if you have many enabled servers. Although PL/pgSQL does not support parallel execution, you can call this function in parallel sessions. This function returns the same type as `take_sample()`. If both parameters are omitted, the function behaves like the `take_sample()` function, i.e., it takes a sample on all enabled servers one by one.

Arguments:

- *sets_cnt* — number of subsets to divide all enabled servers into.
- *current_set* — number of the subset to collect samples for. Takes values from 0 through *sets_cnt* - 1. For the specified subset, samples are collected as usual, server by server.

If a reset of statistics since the previous sample was detected, pgpro_pwr treats corresponding absolute values as differentials; however, the accuracy will be affected anyway.

`show_samples([server name,] [days integer])`

Returns a table with information on server samples (`local` server is assumed if *server* is omitted) for the last *days* days (all existing samples are assumed if omitted). This table has the following columns:

- `sample` — sample identifier.
- `sample_time` — time when this sample was taken.
- `dbstats_reset` — `NULL` or the statistics reset timestamp of the `pg_stat_database` view if the statistics were reset since the previous sample.
- `clustats_reset` — `NULL` or the statistics reset timestamp of the `pg_stat_bgwriter` view if the statistics were reset since the previous sample.
- `archstats_reset` — `NULL` or the statistics reset timestamp of the `pg_stat_archiver` view if the statistics were reset since the previous sample.

Sampling functions also maintain the server repository by deleting obsolete samples and baselines according to the retention policy.

G.2.5.2. Taking Samples

To take samples for all enabled servers, call the `take_sample()` function. Usually, one or two samples per hour is sufficient. You can use a cron-like tool to schedule sampling. Here is an example for a 30-minute sampling period:

```
*/30 * * * *   psql -c 'SELECT profile.take_sample()' &> /dev/null
```

However, the results of such a call are not checked for errors. In a production environment, function results can be used for monitoring. This function returns `OK` for all servers with successfully taken samples and shows error text for failed servers:

```
SELECT * FROM take_sample();
  server   |                                    result
  |   elapsed
-----------
+-------------------------------------------------------------------------------
+-------------
 ok_node   | OK
  | 00:00:00.48
 fail_node | could not establish connection
 +| 00:00:00
           | SQL statement "SELECT dblink_connect('server_connection',server_connstr)"
 +|
           | PL/pgSQL function take_sample(integer) line 69 at PERFORM
 +|
           | PL/pgSQL function take_sample_subset(integer,integer) line 27 at
 assignment+|
           | SQL function "take_sample" statement 1
 +|
           | FATAL:  database "postgresno" does not exist
  |
(2 rows)
```

G.2.5.3. Sample Retention Policy

You can define sample retention at the following levels:

1. *Global*

   The value of the `pgpro_pwr.max_sample_age` parameter in the `postgresql.conf` file defines a common retention setting, which is effective if none of other related settings are defined.

2. *Server*

   Specifying the *`max_sample_age`* parameter while creating a server or calling the `set_server_max_sample_age(`*`server`*`,`*`max_sample_age`*`)` function for an existing server defines the retention for the server. A server retention setting overrides `pgpro_pwr.max_sample_age` for a specific server.

3. *Baseline*

   A baseline created overrides all the other retention periods for included samples.

G.2.6. Managing the Collection of Relation Sizes

It may take considerable time to collect sizes of all relations in a database by Postgres Pro relation-size functions. Besides, those functions require `AccessExclusiveLock` on a relation. However, it may be sufficient for you to collect relation sizes on a daily basis. pgpro_pwr allows you to skip collecting relation sizes by defining the *size-collection policy* for servers. The policy defines:

- A daily window when the collection of relation sizes is permitted.
- A minimum gap between two samples with relation sizes collected.

When the size-collection policy is defined, sampling functions collect relation sizes only when the sample is taken in the defined window and the previous sample with sizes is older than the gap. The following function defines this policy:

`set_server_size_sampling(`*`server`* `name,` *`window_start`* `time with time zone DEFAULT NULL,` *`window_duration`* `interval hour to second DEFAULT NULL,` *`sample_interval`* `interval day to minute DEFAULT NULL,` *`collect_mode`* `text DEFAULT NULL)`

Defines the size-collection policy for a server.

Arguments:

- *`server`* — server name.
- *`window_start`* — start time of the size-collection window.
- *`window_duration`* — duration of the size-collection window.
- *`sample_interval`* — minimum time gap between two samples with relation sizes collected.
- *`collect_mode`* — when set to `off`, which is the default for new installations, relation sizes are collected from `pg_class`, when set to `on`, relation sizes are collected using the `pg_relation_size()` function, when set to `schedule`, pgpro_pwr collects the relation size in the size-collection window. This parameter overrides the relsize_collect_mode extension parameter. Upgrading from a previous version sets the value of this parameter to `on` or `schedule`, so the previous behavior does not change.

> **Note**
>
> When you build a report between samples either of which lacks relation-size data, relation-growth sections will be based on `pg_class.relpages` data. However, you can expand the report interval bounds to the nearest samples with relation sizes collected using the *`with_growth`* parameter of report generation functions; this makes the growth data more accurate.

Relation sizes are needed to calculate sequentially scanned volume for tables and explicit vacuum load for indexes.

Example:

```
SELECT set_server_size_sampling('local','23:00+03',interval '2 hour',interval '8 hour',
 'schedule');
```

The `show_servers_size_sampling` function shows size collection policies for all servers:

```
postgres=# SELECT * FROM show_servers_size_sampling();
 server_name | window_start | window_end  | window_duration | sample_interval |
 limited_collection
-------------+--------------+-------------+-----------------+-----------------
+--------------------
 local       | 23:00:00+03  | 01:00:00+03 | 02:00:00        | 08:00:00        | t
```

G.2.7. Managing Subsamples

Some performance-related data available in Postgres Pro is not cumulative. For example, the most often used data about session states is available through the pg_stat_activity view and can only be obtained with frequent samples. However, the `take_sample()` function is heavy and can take considerable amount of time. So it is not suitable for collecting session state data.

The *subsample* feature provides a new fast `take_subsample()` function. It can be used to collect relatively fast changing data. Every subsample is bound to the next regular sample and is deleted by the retention policy together with it.

The subsample feature can be used to capture the most interesting session states:

- Long running queries
- Long transactions
- Aged transactions, that is, those that hold a snapshot behind a lot of other transactions
- Transactions being in an idle state for a long time

G.2.7.1. Subsampling Functions

The following pgpro_pwr functions relate to subsampling:

`take_subsample()`
`take_subsample(`*`server`* `name)`

If the parameter is omitted, the function takes a subsample on each *enabled* server with subsampling enabled (see set_server_subsampling for details). Server subsamples are taken sequentially, one by one. The function returns a table with the following columns:

- `server` — server name.
- `result` — result of taking the subsample. Can be `OK` if the subsample was taken successfully or contain the error text in case of exception.
- `elapsed` — time elapsed while the subsample was taken.

This tabular return format makes it easy to control subsample creation using an SQL query.

If called with the parameter, the function takes a subsample for the specified server. Use when you need different subsampling frequencies on servers or if you want to take an explicit subsample on a specific server.

Arguments:

- *server* — server name.

> **Note**
>
> Trying to take a subsample during taking a sample fails.

`take_subsample_subset([sets_cnt integer], [current_set integer])`

Takes subsamples for a subset of enabled servers with subsampling enabled. Although subsamples should be fast enough for serial processing, subsamples can be taken in parallel, like regular samples. This function returns the same type as `take_subsample()`. If both parameters are omitted, the function behaves like the `take_subsample()` function.

Arguments:

- *sets_cnt* — number of server subsets.
- *current_set* — the subset to process. Takes values from 0 through *sets_cnt* - 1. For the specified subset, subsamples are collected as usual, server by server.

G.2.7.2. Configuring the Subsample Feature

The following settings affect the subsample behaviour:

- `pgpro_pwr.subsample_enabled` — defines whether the `take_subsample()` function should actually take a subsample.
- `pgpro_pwr.min_query_duration` — the long running query threshold.
- `pgpro_pwr.min_xact_duration` — the long transaction threshold.
- `pgpro_pwr.min_xact_age` — the transaction age threshold.
- `pgpro_pwr.min_idle_xact_dur_age` — the idle transaction threshold.

The subsample behavior can be defined at the server level using the set_server_subsampling function.

The last observed session state is saved in the repository when either of the following threshold-related events happens:

- During query execution, the difference between `now()` and the `query_start` exceeds the `pgpro_pwr.min_query_duration` threshold.
- During a transaction, the difference between `now()` and the `xact_start` exceeds the `pgpro_pwr.min_xact_duration` threshold.
- During a transaction, the `age(backend_xmin)` exceeds the `pgpro_pwr.min_xact_age` threshold.
- During a transaction in a state `idle in transaction` or `idle in transaction (aborted)`, the difference between `now()` and the `state_change` exceeds the `pgpro_pwr.min_idle_xact_duration` threshold.

See Chapter 27 for details of the mentioned fields. Every subsample can hold at most `pg_profile.topn` entries for every threshold type.

G.2.7.3. Scheduling Subsamples

Subsamples are fast enough to take them quite often. However usually you do not need more than 2-4 subsamples per minute. Obviously the subsample frequency depends on the shortest used duration of a threshold setting.

Cron only allows one call per minute, so some effort is needed to schedule more frequent subsamples. For example, the `\watch` psql command can be used:

```
echo "select take_subsample(); \watch 15" | psql &> /dev/null
```

The psql call can be wrapped in the systemd service like this:

```
Description=pg_profile subsampling unit
[Unit]

[Service]
Type=simple
ExecStart=/bin/sh -c 'echo "select take_subsample(); \\watch 15" | /path/to/psql -qo /
dev/null'
User=postgres
Group=postgres

[Install]
WantedBy=multi-user.target
```

G.2.8. Managing Baselines

A *baseline* is a named sequence of samples that has its own retention setting. A baseline can be used as a sample interval in report generation functions. An undefined baseline retention means infinite retention. Use baselines to save information about the database workload for a certain time interval.

G.2.8.1. Baseline Management Functions

Use the following pgpro_pwr functions for baseline management:

`create_baseline([server name,] baseline varchar(25), start_id integer, end_id integer [, days integer])`
`create_baseline([server name,] baseline varchar(25), time_range tstzrange [, days integer])`

Creates a baseline.

Arguments:

- *server* — server name. `local` sever is assumed if omitted.
- *baseline* — baseline name. Must be unique for a server.
- *start_id* — identifier of the first sample in the baseline.
- *end_id* — identifier of the last sample in the baseline.
- *time_range* — time interval for the baseline. The baseline will include all samples for the minimal interval that covers *time_range*.
- *days* — baseline retention time, defined in integer days since `now()`. Omit or set to null for infinite retention.

`drop_baseline([server name,] baseline varchar(25))`

Drops a baseline. For the meaning and usage details of function arguments, see create_baseline. Dropping a baseline does not mean dropping all its samples immediately. The baseline retention just no longer applies to them.

`keep_baseline([server name,] baseline varchar(25) [, days integer])`

Changes the retention of a baseline. For the meaning and usage details of function arguments, see create_baseline. Omit the *baseline* parameter or pass null to it to change the retention of all existing baselines.

`show_baselines([server name])`

Displays existing baselines. Call `show_baselines` to get information about the baselines, such as names, sampling intervals and retention periods. `local` sever is assumed if the *server* parameter is omitted.

G.2.9. Data Export and Import

Collected samples can be exported from one instance of the pgpro_pwr extension and then loaded into another one. This feature helps you to move server data from one instance to another or to send collected data to your support team.

G.2.9.1. Data Export

The export_data function exports data to a regular table. You can use any method available to export this table from your database. For example, you can use the `\copy` meta-command of psql to obtain a single `csv` file:

```
postgres=# \copy (select * from export_data()) to 'export.csv'
```

G.2.9.2. Data Import

Since data can only be imported from a local table, first, load the data you exported. Using the `\copy` meta-command again:

```
postgres=# CREATE TABLE import (section_id bigint, row_data json);
CREATE TABLE
postgres=# \copy import from 'export.csv'
COPY 6437
```

Now you can import the data by providing the `import` table to the import_data function:

```
postgres=# SELECT * FROM import_data('import');
```

After successful import, you can drop the `import` table.

> **Note**
>
> If server data is imported for the first time, your local pgpro_pwr servers with matching names will cause a conflict during import. To avoid this, you can temporarily rename such servers or you can specify the server name prefix for import operations. However, during import of new data for already imported servers, they are matched by system identifiers, so feel free to rename imported severs. Also keep in mind that pgpro_pwr sets servers being imported to the *disabled* state for `take_sample()` to bypass them.

G.2.9.3. Export and Import Functions

Use these functions to export or import data:

`export_data([`*`server`* `name, [`*`min_sample_id`* `integer,] [`*`max_sample_id`* `integer,]] [, `*`obfuscate_queries`* `boolean])`

Exports collected data.

Arguments:

- *`server`* — server name. All configured servers are assumed if omitted.
- *`min_sample_id`*, *`max_sample_id`* — sample identifiers to bound the export (inclusive). If *`min_sample_id`* is omitted or set to null, all samples until *`max_sample_id`* sample are exported; if *`max_sample_id`* is omitted or set to null, all samples since *`min_sample_id`* sample are exported.
- *`obfuscate_queries`* — if `true`, query texts are exported as `MD5` hash.

`import_data(`*`data`* `regclass [, `*`server_name_prefix`* `text])`

Imports previously exported data. Returns the number of actually loaded rows in pgpro_pwr tables.

Arguments:

- *data* is the name of the table containing import data.
- *server_name_prefix* specifies the server name prefix for the import operation. It can be used to avoid name conflicts.

G.2.10. Report Generation Functions

pgpro_pwr reports are generated in HTML format by reporting functions. The following types of reports are available:

- *Regular reports* provide statistics on the workload for an interval.
- *Differential reports* provide statistics on the same objects for two intervals. Corresponding values are located next to each other, which makes it easy to compare the workloads.

Reporting functions take sample identifiers, baselines or time ranges to determine the intervals. For time ranges, these are the minimal intervals that cover the ranges.

G.2.10.1. Regular Reports

Use these functions to generate regular reports:

```
get_report([server name,] start_id integer, end_id integer [, description text [,
with_growth boolean [, db_exclude name[]]]])
get_report([server name,] time_range tstzrange [, description text [, with_growth boolean
[, db_exclude name[]]]])
get_report([server name,] baseline varchar(25) [, description text [, with_growth boolean
[, db_exclude name[]]]])
```

Generates a regular report defined by the arguments.

Arguments:

- *server* — server name. `local` sever is assumed if omitted.
- *start_id* — identifier of the interval starting sample.
- *end_id* — identifier of the interval ending sample.
- *baseline* — baseline name.
- *time_range* — time range.
- *description* — short text to be included in the report as its description.
- *with_growth* — flag requesting interval expansion to the nearest bounds with data on relation growth available. The default value is `false`.
- *db_exclude* — the database exclusion list. Lists databases to be excluded from all report tables having the `Database` column. Use to hide some databases in the report.

```
get_report_latest([server name,])
get_report_latest([server name [, db_exclude name[]]])
```

Generates a regular report for two latest samples.

Arguments:

- *server* — server name. `local` sever is assumed if omitted.
- *db_exclude* — the database exclusion list. Lists databases to be excluded from all report tables having the `Database` column. Use to hide some databases in the report.

G.2.10.2. Differential Reports

Use this function to generate differential reports:

```
get_diffreport([server name,] start1_id integer, end1_id integer, start2_id integer,
end2_id integer [, description text [, with_growth boolean [, db_exclude name[]]]])
get_diffreport([server name,] time_range1 tstzrange, time_range2 tstzrange [, description
text [, with_growth boolean [, db_exclude name[]]]])
get_diffreport([server name,] baseline1 varchar(25), baseline2 varchar(25) [, description
text [, with_growth boolean [, db_exclude name[]]]])
get_diffreport([server name,] baseline1 varchar(25), time_range2 tstzrange [, description
text [, with_growth boolean[, db_exclude name[]]]])
get_diffreport([server name,] time_range1 tstzrange, baseline2 varchar(25) [, description
text [, with_growth boolean[, db_exclude name[]]]])
get_diffreport([server name,] start1_id integer, end1_id integer, baseline2 varchar(25)
[, description text [, with_growth boolean[, db_exclude name[]]]])
get_diffreport([server name,] baseline1 varchar(25), start2_id integer, end2_id integer
[, description text [, with_growth boolean[, db_exclude name[]]]])
```

Generates a differential report for two intervals. The combinations of arguments provide possible ways to specify the two intervals.

Arguments:

- *server* — server name. `local` sever is assumed if omitted.
- *start1_id*, *end1_id* — identifiers of the starting and ending samples for the first interval.
- *start2_id*, *end2_id* — identifiers of the starting and ending samples for the second interval.
- *baseline1* — baseline name for the first interval.
- *baseline2* — baseline name for the second interval.
- *time_range1* — time range for the first interval.
- *time_range2* — time range for the second interval.
- *description* — short text to be included in the report as its description.
- *with_growth* — flag requesting interval expansion to the nearest bounds with data on relation growth available. The default value is `false`.
- *db_exclude* — the database exclusion list. Lists databases to be excluded from all report tables having the `Database` column. Use to hide some databases in the report.

G.2.10.3. Report Generation Example

Generate a report for the `local` server and interval defined by samples:

```
psql -Aqtc "SELECT profile.get_report(480,482)" -o report_480_482.html
```

For any other server, provide its name:

```
psql -Aqtc "SELECT profile.get_report('omega',12,14)" -o report_omega_12_14.html
```

Generate a report using time ranges:

```
psql -Aqtc "SELECT profile.get_report(tstzrange('2020-05-13 11:51:35+03','2020-05-13
 11:52:18+03'))" -o report_range.html
```

Generate a relative time-range report:

```
psql -Aqtc "SELECT profile.get_report(tstzrange(now() - interval '1 day',now()))" -o
 report_last_day.html
```

G.2.11. pgpro_pwr Report Sections

Each pgpro_pwr report is divided into sections, described below. The number of top objects reported in each sorted report table is specified by the `pgpro_pwr.max` parameter.

Almost every item in the report can be accentuated by a single mouse click. The accentuated item will be instantly highlighted in all report sections, making it easy to find. The attributes identifying the item will appear in the bottom-right corner of the page. For example, if you click on a database name in the "Database statistics" report table, you can notice a small table with the database attributes in the bottom-right corner of the page.

When you scroll down the report, its table of contents will be available on the right side of the page. It can be hidden with a single mouse click on the "content" tag.

A substring-based filter is also available that helps limit the report contents to particular objects based on a substring. Specifically, substring-based filtering is applied to query texts.

G.2.11.1. Server statistics

Tables in this section of a pgpro_pwr report are described below.

The report table "Database statistics" provides per-database statistics for the report interval. The statistics are based on the `pg_stat_database` view. Table G.1 lists columns of this report table.

Table G.1. Database statistics

Column	Description	Field/Calculation
`Database`	Database name	`datname`
`Commits`	Number of committed transactions	`xact_commit`
`Rollbacks`	Number of rolled back transactions	`xact_rollback`
`Deadlocks`	Number of deadlocks detected	`deadlocks`
`Checksum Failures`	Number of data page checksum failures detected in this database. This field is only shown if any checksum failures were detected in this database during the report interval.	`checksum_failures`
`Checksums Last`	Time at which the last data page checksum failure was detected in this database. This field is only shown if any checksum failures were detected in this database during the report interval.	`checksum_last_failure`
`Hit%`	Buffer cache hit ratio, i.e., percentage of pages fetched from buffers in all pages fetched	
`Read`	Number of disk blocks read in this database	`blks_read`
`Hit`	Number of times disk blocks were found already in the buffer cache	`blks_hit`
`Ret`	Number of returned tuples	`tup_returned`
`Fet`	Number of fetched tuples	`tup_fetched`
`Ins`	Number of inserted tuples	`tup_inserted`
`Upd`	Number of updated tuples	`tup_updated`
`Del`	Number of deleted tuples	`tup_deleted`

Column	Description	Field/Calculation
Temp Size	Total amount of data written to temporary files by queries in this database	temp_bytes
Temp Files	Number of temporary files created by queries in this database	temp_files
Size	Database size at the time of the last sample in the report interval	pg_database_size()
Growth	Database growth during the report interval	pg_database_size() increment between interval bounds

The report table “Cluster I/O statistics” provides I/O statistics by object types, backend types and contexts. This table is based on the pg_stat_io view of the Cumulative Statistics System, available since Postgres Pro 16. Table G.2 lists columns of this report table. Times are provided in seconds.

Table G.2. Cluster I/O statistics

Column	Description
Object	Target object of an I/O operation
Backend	Type of the backend that performed an I/O operation
Context	The context of an I/O operation
Reads Count	Number of read operations
Reads Bytes	Amount of data read
Reads Time	Time spent in read operations
Writes Count	Number of write operations
Writes Bytes	Amount of data written
Writes Time	Time spent in write operations
Writebacks Count	Number of blocks which the process requested the kernel write out to permanent storage
Writebacks Bytes	Amount of data requested for write out to permanent storage
Writebacks Time	Time spent in writeback operations, including the time spent queueing write-out requests and, potentially, the time spent to write out the dirty data
Extends Count	Number of relation extend operations
Extends Bytes	Amount of space used by extend operations
Extends Time	Time spent in extend operations
Hits	The number of times a desired block was found in a shared buffer
Evictions	Number of times a block has been written out from a shared or local buffer in order to make it available for another use
Reuses	The number of times an existing buffer in a size-limited ring buffer outside of shared buffers was reused as part of an I/O operation in the bulkread, bulkwrite, or vacuum contexts
Fsyncs Count	Number of fsync calls. These are only tracked in context normal.

Column	Description
Fsyncs Time	Time spent in fsync operations

The report table “Cluster SLRU statistics” provides access statistics on SLRU (simple least-recently-used) caches. This table is based on the pg_stat_slru view of the Cumulative Statistics System. Table G.3 lists columns of this report table. Times are provided in seconds.

Table G.3. Cluster SLRU statistics

Column	Description	Field/Calculation
Name	Name of the SLRU	name
Zeroed	Number of blocks zeroed during initializations	blks_zeroed
Hits	Number of times disk blocks were found already in the SLRU, so that a read was not necessary (this only includes hits in the SLRU, not the operating system's file system cache)	blks_hit
Reads	Number of disk blocks read for this SLRU	blks_read
%Hit	Number of disk block hits for this SLRU as the percentage of Reads + Hits	blks_hit *100/blks_read + blks_hit
Writes	Number of disk blocks written for this SLRU	blks_written
Checked	Number of blocks checked for existence for this SLRU	blks_exists
Flushes	Number of flushes of dirty data for this SLRU	flushes
Truncates	Number of truncates for this SLRU	truncates

Table “Session statistics by database” is available in the report for Postgres Pro databases starting with version 14. This table is based on the pg_stat_database view of the Statistics Collector. Table G.4 lists columns of this report table. Times are provided in seconds.

Table G.4. Session statistics by database

Column	Description	Field/Calculation
Database	Database name	
Timing Total	Time spent by database sessions in this database during the report interval (note that statistics are only updated when the state of a session changes, so if sessions have been idle for a long time, this idle time won't be included)	session_time
Timing Active	Time spent executing SQL statements in this database during the report interval (this corresponds to the states active and fastpath function call in pg_stat_activity)	active_time

Column	Description	Field/Calculation
Timing Idle(T)	Time spent idling while in a transaction in this database during the report interval (this corresponds to the states idle in transaction and idle in transaction (aborted) in pg_stat_activity)	idle_in_transaction_time
Sessions Established	Total number of sessions established to this database during the report interval	sessions
Sessions Abandoned	Number of database sessions to this database that were terminated because connection to the client was lost during the report interval	sessions_abandoned
Sessions Fatal	Number of database sessions to this database that were terminated by fatal errors during the report interval	sessions_fatal
Sessions Killed	Number of database sessions to this database that were terminated by operator intervention during the report interval	sessions_killed

In Postgres Pro Enterprise databases of versions that include pgpro_stats version starting with 1.4, workload statistics of vacuum processes are available. The “Database vacuum statistics” report table provides per-database aggregated total vacuum statistics based on the pgpro_stats_vacuum_tables view. Table G.5 lists columns of this report table. Times are provided in seconds.

Table G.5. Database vacuum statistics

Column	Description	Field/Calculation
Database	Database name	
Blocks fetched	Total number of database blocks fetched by vacuum operations	total_blks_read + total_blks_hit
%Total	Total number of database blocks fetched (read+hit) by vacuum operations as the percentage of all blocks fetched in the cluster	Blocks fetched * 100 / Cluster fetched
Blocks read	Total number of database blocks read by vacuum operations	total_blks_read
%Total	Total number of database blocks read by vacuum operations as the percentage of all blocks read in the cluster	Blocks read * 100 / Cluster read
VM Frozen	Total number of blocks marked all-frozen in the visibility map	pages_frozen
VM Visible	Total number of blocks marked all-visible in the visibility map	pages_all_visible
Tuples deleted	Total number of dead tuples vacuum operations deleted from tables of this database	tuples_deleted

Column	Description	Field/Calculation
Tuples left	Total number of dead tuples vacuum operations left in tables of this database due to their visibility in transactions	dead_tuples
%Eff	Vacuum efficiency in terms of deleted tuples. This is the percentage of tuples deleted from tables of this database in all dead tuples to be deleted from tables of this database.	tuples_deleted * 100 / (tuples_deleted + dead_tuples)
WAL size	Total amount of WAL bytes generated by vacuum operations performed on tables of this database	wal_bytes
Read I/O time	Time spent reading database blocks by vacuum operations performed on tables of this database	blk_read_time
Write I/O time	Time spent writing database blocks by vacuum operations performed on tables of this database	blk_write_time
%Total	Vacuum I/O time spent as the percentage of whole cluster I/O time	
Total vacuum time	Total time of vacuuming tables of this database	total_time
Delay vacuum time	Time spent sleeping in a vacuum delay point by vacuum operations performed on tables of this database	delay_time
User CPU time	User CPU time of vacuuming tables of this database	user_time
System CPU time	System CPU time of vacuuming tables of this database	system_time
Interrupts	Number of times vacuum operations performed on tables of this database were interrupted on any errors	interrupts

If the pgpro_stats extension supporting invalidation statistics was available during the report interval, the "Invalidation messages by database" report table provides per-database aggregated total invalidation message statistics. Table G.6 lists columns of this report table.

Table G.6. Invalidation messages by database

Column	Description	Field/Calculation
Database	Database name	
Invalidation messages sent	Total number of invalidation messages sent by backends in this database. Statistics are provided for corresponding message	Fields of pgpro_stats_totals.inval_msgs

Column	Description	Field/Calculation
	types of pgpro_stats_inval_msgs	
Cache resets	Total number of shared cache resets	pgpro_stats_totals .cache_resets

If the pgpro_stats extension was available during the report interval, the “Statement statistics by database” report table provides per-database aggregated total statistics for the pgpro_stats_statements view data. Table G.7 lists columns of this report table. Times are provided in seconds.

Table G.7. Statement statistics by database

Column	Description	Field/Calculation
Database	Database name	
Calls	Number of times all statements in the database were executed	calls
Plan Time	Time spent planning all statements in the database	Sum of total_plan_time
Exec Time	Time spent executing all statements in the database	Sum of total_exec_time
Read Time	Time spent reading blocks by all statements in the database	Sum of blk_read_time
Write Time	Time spent writing blocks by all statements in the database	Sum of blk_write_time
Trg Time	Time spent executing trigger functions by all statements in the database	
Shared Fetched	Total number of shared blocks fetched by all statements in the database	Sum of (shared_blks_read + shared_blks_hit)
Local Fetched	Total number of local blocks fetched by all statements in the database	Sum of (local_blks_read + local_blks_hit)
Shared Dirtied	Total number of shared blocks dirtied by all statements in the database	Sum of shared_blks_dirtied
Local Dirtied	Total number of local blocks dirtied by all statements in the database	Sum of local_blks_dirtied
Read Temp	Total number of temp blocks read by all statements in the database	Sum of temp_blks_read
Write Temp	Total number of temp blocks written by all statements in the database	Sum of temp_blks_written
Read Local	Total number of local blocks read by all statements in the database	Sum of local_blks_read
Write Local	Total number of local blocks written by all statements in the database	Sum of local_blks_written

Column	Description	Field/Calculation
Statements	Total number of captured statements	
WAL Size	Total amount of WAL generated by all statements in the database	Sum of wal_bytes

The “Statement average min/max timings” report table contains per-database aggregated min/max timing statistics from the one of pgpro_stats or pg_stat_statements extensions that was available during the report interval, with the precedence of pgpro_stats. This report is sensitive to the fastest and slowest planning and execution of every statement in a cluster. That is, you can see execution and planning stability in your database. Table G.8 lists columns of this report table.

Table G.8. Statement average min/max timings

Column	Description
Database	Database name
Min average planning time (ms)	The average value of min_plan_time for all statements and all samples included in the report
Max average planning time (ms)	The average value of max_plan_time for all statements and all samples included in the report
Delta% of average planning times	Difference between the mean max_plan_time and mean min_plan_time as the percentage of the mean min_plan_time . The less this difference, the more stable query planning in your database is.
Min average execution time (ms)	The average value of min_exec_time for all statements and all samples included in the report
Max average execution time (ms)	The average value of max_exec_time for all statements and all samples included in the report
Delta% of average execution times	Difference between the mean max_exec_time and mean min_exec_time as the percentage of the mean min_exec_time . The less this difference, the more stable query execution in your database is.
Statements	Total count of captured statements

If the JIT-related statistics was avaliable in the statement statistics extension during the report interval, the “JIT statistics by database” report table provides per-database aggregated total statistics of JIT executions. Table G.9 lists columns of this report table. Times are provided in seconds.

Table G.9. JIT statistics by database

Column	Description	Field/Calculation
Database	Database name	
Calls	Number of times all statements in the database were executed	calls
Plan Time	Time spent planning all statements in the database	Sum of total_plan_time
Exec Time	Time spent executing all statements in the database	Sum of total_exec_time
Generation count	Total number of functions JIT-compiled by the statements	Sum of jit_functions

Column	Description	Field/Calculation
Generation time	Total time spent by the statements on generating JIT code	Sum of jit_generation_time
Inlining count	Number of times functions have been inlined	Sum of jit_inlining_count
Inlining time	Total time spent by statements on inlining functions	Sum of jit_inlining_time
Optimization count	Number of times statements have been optimized	Sum of jit_optimization_count
Optimization time	Total time spent by statements on optimizing	Sum of jit_optimization_time
Emission count	Number of times code has been emitted	Sum of jit_emission_count
Emission time	Total time spent by statements on emitting code	Sum of jit_emission_time
Deform count	Number of tuple deform functions JIT-compiled by the statement of the database	
Deform time	Total time spent by the statements of the database on JIT-compiling the tuple deform functions	

The report table “Cluster statistics” provides data from the pg_stat_bgwriter view. Table G.10 lists rows of this report table. Times are provided in seconds.

Table G.10. Cluster statistics

Row	Description	Field/Calculation
Scheduled checkpoints	Number of scheduled checkpoints that have been performed	checkpoints_timed
Requested checkpoints	Number of requested checkpoints that have been performed	checkpoints_req
Checkpoint write time (s)	Total amount of time that has been spent in the portion of checkpoint processing where files are written to disk	checkpoint_write_time
Checkpoint sync time (s)	Total amount of time that has been spent in the portion of checkpoint processing where files are synchronized to disk	checkpoint_sync_time
Checkpoint buffers written	Number of buffers written during checkpoints	buffers_checkpoint
Background buffers written	Number of buffers written by the background writer	buffers_clean
Backend buffers written	Number of buffers written directly by a backend. Will not be shown since Postgres Pro 17.	buffers_backend
Backend fsync count	Number of times a backend had to execute its own fsync call (normally the background writer handles those even when the	buffers_backend_fsync

Row	Description	Field/Calculation
	backend does its own write). Will not be shown since Postgres Pro 17.	
Bgwriter interrupts (too many buffers)	Number of times the background writer stopped a cleaning scan because it had written too many buffers	maxwritten_clean
Number of buffers allocated	Total number of buffers allocated	buffers_alloc
WAL generated	Total amount of WAL generated	pg_current_wal_lsn() value increment
Start LSN	Log sequence number at the start of a report interval	pg_current_wal_lsn() at the first sample of a report
End LSN	Log sequence number at the end of a report interval	pg_current_wal_lsn() at the last sample of a report
WAL generated by vacuum	Total amount of WAL generated by vacuum	Based on the wal_bytes field of the pgpro_stats_vacuum_databases view.
WAL segments archived	Total number of archived WAL segments	Based on pg_stat_archiver.archived_count
WAL segments archive failed	Total number of WAL segment archiver failures	Based on pg_stat_archiver.failed_count .
Archiver performance	Average archiver process performance per second	Based on the active_time field of the pgpro_stats_archiver view.
Archive command performance	Average archive_command performance per second	Based on the archive_command_time field of the pgpro_stats_archiver view.

Table “WAL statistics” is available in the report for Postgres Pro databases starting with version 14. This table is based on the pg_stat_wal view of the Statistics Collector. Table G.11 lists columns of this report table. Times are provided in seconds.

Table G.11. WAL statistics

Row	Description	Field/Calculation
WAL generated	Total amount of WAL generated during the report interval	wal_bytes
WAL per second	Average amount of WAL generated per second during the report interval	wal_bytes / report_duration
WAL records	Total number of WAL records generated during the report interval	wal_records
WAL FPI	Total number of WAL full page images generated during the report interval	wal_fpi
WAL buffers full	Number of times WAL data was written to disk because WAL buffers became full during the report interval	wal_buffers_full

Row	Description	Field/Calculation
WAL writes	Number of times WAL buffers were written out to disk via XLogWrite request during the report interval	wal_write
WAL writes per second	Average number of times WAL buffers were written out to disk via XLogWrite request per second during the report interval	wal_write / report_duration
WAL sync	Number of times WAL files were synced to disk via issue_xlog_fsync request during the report interval (if fsync is on and wal_sync_method is either fdatasync, fsync or fsync_writethrough , otherwise zero). See Section 29.5 for more information about the internal WAL function issue_xlog_fsync .	wal_sync
WAL syncs per second	Average number of times WAL files were synced to disk via issue_xlog_fsync request per second during the report interval	wal_sync / report_duration
WAL write time	Total amount of time spent writing WAL buffers to disk via XLogWrite request during the report interval (if track_wal_io_timing is enabled, otherwise zero; for more details, see Section 19.9). This includes the sync time when wal_sync_method is either open_datasync or open_sync .	wal_write_time
WAL write duty	WAL write time as the percentage of the report interval duration	wal_write_time * 100 / report_duration
WAL sync time	Total amount of time spent syncing WAL files to disk via issue_xlog_fsync request during the report interval (if track_wal_io_timing is enabled, fsync is on, and wal_sync_method is either fdatasync, fsync or fsync_writethrough , otherwise zero).	wal_sync_time
WAL sync duty	WAL sync time as the percentage of the report interval duration	wal_sync_time * 100 / report_duration

The report table “Tablespace statistics” provides information on the sizes and growth of tablespaces. Table G.12 lists columns of this report table.

Table G.12. Tablespace statistics

Column	Description	Field/Calculation
`Tablespace`	Tablespace name	`pg_tablespace .spcname`
`Path`	Tablespace path	`pg_tablespace_location()`
`Size`	Tablespace size at the time of the last sample in the report interval	`pg_tablespace_size()`
`Growth`	Tablespace growth during the report interval	`pg_tablespace_size()` increment between interval bounds

If the pgpro_stats extension was available during the report interval, the report table “Wait statistics by database” shows the total wait time by wait event type and database. Table G.13 lists columns of this report table.

Table G.13. Wait statistics by database

Column	Description
`Database`	Database name
`Wait event type`	Type of event for which the backends were waiting. Asterisk means aggregation of all wait event types in the database.
`Waited (s)`	Time spent waiting in events of `Wait event type`, in seconds
`%Total`	Percentage of wait time spent in the database events of `Wait event type` in all wait time for the cluster

If the pgpro_stats extension was available during the report interval, the report table “Top wait events” shows top wait events in the cluster by wait time. Table G.14 lists columns of this report table.

Table G.14. Top wait events

Column	Description
`Database`	Database name
`Wait event type`	The type of event for which the backends were waiting
`Wait event`	Wait event name for which the backends were waiting
`Waited`	Total wait time spent in `Wait event` of the database, in seconds
`%Total`	Percentage of wait time spent in `Wait event` of the database in all wait time in the cluster

G.2.11.2. Load distribution

This section of a pgpro_pwr report is based on the `pgpro_stats_totals` view of the pgpro_stats extension if it was available during the report interval. Each table in this section provides data for the report interval on load distribution for a certain kind of objects for which aggregated statistics are collected, such as databases, applications, hosts, or users. Each table contains one row for each resource (for example, total time or shared blocks written), where load distribution is shown in graphics, as a stacked bar chart for top objects by load of this resource. If the bar chart area that corresponds to an object is too narrow to include captions, point that area to get a hint with the caption, value and percentage.

The report tables “Load distribution among heavily loaded databases”, “Load distribution among heavily loaded applications”, “Load distribution among heavily loaded hosts” and “Load distribution among heavily loaded users” show load distribution for respective objects. Table G.15 lists rows of these report tables.

Table G.15. Load distribution

Row	Description	Calculation
Total time (sec.)	Total time spent in the planning and execution of statements	total_plan_time + total_exec_time
Executed count	Number of queries executed	queries_executed
I/O time (sec.)	Total time the statements spent reading or writing blocks (if track_io_timing is enabled, otherwise zero)	blk_read_time + blk_write_time
Blocks fetched	Total number of shared block cache hits and shared blocks read by the statements	shared_blks_hit + shared_blks_read
Shared blocks read	Total number of shared blocks read by the statements	shared_blks_read
Shared blocks dirtied	Total number of shared blocks dirtied by the statements	shared_blks_dirtied
Shared blocks written	Total number of shared blocks written by the statements	shared_blks_written
WAL generated	Total amount of WAL generated by the statements	wal_bytes
Temp and Local blocks written	Total number of temporary and local blocks written by the statements	temp_blks_written + local_blks_written
Temp and Local blocks read	Total number of temp and local blocks read by the statements	temp_blks_read + local_blks_read
Invalidation messages sent	Total number of all invalidation messages sent by backends in this database	(pgpro_stats_totals.inval_msgs).all
Cache resets	Total number of shared cache resets	pgpro_stats_totals.cache_resets

G.2.11.3. Session states observed by subsamples

This section of a pgpro_pwr report provides information about session states captured by subsamples during the report interval.

Tables of this report section are described below.

The report subsection “Chart with session state” visualizes session states captured by subsamples. It is the timeline chart showing captured session states in backends and transactions. Every state contains a popup with session state attributes. Click on a state to see this state in the table of session states.

The report table “Session state statistics by database” shows the aggregated data on session states. Only session states captured in subsamples are counted. Table G.16 lists columns of this report table.

Table G.16. Session state statistics by database

Column	Description
Database	Database name

Column	Description
Summary Active	Overall time of active states captured in subsamples
Summary Idle in xact	Overall time of idle in transaction states captured in subsamples
Summary Idle in xact (A)	Overall time of idle in transaction (aborted) states captured in subsamples
Maximal Active	Time of the longest active state captured in subsamples
Maximal Idle in xact	Time of the longest idle in transaction state captured in subsamples
Maximal Idle in xact (A)	Time of the longest idle in transaction (aborted) state captured in subsamples
Maximal xact age	Maximal transaction age detected in subsamples

The report table “Top 'idle in transaction' session states by duration” shows top pgpro_pwr.topn longest idle in transaction states that were last observed in the pg_stat_activity view for each session. Table G.17 lists columns of this report table.

Table G.17. Top 'idle in transaction' session states by duration

Column	Description	Field/Calculation
Database	Database name	datname
User	User name	usename
App	Application name	application_name
Pid	Process ID	pid
Xact start	Transaction start timestamp	xact_start
State change	State change timestamp	state_change
State duration	State duration	clock_timestamp() - state_change

The report table “Top 'active' session states by duration” shows top pgpro_pwr.topn longest active states that were last observed in the pg_stat_activity view for each session. Table G.18 lists columns of this report table.

Table G.18. Top 'active' session states by duration

Column	Description	Field/Calculation
Database	Database name	datname
User	User name	usename
App	Application name	application_name
Pid	Process ID	pid
Xact start	Transaction start timestamp	xact_start
State change	State change timestamp	state_change
State duration	State duration	clock_timestamp() - state_change

The report table “Top states by transaction age” shows top session states by transaction age that were last observed in the pg_stat_activity view for each session. Table G.19 lists columns of this report table.

Table G.19. Top states by transaction age

Column	Description	Field/Calculation
Database	Database name	datname
User	User name	usename
App	Application name	application_name
Pid	Process ID	pid
Xact start	Transaction start timestamp	xact_start
Xact duration	Transaction duration	clock_timestamp() - xact_start
Age	Transaction age	age(backend_xmin)
State	Session state at the maximum age detected	
State change	State change timestamp	state_change
State duration	State duration	clock_timestamp() - state_change

The report table “Top states by transaction duration” shows top longest session states that were last observed in the pg_stat_activity view for each session. Table G.20 lists columns of this report table.

Table G.20. Top states by transaction duration

Column	Description	Field/Calculation
Database	Database name	datname
User	User name	usename
App	Application name	application_name
Pid	Process ID	pid
Xact start	Transaction start timestamp	xact_start
Xact duration	Transaction duration	clock_timestamp() - xact_start
Age	Transaction age	age(backend_xmin)
State	Session state at the maximum age detected	
State change	State change timestamp	state_change
State duration	State duration	clock_timestamp() - state_change

G.2.11.4. SQL query statistics

This section of a pgpro_pwr report provides data for the report interval on top statements by several important statistics. The data is mainly captured from views of the one of pgpro_stats and pg_stat_statements extensions that was available during the report interval, with the precedence of pgpro_stats. Each statement can be highlighted in all SQL-related sections with a single mouse click on it. This click will also show a query text preview just under the query statistics row. The query text preview can be hidden with a second click on a query.

Tables of this report section are described below.

The report table “Top SQL by elapsed time” shows top statements by the sum of total_plan_time and total_exec_time fields of the pgpro_stats_statements or pg_stat_statements view. Table G.21 lists columns of this report table. Times are provided in seconds.

Table G.21. Top SQL by elapsed time

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
%Total	Percentage of elapsed time of this statement plan in the total elapsed time of all statements in the cluster	
Elapsed Time (s)	Total time spent in planning and execution of the statement plan	total_plan_time + total_exec_time
Plan Time (s)	Total time spent in planning of the statement	total_plan_time
Exec Time (s)	Total time spent in execution of the statement plan	total_exec_time
JIT Time (s)	Total time spent by JIT executing this statement plan, in seconds	jit_generation_time + jit_inlining_time + jit_optimization_time + jit_emission_time
Read I/O time (s)	Total time the statement spent reading blocks	blk_read_time
Write I/O time (s)	Total time the statement spent writing blocks	blk_write_time
Usr CPU time (s)	Time spent on CPU in the user space, in seconds	rusage.user_time
Sys CPU time (s)	Time spent on CPU in the system space, in seconds	rusage.system_time
Plans	Number of times the statement was planned	plans
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by planning time” shows top statements by the value of the total_plan_time field of the pgpro_stats_statements or pg_stat_statements view. Table G.22 lists columns of this report table.

Table G.22. Top SQL by planning time

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Plan elapsed(s)	Total time spent in planning of the statement, in seconds	total_plan_time
%Elapsed	Percentage of total_plan_time in the sum of total_plan_time and total_exec_time of this statement plan	
Mean plan time	Mean time spent planning the statement, in milliseconds	mean_plan_time
Min plan time	Minimum time spent planning the statement, in milliseconds	min_plan_time
Max plan time	Maximum time spent planning the statement, in milliseconds	max_plan_time
StdErr plan time	Population standard deviation of time spent planning the statement, in milliseconds	stddev_plan_time
Plans	Number of times the statement was planned	plans
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by execution time” shows top statements by the value of the total_time field of the pgpro_stats_statements or pg_stat_statements view. Table G.23 lists columns of this report table.

Table G.23. Top SQL by execution time

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	

Column	Description	Field/Calculation
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Exec (s)	Total time spent executing the statement plan, in seconds	total_exec_time
%Elapsed	Percentage of total_exec_time of this statement plan in this statement elapsed time	
%Total	Percentage of total_exec_time of this statement plan in the total elapsed time of all statements in the cluster	
JIT Time (s)	Total time spent by JIT executing this statement plan, in seconds	jit_generation_time + jit_inlining_time + jit_optimization_time + jit_emission_time
Read I/O time (s)	Total time spent in reading pages while executing the statement plan, in seconds	blk_read_time
Write I/O time (s)	Total time spent in writing pages while executing the statement plan, in seconds	blk_write_time
Usr CPU time (s)	Time spent on CPU in the user space, in seconds	rusage.user_time
Sys CPU time (s)	Time spent on CPU in the system space, in seconds	rusage.system_time
Rows	Number of rows retrieved or affected by execution of the statement plan	rows
Mean execution time	Mean time spent executing the statement plan, in milliseconds	mean_exec_time
Min execution time	Minimum time spent executing the statement plan, in milliseconds	min_exec_time
Max execution time	Maximum time spent executing the statement plan, in milliseconds	max_exec_time
StdErr execution time	Population standard deviation of time spent executing the statement plan, in milliseconds	stddev_exec_time
Executions	Number of executions of this statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table "Top SQL by mean execution time" shows top `pgpro_pwr.topn` statements by the value of the `mean_time` or `mean_exec_time` field of the `pgpro_stats_statements` or `pg_stat_statements` view. Table G.24 lists columns of this report table.

Table G.24. Top SQL by mean execution time

Column	Description	Field/Calculation
`Query ID`	Hex representation of `queryid`. The hash of the query ID, database ID and user ID is in square brackets. The `(N)` mark will appear here for nested statements (such as statements invoked within top-level statements).	
`Database`	Database name for the statement	Derived from `dbid`
`User`	Name of the user executing the statement	Derived from `userid`
`Mean execution time (ms)`	Mean time spent executing the statement, in milliseconds	`mean_exec_time`
`Min execution time (ms)`	Minimum time spent executing the statement, in milliseconds	`min_exec_time`
`Max execution time (ms)`	Maximum time spent executing the statement, in milliseconds	`max_exec_time`
`StdErr execution time`	Population standard deviation of time spent executing the statement, in milliseconds	`stddev_exec_time (ms)`
`Exec (s)`	Time spent executing this statement, in seconds	`total_exec_time`
`%Elapsed`	Execution time of this statement as the percentage of the statement elapsed time	
`%Total`	Execution time of this statement as the percentage of the total elapsed time of all statements in the cluster	
`JIT time (s)`	Total time spent by JIT executing this statement, in seconds	`jit_generation_time` + `jit_inlining_time` + `jit_optimization_time` + `jit_emission_time`
`Read I/O time (s)`	Time spent reading blocks, in seconds	`blk_read_time`
`Write I/O time (s)`	Time spent writing blocks, in seconds	`blk_write_time`
`Rows`	Number of rows retrieved or affected by the statement	`rows`
`Executions`	Number of times this statement was executed	`calls`
`%Cvr`	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table "Top SQL by executions" shows top statements by the value of the `calls` field of the `pgpro_stats_statements` or `pg_stat_statements` view. Table G.25 lists columns of this report table.

Table G.25. Top SQL by executions

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Executions	Number of executions of the statement plan	calls
%Total	Percentage of calls of this statement plan in the total calls of all statements in the cluster	
Rows	Number of rows retrieved or affected by execution of the statement plan	rows
Mean (ms)	Mean time spent executing the statement plan, in milliseconds	mean_exec_time
Min (ms)	Minimum time spent executing the statement plan, in milliseconds	min_exec_time
Max (ms)	Maximum time spent executing the statement plan, in milliseconds	max_exec_time
StdErr (ms)	Population standard deviation of time spent executing the statement plan, in milliseconds	stddev_time
Elapsed(s)	Total time spent executing the statement plan, in seconds	total_exec_time
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by I/O wait time” shows top statements by read and write time, i.e., sum of values of blk_read_time and blk_write_time fields of the pgpro_stats_statements or pg_stat_statements view. Table G.26 lists columns of this report table. Times are provided in seconds.

Table G.26. Top SQL by I/O wait time

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements	

Column	Description	Field/Calculation
	(such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
IO(s)	Total time spent in reading and writing while executing this statement plan, i.e., I/O time	blk_read_time + blk_write_time
R(s)	Total time spent in reading while executing this statement plan	blk_read_time
W(s)	Total time spent in writing while executing this statement plan	blk_write_time
%Total	Percentage of I/O time of this statement plan in the total I/O time of all statements in the cluster	
Shr Reads	Total number of shared blocks read while executing the statement plan	shared_blks_read
Loc Reads	Total number of local blocks read while executing the statement plan	local_blks_read
Tmp Reads	Total number of temp blocks read while executing the statement plan	temp_blks_read
Shr Writes	Total number of shared blocks written while executing the statement plan	shared_blks_written
Loc Writes	Total number of local blocks written while executing the statement plan	local_blks_written
Tmp Writes	Total number of temp blocks written while executing the statement plan	temp_blks_written
Elapsed(s)	Total time spent in execution of the statement plan	total_plan_time + total_exec_time
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by shared blocks fetched” shows top statements by the number of read and hit blocks, which helps to detect the most data-intensive statements. Table G.27 lists columns of this report table.

Table G.27. Top SQL by shared blocks fetched

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Blks fetched	Number of blocks retrieved while executing the statement plan	shared_blks_hit + shared_blks_read
%Total	Percentage of blocks fetched while executing the statement plan in all blocks fetched for all statements in the cluster	
Hits(%)	Percentage of blocks got from buffers in all blocks got	
Elapsed(s)	Total time spent in execution of the statement plan, in seconds	total_plan_time + total_exec_time
Rows	Number of rows retrieved or affected by execution of the statement plan	rows
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by shared blocks read” shows top statements by the number of shared reads, which helps to detect the most read-intensive statements. Table G.28 lists columns of this report table.

Table G.28. Top SQL by shared blocks read

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid

Column	Description	Field/Calculation
User	Name of the user executing the statement	Derived from userid
Reads	Number of shared blocks read while executing this statement plan	shared_blks_read
%Total	Percentage of shared reads for this statement plan in all shared reads of all statements in the cluster	
Hits(%)	Percentage of blocks got from buffers in all blocks got while executing this statement plan	
Elapsed(s)	Total time spent in execution of the statement plan, in seconds	total_plan_time + total_exec_time
Rows	Number of rows retrieved or affected by execution of the statement plan	rows
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by shared blocks dirtied” shows top statements by the number of shared dirtied buffers, which helps to detect statements that do most data changes in the cluster. Table G.29 lists columns of this report table.

Table G.29. Top SQL by shared blocks dirtied

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Dirtied	Number of shared buffers dirtied while executing this statement plan	shared_blks_dirtied
%Total	Percentage of dirtied shared buffers for this statement plan in all dirtied shared buffers of all statements in the cluster	

Column	Description	Field/Calculation
Hits(%)	Percentage of blocks got from buffers in all blocks got while executing this statement plan	
WAL	Total amount of WAL bytes generated by the statement plan	wal_bytes
%Total	Percentage of WAL bytes generated by the statement plan in total WAL generated in the cluster	
Elapsed(s)	Total time spent in execution of the statement plan, in seconds	total_plan_time + total_exec_time
Rows	Number of rows retrieved or affected by execution of the statement plan	rows
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by shared blocks written” shows top statements by the number of blocks written. Table G.30 lists columns of this report table.

Table G.30. Top SQL by shared blocks written

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Written	Number of blocks written while executing this statement plan	shared_blks_written
%Total	Percentage of blocks written by this statement plan in all written blocks in the cluster	Percentage of shared_blks_written in (pg_stat_bgwriter.buffers_checkpoint + pg_stat_bgwriter.buffers_clean + pg_stat_bgwriter.buffers_backend)
%BackendW	Percentage of blocks written by this statement plan in all blocks in the cluster written by backends	Percentage of shared_blks_written in pg_stat_bgwriter.buffers_backend

Column	Description	Field/Calculation
Hits(%)	Percentage of blocks got from buffers in all blocks got while executing this statement plan	
Elapsed(s)	Total time spent in execution of the statement plan, in seconds	total_plan_time + total_exec_time
Rows	Number of rows retrieved or affected by execution of the statement plan	rows
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by WAL size” shows top statements by the amount of WAL generated. Table G.31 lists columns of this report table.

Table G.31. Top SQL by WAL size

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
WAL	Total amount of WAL bytes generated by the statement plan	wal_bytes
%Total	Percentage of WAL bytes generated by the statement plan in total WAL generated in the cluster	
Dirtied	Number of shared buffers dirtied while executing this statement plan	shared_blks_dirtied
WAL FPI	Total number of WAL full page images generated by the statement plan	wal_fpi
WAL records	Total number of WAL records generated by the statement plan	wal_records
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by temp usage” shows top statements by temporary I/O, which is calculated as the sum of temp_blks_read, temp_blks_written, local_blks_read and local_blks_written fields. Table G.32 lists columns of this report table.

Table G.32. Top SQL by temp usage

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Local fetched	Number of local blocks retrieved	local_blks_hit + local_blks_read
Hits(%)	Percentage of local blocks got from buffers in all local blocks got	
Write Local (blk)	Number of blocks written by this statement plan that are used in temporary tables	local_blks_written
Write Local %Total	Percentage of local_blks_written of this statement plan in the total of local_blks_written for all statements in the cluster	
Read Local (blk)	Number of blocks read by this statement plan that are used in temporary tables	local_blks_read
Read Local %Total	Percentage of local_blks_read of this statement plan in the total of local_blks_read for all statements in the cluster	
Write Temp (blk)	Number of temp blocks written by this statement plan	temp_blks_written
Write Temp %Total	Percentage of temp_blks_written of this statement plan in the total of temp_blks_written for all statements in the cluster	
Read Temp (blk)	Number of temp blocks read by this statement plan	temp_blks_read
Read Temp %Total	Percentage of temp_blks_read of this statement plan in the to-	

Column	Description	Field/Calculation
	tal of temp_blks_read for all statements in the cluster	
Elapsed(s)	Total time spent in execution of the statement plan, in seconds	total_plan_time + total_exec_time
Rows	Number of rows retrieved or affected by execution of the statement plan	rows
Executions	Number of executions of the statement plan	calls
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

The report table “Top SQL by invalidation messages sent” shows top statements by the number of invalidation messages sent. Table G.33 lists columns of this report table.

Table G.33. Top SQL by invalidation messages sent

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	queryid
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Invalidation messages sent	Total number of invalidation messages sent by backends executing this statement. Statistics are provided for corresponding message types of pgpro_stats_inval_msgs	fields of pgpro_stats_statements.inval_msgs

G.2.11.4.1. rusage statistics

This section is included in the report only if the pgpro_stats or pg_stat_kcache extension was available during the report interval.

The report table “Top SQL by system and user time” shows top statements by the sum of user_time and system_time fields of pg_stat_kcache or of the pgpro_stats_totals view. Table G.34 lists columns of this report table.

Table G.34. Top SQL by system and user time

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square	

Column	Description	Field/Calculation
	brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Plan User (s)	User CPU time elapsed during planning, in seconds	plan_user_time
Exec User (s)	User CPU time elapsed during execution, in seconds	exec_user_time
User %Total	Percentage of plan_user_time + exec_user_time in the total user CPU time for all statements	
Plan System (s)	System CPU time elapsed during planning, in seconds	plan_system_time
Exec System (s)	System CPU time elapsed during execution, in seconds	exec_system_time
System %Total	Percentage of plan_system_time + exec_system_time in the total system CPU time for all statements	

The report table “Top SQL by reads/writes done by filesystem layer” shows top statements by the sum of reads and writes fields of pg_stat_kcache. Table G.35 lists columns of this report table.

Table G.35. Top SQL by reads/writes done by filesystem layer

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Plan Read Bytes	Bytes read during planning	plan_reads
Exec Read Bytes	Bytes read during execution	exec_reads
Read Bytes %Total	Percentage of plan_reads + exec_reads in the total number of bytes read by the filesystem layer for all statements	

Column	Description	Field/Calculation
Plan Writes	Bytes written during planning	plan_writes
Exec Writes	Bytes written during execution	exec_writes
Write %Total	Percentage of plan_writes + exec_writes in the total number of bytes written by the filesystem layer for all statements	

G.2.11.5. SQL query wait statistics

If the pgpro_stats extension was available during the report interval, this section of the report will contain a table that is split into sections, each showing top statements by overall wait time or by wait time for a certain wait event type. Table sections related to specific wait events follow in the descending order of the total wait time in wait events of this type. Table G.36 lists columns of this report table. Times are provided in seconds.

Table G.36. SQL query wait statistics

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	
Plan ID	Hash of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
Waited	Total wait time for all wait events of this statement plan	
%Total	Percentage of the total wait time of this statement plan in all the wait time in the cluster	
Details	Waits of this statement plan by wait types	

If the JIT-related statistics was avaliable in the statement statistics extension during the report interval, the report table “Top SQL by JIT elapsed time” shows top statements by the sum of jit_*_time fields of the pgpro_stats_statements or pg_stat_statements view. Table G.37 lists columns of this report table. Times are provided in seconds.

Table G.37. Top SQL by JIT elapsed time

Column	Description	Field/Calculation
Query ID	Hex representation of queryid. The hash of the query ID, database ID and user ID is in square brackets. The (N) mark will appear here for nested statements (such as statements invoked within top-level statements).	

Column	Description	Field/Calculation
Plan ID	Internal hash code, computed from the tree of the statement plan	planid
Database	Database name for the statement	Derived from dbid
User	Name of the user executing the statement	Derived from userid
JIT Time (s)	Total time spent by JIT executing this statement plan	jit_generation_time + jit_inlining_time + jit_optimization_time + jit_emission_time
Generation count	Total number of functions JIT-compiled by this statement	Sum of jit_functions
Generation time	Total time spent by this statement on generating JIT code	Sum of jit_generation_time
Inlining count	Number of times functions have been inlined	Sum of jit_inlining_count
Inlining time	Total time spent by this statement on inlining functions	Sum of jit_inlining_time
Optimization count	Number of times this statement has been optimized	Sum of jit_optimization_count
Optimization time	Total time spent by this statement on optimizing	Sum of jit_optimization_time
Emission count	Number of times code has been emitted	Sum of jit_emission_count
Emission time	Total time spent by this statement on emitting code	Sum of jit_emission_time
Deform count	Number of tuple deform functions JIT-compiled by the statement	
Deform time	Total time spent by the statement on JIT-compiling the tuple deform	
Plan Time (s)	Total time spent in planning of the statement	total_plan_time
Exec Time (s)	Total time spent in execution of the statement plan	total_exec_time
Read I/O time (s)	Total time the statement spent reading blocks	blk_read_time
Write I/O time (s)	Total time the statement spent writing blocks	blk_write_time
%Cvr	Coverage: duration of statement statistics collection as the percentage of the report duration	

G.2.11.6. Complete list of SQL texts

The “Complete list of SQL texts” section of the report contains a table that provides query and plan texts for all statements mentioned in the report. Use an appropriate Query ID/Plan ID link in any statistics table to see the corresponding query/plan text. Table G.38 lists columns of this report table.

Table G.38. Complete list of SQL texts

Column	Description
ID	Hex representation of the query or plan identifier
Query/Plan Text	Text of the query or statement plan

G.2.11.7. Schema object statistics

Tables in this section of the report show top database objects by statistics from the Postgres Pro's Statistics Collector views. Report tables that contain data for tables and indexes provide a preview of storage parameters. You can click on a row to see storage parameters of the object right under the row.

The report table “Top tables by estimated sequentially scanned volume” shows top tables by estimated volume read by sequential scans. This can help you find database tables that possibly lack some index. When there are no relation sizes collected with pg_relation_size(), relation-size estimates are based on the pg_class.relpages field. Since such values are less accurate, they are shown in square brackets. The data is based on the pg_stat_all_tables view. Table G.39 lists columns of this report table.

Table G.39. Top tables by estimated sequentially scanned volume

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
~SeqBytes	Estimated volume read by sequential scans	Sum of (pg_relation_size() * seq_scan)
SeqScan	Number of sequential scans performed on the table	seq_scan
IxScan	Number of index scans initiated on the table	idx_scan
IxFet	Number of live rows fetched by index scans	idx_tup_fetch
Ins	Number of rows inserted	n_tup_ins
Upd	Number of rows updated	n_tup_upd
Del	Number of rows deleted	n_tup_del
Upd(HOT)	Number of rows HOT updated	n_tup_hot_upd

In the report table “Top tables by blocks fetched”, blocks fetched include blocks being processed from disk (read) and from shared buffers (hit). This report table shows top database tables by the sum of blocks fetched for the table's heap, indexes, TOAST table (if any) and TOAST table index (if any). This can help you focus on tables with excessive processing of blocks. The data is based on the pg_statio_all_tables view. Table G.40 lists columns of this report table.

Table G.40. Top tables by blocks fetched

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	

Column	Description	Field/Calculation
Table	Table name	
Heap Blks	Number of blocks fetched for the table's heap	heap_blks_read + heap_blks_hit
Heap Blks %Total	Percentage of blocks fetched for the table's heap in all blocks fetched in the cluster	
Ix Blks	Number of blocks fetched for table's indexes	idx_blks_read + idx_blks_hit
Ix Blks %Total	Percentage of blocks fetched for table's indexes in all blocks fetched in the cluster	
TOAST Blks	Number of blocks fetched for the table's TOAST table	toast_blks_read + toast_blks_hit
TOAST Blks %Total	Percentage of blocks fetched for the table's TOAST table in all blocks fetched in the cluster	
TOAST-Ix Blks	Number of blocks fetched for the table's TOAST index	tidx_blks_read + tidx_blks_hit
TOAST-Ix Blks %Total	Percentage of blocks fetched for the table's TOAST index in all blocks fetched in the cluster	

The report table “Top tables by blocks read” shows top database tables by the number of blocks read for the table's heap, indexes, TOAST table (if any) and TOAST table index (if any). This can help you focus on tables with excessive block readings. The data is based on the pg_statio_all_tables view. Table G.41 lists columns of this report table.

Table G.41. Top tables by blocks read

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Heap Blks	Number of blocks read for the table's heap	heap_blks_read
Heap Blks %Total	Percentage of blocks read from the table's heap in all blocks read in the cluster	
Ix Blks	Number of blocks read from table's indexes	idx_blks_read
Ix Blks %Total	Percentage of blocks read from table's indexes in all blocks read in the cluster	
TOAST Blks	Number of blocks read from the table's TOAST table	toast_blks_read
TOAST Blks %Total	Percentage of blocks read from the table's TOAST table in all blocks read in the cluster	

Column	Description	Field/Calculation
TOAST-Ix Blks	Number of blocks read from the table's TOAST index	tidx_blks_read
TOAST-Ix Blks %Total	Percentage of blocks read from the table's TOAST index in all blocks read in the cluster	
Hit(%)	Percentage of table, index, TOAST and TOAST index blocks got from buffers for this table in all blocks got for this table from either file system or buffers	

The report table “Top DML tables” shows top tables by the number of DML-affected rows, i.e., by the sum of n_tup_ins, n_tup_upd and n_tup_del (including TOAST tables). The data is based on the pg_stat_all_tables view. Table G.42 lists columns of this report table.

Table G.42. Top DML tables

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Ins	Number of rows inserted	n_tup_ins
Upd	Number of rows updated, including HOT	n_tup_upd
Del	Number of rows deleted	n_tup_del
Upd(HOT)	Number of rows HOT updated	n_tup_hot_upd
SeqScan	Number of sequential scans performed on the table	seq_scan
SeqFet	Number of live rows fetched by sequential scans	seq_tup_read
IxScan	Number of index scans initiated on this table	idx_scan
IxFet	Number of live rows fetched by index scans	idx_tup_fetch

The report table “Top tables by updated/deleted tuples” shows top tables by tuples modified by UPDATE/DELETE operations, i.e., by the sum of n_tup_upd and n_tup_del (including TOAST tables). The data is based on the pg_stat_all_tables view. Table G.43 lists columns of this report table.

Table G.43. Top tables by updated/deleted tuples

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Upd	Number of rows updated, including HOT	n_tup_upd

Column	Description	Field/Calculation
Upd(HOT)	Number of rows HOT updated	n_tup_hot_upd
Del	Number of rows deleted	n_tup_del
Vacuum	Number of times this table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
AutoVacuum	Number of times this table has been vacuumed by the autovacuum daemon	autovacuum_count
Analyze	Number of times this table was manually analyzed	analyze_count
AutoAnalyze	Number of times this table was analyzed by the autovacuum daemon	autoanalyze_count

The report table “Top tables by removed all-visible marks” shows top tables by the number of times that the all-visible mark was removed from the visibility map by any backend. This report section is only shown when corresponding statistics are available. Table G.44 lists columns of this report table.

Table G.44. Top tables by removed all-visible marks

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
All-Visible marks cleared	Number of times that the all-visible mark was removed from the relation visibility map	rev_all_visible_pages
All-Visible marks set	Number of times that the all-visible mark was set in the relation visibility map	pages_all_visible
All-Visible marks %Set	Percentage of the number of times that the all-visible mark was set in the number of times that it was set or removed	pages_all_visible * 100% / (rev_all_visible_pages + pages_all_visible)
Vacuum	Number of times this table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
AutoVacuum	Number of times this table has been vacuumed by the autovacuum daemon	autovacuum_count

The report table “Top tables by removed all-frozen marks” shows top tables by the number of times that the all-frozen mark was removed from the visibility map by any backend. This report section is only shown when corresponding statistics are available. Table G.45 lists columns of this report table.

Table G.45. Top tables by removed all-frozen marks

Column	Description	Field/Calculation
DB	Database name for the table	

Column	Description	Field/Calculation
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
All-Frozen marks cleared	Number of times that the all-frozen mark was removed from the relation visibility map	rev_all_frozen_pages
All-Frozen marks set	Number of times that the all-frozen mark was set in the relation visibility map	pages_frozen
All-Frozen marks %Set	Percentage of the number of times that the all-frozen mark was set in the number of times that it was set or removed	pages_frozen * 100% / (rev_all_frozen_pages + pages_frozen)
Vacuum	Number of times this table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
AutoVacuum	Number of times this table has been vacuumed by the autovacuum daemon	autovacuum_count

The report table “Top tables by new-page updated tuples” shows top tables by the number of rows updated where the successor version goes onto a *new* heap page, leaving behind an original version with a t_ctid field that points to a different heap page. These are always non-HOT updates. Table G.46 lists columns of this report table.

Table G.46. Top tables by new-page updated tuples

Column	Description
DB	Database name for the table
Tablespace	Name of the tablespace where the table is located
Schema	Schema name for the table
Table	Table name
NP Upd	Number of rows updated to a new heap page
%Upd	Number of new-page updated rows as the percentage of all rows updated
Upd	Number of rows updated, including HOT
Upd(HOT)	Number of rows HOT updated (i.e., with no separate index update required)

The report table “Top growing tables” shows top tables by growth. The data is based on the pg_stat_all_tables view. When there are no relation sizes collected with pg_relation_size(), relation-size estimates are based on the pg_class.relpages field. Since such values are less accurate, they are shown in square brackets. Table G.47 lists columns of this report table.

Table G.47. Top growing tables

Column	Description	Field/Calculation
DB	Database name for the table	

Column	Description	Field/Calculation
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Size	Table size at the time of the last sample in the report interval	pg_table_size() - pg_relation_size(toast)
Growth	Table growth	
Ins	Number of rows inserted	n_tup_ins
Upd	Number of rows updated, including HOT	n_tup_upd
Del	Number of rows deleted	n_tup_del
Upd(HOT)	Number of rows HOT updated	n_tup_hot_upd

In the report table "Top indexes by blocks fetched", blocks fetched include index blocks processed from disk (read) and from shared buffers (hit). The data is based on the pg_statio_all_indexes view. Table G.48 lists columns of this report table.

Table G.48. Top indexes by blocks fetched

Column	Description	Field/Calculation
DB	Database name for the index	
Tablespace	Name of the tablespace where the index is located	
Schema	Schema name for the underlying table	
Table	Underlying table name	
Index	Index name	
Scans	Number of index scans initiated on this index	idx_scan
Blks	Number of blocks fetched for this index	idx_blks_read + idx_blks_hit
%Total	Percentage of blocks fetched for this index in all blocks fetched in the cluster	

The report table "Top indexes by blocks read" is also based on the pg_statio_all_indexes and pg_stat_all_indexes views. Table G.49 lists columns of this report table.

Table G.49. Top indexes by blocks read

Column	Description	Field/Calculation
DB	Database name for the index	
Tablespace	Name of the tablespace where the index is located	
Schema	Schema name for the underlying table	
Table	Underlying table name	
Index	Index name	

Column	Description	Field/Calculation
Scans	Number of index scans initiated on this index	idx_scan
Blk Reads	Number of disk blocks read from this index	idx_blks_read
%Total	Percentage of disk blocks read from this index in all disk blocks read in the cluster	
Hits(%)	Percentage of index blocks got from buffers in all index blocks got for this index	

The report table “Top growing indexes” shows top indexes by growth. The table uses data from the pg_stat_all_tables and pg_stat_all_indexes views. When there are no relation sizes collected with pg_relation_size(), relation-size estimates are based on the pg_class.relpages field. Since such values are less accurate, they are shown in square brackets. Table G.50 lists columns of this report table.

Table G.50. Top growing indexes

Column	Description	Field/Calculation
DB	Database name for the index	
Tablespace	Name of the tablespace where the index is located	
Schema	Schema name for the underlying table	
Table	Underlying table name	
Index	Index name	
Index Size	Index size at the time of the last sample in the report interval	pg_relation_size()
Index Growth	Index growth during the report interval	
Table Ins	Number of rows inserted into the underlying table	n_tup_ins
Table Upd	Number of rows updated in the underlying table, without HOT	n_tup_upd - n_tup_hot_upd
Table Del	Number of rows deleted from the underlying table	n_tup_del

The report table “Unused indexes” shows top non-scanned indexes (during the report interval) by DML operations on underlying tables that caused index support. Constraint indexes are not counted. The table uses data from the pg_stat_all_tables view. Table G.51 lists columns of this report table.

Table G.51. Unused indexes

Column	Description	Field/Calculation
DB	Database name for the index	
Tablespace	Name of the tablespace where the index is located	
Schema	Schema name for the underlying table	

Column	Description	Field/Calculation
Table	Underlying table name	
Index	Index name	
Index Size	Index size at the time of the last sample in the report interval	pg_relation_size()
Index Growth	Index growth during the report interval	
Table Ins	Number of rows inserted into the underlying table	n_tup_ins
Table Upd	Number of rows updated in the underlying table, without HOT	n_tup_upd - n_tup_hot_upd
Table Del	Number of rows deleted from the underlying table	n_tup_del

G.2.11.8. User function statistics

Tables in this section of the report show top functions in the cluster by statistics from the pg_stat_user_functions view. Times in the tables are provided in seconds.

The report table “Top functions by total time” shows top functions by the total time elapsed. The report table “Top functions by executions” shows top functions by the number of executions. The report table “Top trigger functions by total time” shows top trigger functions by the total time elapsed. Table G.52 lists columns of these report tables.

Table G.52. User function statistics

Column	Description	Field/Calculation
DB	Database name for the function	
Schema	Schema name for the function	
Function	Function name	
Executions	Number of times this function has been called	calls
Total Time (s)	Total time spent in this function and all other functions called by it	total_time
Self Time (s)	Total time spent in this function itself, not including other functions called by it	self_time
Mean Time (s)	Mean time of a single function execution	total_time /calls
Mean self Time (s)	Mean self time of a single function execution	self_time /calls

G.2.11.9. Vacuum-related statistics

The report table “Top tables by vacuum time spent” is available if pgpro_stats can provide extended vacuum statistics. This table shows top tables by total time spent vacuuming them. The data is based on the pgpro_stats_vacuum_tables view. Table G.53 lists columns of this report table.

Table G.53. Top tables by vacuum time spent

Column	Description	Field/Calculation
DB	Database name for the table	

Column	Description	Field/Calculation
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Total vacuum time	Total time of vacuuming this table	total_time
Delay vacuum time	Time spent sleeping in a vacuum delay point by vacuum operations performed on this table	delay_time
Read I/O time	Time spent reading database blocks by vacuum operations performed on this table	blk_read_time
Write I/O time	Time spent writing database blocks by vacuum operations performed on this table	blk_write_time
User CPU time	User CPU time of vacuuming tables of this database	user_time
System CPU time	System CPU time of vacuuming tables of this database	system_time
Vacuum count	Number of times this table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
Autovacuum count	Number of times this table has been vacuumed by the autovacuum daemon	autovacuum_count
Total fetched	Total number of database blocks fetched by vacuum operations performed on this table	total_blks_read + total_blks_hit
Heap fetched	Total number of blocks fetched from this table by vacuum operations performed on it	rel_blks_read + rel_blks_hit
Scanned	Number of pages examined by vacuum operations performed on this table	pages_scanned

The report table “Top indexes by vacuum time spent” is available if pgpro_stats can provide extended vacuum statistics. This table shows top indexes by total time spent vacuuming them. The data is based on the pgpro_stats_vacuum_indexes view. Table G.54 lists columns of this report table.

Table G.54. Top indexes by vacuum time spent

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Index	Index name	
Total vacuum time	Total time of vacuuming this index	total_time

Column	Description	Field/Calculation
Delay vacuum time	Time spent sleeping in a vacuum delay point by vacuum operations performed on this index	delay_time
Read I/O time	Time spent reading database blocks by vacuum operations performed on this index	blk_read_time
Write I/O time	Time spent writing database blocks by vacuum operations performed on this index	blk_write_time
User CPU time	User CPU time of vacuuming this index	user_time
System CPU time	System CPU time of vacuuming this index	system_time
Vacuum count	Number of times the underlying table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
Autovacuum count	Number of times the underlying table has been vacuumed by the autovacuum daemon	autovacuum_count
Total fetched	Total number of database blocks fetched by vacuum operations performed on the underlying table	total_blks_read + total_blks_hit
Index fetched	Total number of blocks fetched from this index by vacuum operations performed on it	rel_blks_read + rel_blks_hit

The report table “Top tables by blocks vacuum fetched” is available if pgpro_stats can provide extended vacuum statistics. This table shows top tables by blocks fetched vacuuming these tables. The data is based on the pgpro_stats_vacuum_tables view. Table G.55 lists columns of this report table.

Table G.55. Top tables by blocks vacuum fetched

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
DB fetched	Total number of database blocks fetched by vacuum operations performed on this table	total_blks_read + total_blks_hit
%Total	Total number of database blocks fetched by vacuum operations performed on this table as the percentage of all blocks fetched in the cluster	
DB read	Total number of database blocks read by vacuum operations performed on this table	total_blks_read

Column	Description	Field/Calculation
%Total	Total number of database blocks read by vacuum operations performed on this table as the percentage of all blocks read in the cluster	
Heap fetched	Total number of blocks fetched from this table by vacuum operations performed on it	rel_blks_read + rel_blks_hit
%Rel	Total number of table blocks fetched by vacuum operations performed on this table as the percentage of all blocks fetched from this table	
Heap read	Total number of blocks read from this table by vacuum operations performed on it	rel_blks_read
%Rel	Total number of table blocks read by vacuum operations performed on this table as the percentage of all blocks read from this table	
Scanned	Number of pages examined by vacuum operations performed on this table	pages_scanned

The report table “Top indexes by blocks vacuum fetched” is available if pgpro_stats can provide extended vacuum statistics. This table shows top indexes by blocks fetched vacuuming underlying tables. The data is based on the pgpro_stats_vacuum_indexes view. Table G.56 lists columns of this report table.

Table G.56. Top indexes by blocks vacuum fetched

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Index	Index name	
DB fetched	Total number of database blocks fetched by vacuum operations performed on this index	total_blks_read + total_blks_hit
%Total	Total number of database blocks fetched by vacuum operations performed on this index as the percentage of all blocks fetched in the cluster	
DB read	Total number of database blocks read by vacuum operations performed on this index	total_blks_read
%Total	Total number of database blocks read by vacuum operations per-	

Column	Description	Field/Calculation
	formed on this index as the percentage of all blocks read in the cluster	
Idx fetched	Total number of blocks fetched from this index by vacuum operations on it	rel_blks_read + rel_blks_hit
%Idx	Total number of index blocks fetched by vacuum operations performed on this index as the percentage of all blocks fetched from this index	
Idx read	Total number of blocks read from this index by vacuum operations performed on it	rel_blks_read
%Idx	Total number of index blocks read by vacuum operations performed on this index as the percentage of all blocks read from this index	

The report table “Top tables by blocks vacuum read” is available if pgpro_stats can provide extended vacuum statistics. This table shows top tables by blocks read vacuuming these tables. The data is based on the pgpro_stats_vacuum_indexes view. Table G.57 lists columns of this report table.

Table G.57. Top tables by blocks vacuum read

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
DB read	Total number of database blocks read by vacuum operations performed on this table	total_blks_read
%Total	Total number of database blocks read by vacuum operations performed on this table as the percentage of all blocks read in the cluster	
%Hit	Total number of database blocks found in shared buffers by vacuum operations performed on this table as the percentage of all blocks fetched by vacuum operations performed on this table	
Heap read	Total number of database blocks vacuum operations read from this table	rel_blks_read
%Rel	Total number of table blocks read by vacuum operations performed on this table as the per-	

Column	Description	Field/Calculation
	centage of all blocks read from this table	
%Hit	Total number of table blocks found in shared buffers by vacuum operations performed on this table as the percentage of table blocks fetched by vacuum operations performed on this table	
Scanned	Number of pages examined by vacuum operations performed on this table	pages_scanned

The report table “Top indexes by blocks vacuum read” is available if pgpro_stats can provide extended vacuum statistics. This table shows top indexes by blocks read vacuuming underlying tables. The data is based on the pgpro_stats_vacuum_indexes view. Table G.58 lists columns of this report table.

Table G.58. Top indexes by blocks vacuum read

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Index	Index name	
DB read	Total number of database blocks read by vacuum operations performed on this index	total_blks_read
%Total	Total number of database blocks read by vacuum operations performed on this index as the percentage of all blocks read in the cluster	
%Hit	Total number of database blocks found in shared buffers by vacuum operations performed on this index as the percentage of all database blocks fetched by vacuum operations performed on this index	
Idx read	Total number of blocks read from this index by vacuum operations performed on it	rel_blks_read
%Idx	Total number of index blocks read by vacuum operations performed on this index as the percentage of all blocks read from this index	
%Hit	Total number of index blocks found in shared buffers by vacuum operations performed on this index as the percentage of index	

Column	Description	Field/Calculation
	blocks fetched by vacuum operations performed on this index	

The report table “Top tables by dead tuples vacuum left” is available if pgpro_stats can provide extended vacuum statistics. This table shows top tables by the number of dead tuples left by vacuum due to their visibility in transactions. The data is based on the `pgpro_stats_vacuum_tables` view. Table G.59 lists columns of this report table.

Table G.59. Top tables by dead tuples vacuum left

Column	Description	Field/Calculation
`DB`	Database name for the table	
`Tablespace`	Name of the tablespace where the table is located	
`Schema`	Schema name for the table	
`Table`	Table name	
`Dead tuples left`	Total number of dead tuples vacuum operations left in this table due to their visibility in transactions	`dead_tuples`
`Dead tuples deleted`	Total number of dead tuples vacuum operations deleted from this table	`tuples_deleted`
`%Eff`	Vacuum efficiency in terms of deleted tuples. This is the percentage of dead tuples deleted from this table in all dead tuples to be deleted from this table.	`tuples_deleted` * 100 / (`tuples_deleted` + `dead_tuples`)
`Tuples del`	Number of rows deleted	`pg_stat_all_tables .n_tup_del`
`Tuples upd`	Number of rows updated (includes HOT updated rows)	`pg_stat_all_tables .n_tup_upd`
`Vacuum`	Number of times this table has been manually vacuumed (not counting `VACUUM FULL`)	`vacuum_count`
`Autovacuum`	Number of times this table has been vacuumed by the autovacuum daemon	`autovacuum_count`

The report table “Top tables by WAL size generated by vacuum” is available if pgpro_stats can provide extended vacuum statistics. This table shows top tables by the amount of WAL generated by vacuum operations performed on them. The data is based on the `pgpro_stats_vacuum_tables` view. Table G.60 lists columns of this report table.

Table G.60. Top tables by WAL size generated by vacuum

Column	Description	Field/Calculation
`DB`	Database name for the table	
`Tablespace`	Name of the tablespace where the table is located	
`Schema`	Schema name for the table	
`Table`	Table name	

Column	Description	Field/Calculation
WAL size	Total amount of WAL bytes generated by vacuum operations performed on this table	wal_bytes
%Total	Total amount of WAL bytes generated by vacuum operations performed on this table as the percentage of all WAL generated in the cluster	
WAL FPI	Total number of WAL full page images generated by vacuum operations performed on this table	wal_fpi
Scanned blocks	Number of pages examined by vacuum operations performed on this table	pages_scanned
Dirtied blocks	Number of database blocks dirtied by vacuum operations performed on this table	total_blks_dirtied
Removed blocks	Number of pages removed by vacuum operations performed on this table	pages_removed
Vacuum	Number of times this table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
Autovacuum	Number of times this table has been vacuumed by the autovacuum daemon	autovacuum_count

The report table “Top tables by vacuum operations” shows top tables by the number of vacuum operations performed (vacuum_count + autovacuum_count). The data is based on the pg_stat_all_tables view. Table G.61 lists columns of this report table.

Table G.61. Top tables by vacuum operations

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Vacuum count	Number of times this table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
Autovacuum count	Number of times this table has been vacuumed by the autovacuum daemon	autovacuum_count
Ins	Number of rows inserted	n_tup_ins
Upd	Number of rows updated (includes HOT updated rows)	n_tup_upd
Del	Number of rows deleted	n_tup_del
Upd(HOT)	Number of rows HOT updated	n_tup_hot_upd

The report table "Top tables by analyze operations" shows top tables by the number of analyze operations performed (analyze_count + autoanalyze_count). The data is based on the pg_stat_all_tables view. Table G.62 lists columns of this report table.

Table G.62. Top tables by analyze operations

Column	Description	Field/Calculation
DB	Database name for the table	
Tablespace	Name of the tablespace where the table is located	
Schema	Schema name for the table	
Table	Table name	
Analyze count	Number of times this table has been manually analyzed	analyze_count
Autoanalyze count	Number of times this table has been analyzed by the autovacuum daemon	autoanalyze_count
Ins	Number of rows inserted	n_tup_ins
Upd	Number of rows updated, including HOT	n_tup_upd
Del	Number of rows deleted	n_tup_del
Upd(HOT)	Number of rows HOT updated	n_tup_hot_upd

The report table "Top indexes by estimated vacuum load" shows top indexes by estimated implicit vacuum load. This load is calculated as the number of vacuum operations performed on the underlying table multiplied by the index size. The data is based on the pg_stat_all_indexes view. When there are no relation sizes collected with pg_relation_size(), relation-size estimates are based on the pg_class.relpages field. Since such values are less accurate, they are shown in square brackets. Table G.63 lists columns of this report table.

Table G.63. Top indexes by estimated vacuum load

Column	Description	Field/Calculation
DB	Database name for the index	
Tablespace	Name of the tablespace where the index is located	
Schema	Schema name for the underlying table	
Table	Underlying table name	
Index	Index name	
~Vacuum bytes	Vacuum load estimation	(vacuum_count + autovacuum_count) * index_size
Vacuum count	Number of times this table has been manually vacuumed (not counting VACUUM FULL)	vacuum_count
Autovacuum count	Number of times this table has been vacuumed by the autovacuum daemon	autovacuum_count
IX size	Average index size during the report interval	
Relsize	Average relation size during the report interval	

The report table “Top tables by dead tuples ratio” shows top tables larger than 5 MB by the ratio of dead tuples. Statistics are valid for the last sample in the report interval. The data is based on the pg_stat_all_tables view. When there are no relation sizes collected with pg_relation_size(), relation-size estimates are based on the pg_class.relpages field. Since such values are less accurate, they are shown in square brackets. Table G.64 lists columns of this report table.

Table G.64. Top tables by dead tuples ratio

Column	Description	Field/Calculation
DB	Database name for the table	
Schema	Schema name for the table	
Table	Table name	
Live	Estimated number of live rows	n_live_tup
Dead	Estimated number of dead rows	n_dead_tup
%Dead	Percentage of dead rows in all table rows	
Last AV	Last time at which this table was vacuumed by the autovacuum daemon	last_autovacuum
Size	Table size	pg_table_size() - pg_relation_size(toast)

The report table “Top tables by modified tuples ratio” shows top tables larger than 5 MB by the ratio of modified tuples. Statistics are valid for the last sample in the report interval. The data is based on the pg_stat_all_tables view. When there are no relation sizes collected with pg_relation_size(), relation-size estimates are based on the pg_class.relpages field. Since such values are less accurate, they are shown in square brackets. Table G.65 lists columns of this report table.

Table G.65. Top tables by modified tuples ratio

Column	Description	Field/Calculation
DB	Database name for the table	
Schema	Schema name for the table	
Table	Table name	
Live	Estimated number of live rows	n_live_tup
Dead	Estimated number of dead rows	n_dead_tup
Mod	Estimated number of rows modified since this table was last analyzed	n_mod_since_analyze
%Mod	Percentage of modified rows in all table rows	
Last AA	Last time at which this table was analyzed by the autovacuum daemon	last_autoanalyze
Size	Table size	pg_table_size() - pg_relation_size(toast)

G.2.11.10. Cluster settings during the report interval

This section of the report contains a table with Postgres Pro GUC parameters, values of functions version(), pg_postmaster_start_time(), pg_conf_load_time() and the system_identifier field of the pg_control_system() function during the report interval. The data in the table is grouped under Defined settings and Default settings. Table G.66 lists columns of this report table.

Table G.66. Cluster settings during the report interval

Column	Description
Setting	Name of the parameter
reset_val	reset_val field of the pg_settings view. Settings changed during the report interval are shown in bold font.
Unit	Unit of the setting
Source	Configuration file where this setting is defined, semicolon, line number
Notes	Timestamp of the sample where this value was first observed

G.2.11.11. Extension versions during the report interval

This section of the report contains a table that lists installed extension versions found in databases during the report interval. First seen and Last seen columns are not shown if the extension versions have not changed during the report interval. Table G.67 lists columns of this report table.

Table G.67. Extension versions during the report interval

Column	Description
Name	Extension name
DB	Database name
First seen	Timestamp of the sample where this extension version appeared first
Last seen	Timestamp of the sample where this extension version appeared last
Version	Version name of the extension

G.2.12. pgpro_pwr Diagnostic Tools

pgpro_pwr provides self-diagnostic tools.

G.2.12.1. Collecting Detailed Timing Statistics for Sampling Procedures

pgpro_pwr collects detailed timing statistics of taking samples when the *pgpro_pwr.track_sample_timings* parameter is on. You can get the results from the v_sample_timings view. Table G.68 lists columns of this view.

Table G.68. v_sample_timings View

Column	Description
server_name	Name of the server
sample_id	Sample identifier
sample_time	Time when the sample was taken
sampling_event	Sampling stage. See Table G.69 for descriptions of sampling stages.
time_spent	Time spent in the event

Table G.69. sampling_event Description

Event	Description
total	Taking the sample (all stages)
connect	Making dblink connection to the server

Event	Description
get server environment	Getting server GUC parameters, available extensions, etc.
collect database stats	Querying the pg_stat_database view for statistics on databases
calculate database stats	Calculating differential statistics on databases since the previous sample
collect tablespace stats	Querying the pg_tablespace view for statistics on tablespaces
collect statement stats	Collecting statistics on statements using the pg_pro_stats and pg_stat_kcache extensions
query pg_stat_bgwriter	Collecting cluster statistics using the pg_stat_bgwriter view
query pg_stat_archiver	Collecting cluster statistics using the pg_stat_archiver view
collect object stats	Collecting statistics on database objects. Includes events from Table G.70.
maintain repository	Executing support routines
calculate tablespace stats	Calculating differential statistics on tablespaces
calculate object stats	Calculating differential statistics on database objects. Includes events from Table G.71.
calculate cluster stats	Calculating cluster differential statistics
calculate archiver stats	Calculating archiver differential statistics
delete obsolete samples	Deleting obsolete baselines and samples

Table G.70. Events of Collecting Statistics on Database Objects

Event	Description
db:*dbname* collect tables stats	Collecting statistics on tables for the *dbname* database
db:*dbname* collect indexes stats	Collecting statistics on indexes for the *dbname* database
db:*dbname* collect functions stats	Collecting statistics on functions for the *dbname* database

Table G.71. Events of Calculating Differences of Statistics on Database Objects

Event	Description
calculate tables stats	Calculating differential statistics on tables of all databases
calculate indexes stats	Calculating differential statistics on indexes of all databases
calculate functions stats	Calculating differential statistics on functions of all databases

G.2.13. Important Notes

When using the pgpro_pwr extension, be aware of the following:

- Postgres Pro collects execution statistics *after* the execution is complete. If a single execution of a statement lasts for several samples, it will only affect statistics of the last sample (in which the ex-

ecution completed). Besides, statistics on statements that are still running are unavailable. Maintenance processes, such as vacuum and checkpointer, will update the statistics only on completion.

- Resetting any Postgres Pro statistics may affect the accuracy of the next sample.
- Exclusive locks on relations conflict with calculation of the relation size. If the `take_sample()` function is unable to acquire a lock for a short period of time (3 seconds), it will fail and no sample will be generated.

G.3. pgpro_stats

The `pgpro_stats` extension provides a means for tracking planning and execution statistics of all SQL statements executed by a server. It is based on the pg_stat_statements module and provides the following additional functionality:

- Storing query plans in addition to query statements.
- Configuring sample rate for statistics collection to reduce overhead.
- Calculating wait event statistics for executed queries.
- Calculating resource usage statistics of statement planning and execution.
- Calculating cache invalidation statistics.
- Calculating additional archiver statistics.
- Providing an interface to statistics about vacuuming databases, tables, and indexes collected by the core system.
- Tracing of application sessions.
- Creating views that emulate other extensions.

> **Note**
>
> When the server gets shut down, pgpro_stats saves the collected statistics to two dump files on disk in the format that depends on the number and order of columns in the `pgpro_stats_statements` and `pgpro_stats_totals` views. If this format has changed in a new pgpro_stats version, during the first server restart after upgrading the extension, the saved statistics will fail to be read with an error reported to the log:
>
> ```
> LOG:  pgpro_stats: could not load statements data file of obsolete format
>  "pg_stat/pgpro_stats.stat"
> ```
>
> or
>
> ```
> LOG:  pgpro_stats: could not load statements data file of obsolete format
>  "pg_stat/pgpro_stats_totals.stat"
> ```
>
> The contents of the files will be ignored, and respective statistics will be nullified. To learn whether the format has changed, see the Release Notes for pgpro_stats version being installed. To retain the previously collected statistics, download them as CSV files before upgrading.

The background information, along with views and types, related to calculating cache invalidation statistics is provided in a separate section Section G.3.9.

G.3.1. Limitations

- `pgpro_stats` can sometimes fail to match identical parameters in the query statement and the corresponding query plan.
- Some SPI queries are not included into statistics.
- Texts and plans of some SPI queries are not normalized.
- `pgpro_stats` is incompatible with pg_stat_statements, as well as other extensions that use parser, planner, or executor hooks to modify parse and plan trees and execution of the queries. Moreover, if both `pgpro_stats` and pg_stat_statements are on the list of `shared_preload_libraries`, the database server will not start. Note also that in order to dump the final versions of the queries

and plans, pgpro_stats should be the last on the list of shared_preload_libraries, but some existing extensions, such as pg_pathman, will not work at all unless they are the last on this list.

- pgpro_stats may not work correctly with third-party extensions that produce CustomScan and ForeignScan nodes.

G.3.2. Installation and Setup

pgpro_stats is provided with Postgres Pro Enterprise as a separate pre-built package pgpro-stats-ent-14 (for the detailed installation instructions, see Chapter 17). Once you have pgpro_stats installed, complete the following steps to enable pgpro_stats:

1. Add pgpro_stats to the shared_preload_libraries parameter in the postgresql.conf file:

   ```
   shared_preload_libraries = 'pgpro_stats'
   ```

2. Restart the Postgres Pro Enterprise instance for the changes to take effect.

   Once the server is reloaded, pgpro_stats starts tracking statistics across all databases of the cluster. If required, you can change the scope of statistics collection or disable it altogether using pgpro_stats configuration parameters.

3. To access the collected statistics, you have to create pgpro_stats extension:

   ```
   CREATE EXTENSION pgpro_stats;
   ```

In addition, query identifier calculation must be enabled in order for pgpro_stats to be active, which is done automatically if compute_query_id is set to auto or on, or any third-party module that calculates query identifiers is loaded.

G.3.3. Usage

- Collecting Statistics on Query Statements and Plans
- Monitoring Custom Metrics

G.3.3.1. Collecting Statistics on Query Statements and Plans

Once installed, the pgpro_stats extension starts collecting statistics on the executed statements. The collected data is similar to the one provided by pg_stat_statements, but also includes information on query plans and wait events for each query type. The statistics is saved into an in-memory ring buffer and is accessible through the pgpro_stats_statements view.

By default, pgpro_stats collects statistics on all the executed statements that satisfy the pgpro_stats.track and pgpro_stats.track_utility settings. If performance is a concern, you can set a sample rate for queries using the pgpro_stats.query_sample_rate parameter, and pgpro_stats will randomly select queries for statistics calculation at the specified rate.

To collect statistics on wait events, pgpro_stats uses time-based sampling. Wait events are sampled at the time interval specified by the pgpro_stats.profile_period parameter, which is set to 10ms by default. If the sampling shows that the process is waiting, the pgpro_stats.profile_period value is added to the wait event duration. Thus, time estimation for each wait event remains valid even if the pgpro_stats.profile_period parameter value has changed. If you are not interested in wait event statistics, you can disable wait event sampling by setting the pgpro_stats.enable_profile parameter to false.

pgpro_stats_statements.plans and pgpro_stats_statements.calls aren't always expected to match because planning and execution statistics are updated at their respective end phase, and only for successful operations. For example, if a statement is successfully planned but fails during the execution phase, only its planning statistics will be updated. If planning is skipped because a cached plan is used, only its execution statistics will be updated.

As an example, let's create a table with some random data and build an index on this table:

```
CREATE TABLE test AS (SELECT i, random() x FROM generate_series(1,1000000) i);
CREATE INDEX test_x_idx ON test (x);
```

Now run the following query several times using different values for *:x_min* and *:x_max*:

```
select * from test where x >= :x_min and x <= :x_max;
```

The collected statistics should appear in the pgpro_stats_statements view:

```
SELECT queryid, query, planid, plan, wait_stats FROM pgpro_stats_statements WHERE query
 LIKE 'select * from test where%';
-[ RECORD
 1 ]----------------------------------------------------------------------------------------
queryid    | 1109491335754870054
query      | select * from test where x >= $1 and x <= $2
planid     | 8287793242828473388
plan       | Gather
           |   Output: i, x
           |   Workers Planned: 2
           |   ->  Parallel Seq Scan on public.test
           |         Output: i, x
           |         Filter: ((test.x >= $3) AND (test.x <= $4))
           |
wait_stats | {"IO": {"DataFileRead": 10}, "IPC": {"BgWorkerShutdown": 10}, "Total":
 {"IO": 10, "IPC": 10, "Total": 20}}
-[ RECORD
 2 ]----------------------------------------------------------------------------------------
queryid    | 1109491335754870054
query      | select * from test where x >= $1 and x <= $2
planid     | -9045072158333552619
plan       | Bitmap Heap Scan on public.test
           |   Output: i, x
           |   Recheck Cond: ((test.x >= $3) AND (test.x <= $4))
           |   ->  Bitmap Index Scan on test_x_idx
           |         Index Cond: ((test.x >= $5) AND (test.x <= $6))
           |
wait_stats | {"IO": {"DataFileRead": 40}, "Total": {"IO": 40, "Total": 40}}
-[ RECORD
 3 ]----------------------------------------------------------------------------------------
queryid    | 1109491335754870054
query      | select * from test where x >= $1 and x <= $2
planid     | -1062789671372193287
plan       | Seq Scan on public.test
           |   Output: i, x
           |   Filter: ((test.x >= $3) AND (test.x <= $4))
           |
wait_stats | NULL
-[ RECORD
 4 ]----------------------------------------------------------------------------------------
queryid    | 1109491335754870054
query      | select * from test where x >= $1 and x <= $2
planid     | -1748292253893834280
plan       | Index Scan using test_x_idx on public.test
           |   Output: i, x
           |   Index Cond: ((test.x >= $3) AND (test.x <= $4))
           |
wait_stats | NULL
```

G.3.3.2. Monitoring Custom Metrics

With pgpro_stats, you can define custom metrics to be monitored. The collected data will be saved into an in-memory ring buffer and then sent to a monitoring system. Unlike direct polling of a database by a

monitoring system that can lose some data if the connection is interrupted, this approach allows to get all the collected data regardless of connection issues, as long as this data is still available in the ring buffer.

To set up a custom metric to collect, do the following:

1. For each metric, define all configuration parameters listed in Section G.3.7.2. You must specify a unique numeric identifier of each metric in the parameter names.

   For example, to monitor index bloating each 60 seconds, you can define a new metric by setting metrics-related parameters as follows:

   ```
   pgpro_stats.metric_1_name = index_bloat
   pgpro_stats.metric_1_query = 'select iname, ibloat, ipages from bloat'
   pgpro_stats.metric_1_db = 'postgres'
   pgpro_stats.metric_1_user = postgres
   pgpro_stats.metric_1_period = '60s'
   ```

2. Restart the server.

   `pgpro_stats` starts collecting statistics on executed statements and saves it into the ring buffer, and the collected data appears in the `pgpro_stats_metrics` view:

   ```
   SELECT * FROM pgpro_stats_metrics;
   ```

   Once the new metric is added, its parameters can be changed without a server restart by simply reloading the `postgresql.conf` configuration file.

3. If required, set up data export to a monitoring system of your choice.

G.3.4. Views

G.3.4.1. The `pgpro_stats_statements` View

The statistics gathered by the module are made available via a view named `pgpro_stats_statements`. This view contains one row for each distinct database ID, user ID and query ID (up to the maximum number of distinct statements that the module can track). The columns of the view are shown in Table G.72.

Table G.72. `pgpro_stats_statements` Columns

Name	Type	References	Description
`userid`	`oid`	`pg_authid .oid`	OID of user who executed the statement
`dbid`	`oid`	`pg_database .oid`	OID of database in which the statement was executed
`toplevel`	`bool`		True if the query was executed as a top-level statement (always true if pgpro_stats.track is set to `top`)
`queryid`	`bigint`		Internal hash code, computed from the statement's parse tree
`planid`	`bigint`		Internal hash code, computed from the statement's plan tree
`query`	`text`		Text of a representative statement
`plan`	`text`		The text of the query plan, in the format de-

Name	Type	References	Description
			fined by the pgpro_stats.plan_format configuration parameter
plans	int8		Number of times the statement was planned (if pgpro_stats.track_planning is enabled, otherwise zero)
total_plan_time	float8		Total time spent planning the statement, in milliseconds (if pgpro_stats.track_planning is enabled, otherwise zero).
min_plan_time	float8		Minimum time spent planning the statement, in milliseconds (if pgpro_stats.track_planning is enabled, otherwise zero)
max_plan_time	float8		Maximum time spent planning the statement, in milliseconds (if pgpro_stats.track_planning is enabled, otherwise zero)
mean_plan_time	float8		Mean time spent planning the statement, in milliseconds (if pgpro_stats.track_planning is enabled, otherwise zero)
stddev_plan_time	float8		Population standard deviation of time spent planning the statement, in milliseconds (if pgpro_stats.track_planning is enabled, otherwise zero)
plan_rusage	pgpro_stats_rusage		Resource usage statistics of the statement planning.
calls	int8		Number of times the statement was executed
total_exec_time	float8		Total time spent executing the statement, in milliseconds
min_exec_time	float8		Minimum time spent executing the statement, in milliseconds

Name	Type	References	Description
max_exec_time	float8		Maximum time spent executing the statement, in milliseconds
mean_exec_time	float8		Mean time spent executing the statement, in milliseconds
stddev_exec_time	float8		Population standard deviation of time spent executing the statement, in milliseconds
exec_rusage	pgpro_stats_rusage		Resource usage statistics of the statement execution.
rows	int8		Total number of rows retrieved or affected by the statement
shared_blks_hit	int8		Total number of shared block cache hits by the statement
shared_blks_read	int8		Total number of shared blocks read by the statement
shared_blks_dirtied	int8		Total number of shared blocks dirtied by the statement
shared_blks_written	int8		Total number of shared blocks written by the statement
local_blks_hit	int8		Total number of local block cache hits by the statement
local_blks_read	int8		Total number of local blocks read by the statement
local_blks_dirtied	int8		Total number of local blocks dirtied by the statement
local_blks_written	int8		Total number of local blocks written by the statement
temp_blks_read	int8		Total number of temp blocks read by the statement
temp_blks_written	int8		Total number of temp blocks written by the statement
shared_blk_read_time	float8		Total time the statement spent reading shared blocks, in milliseconds (

Name	Type	References	Description
			if track_io_timing is enabled, otherwise zero)
shared_blk_write_time	float8		Total time the statement spent writing shared blocks, in milliseconds (if track_io_timing is enabled, otherwise zero)
local_blk_read_time	float8		Total time the statement spent reading local blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 17, contains zero.
local_blk_write_time	float8		Total time the statement spent writing local blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 17, contains zero.
temp_blk_read_time	float8		Total time the statement spent reading temp blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 15, contains zero.
temp_blk_write_time	float8		Total time the statement spent writing temp blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 15, contains zero.
wal_records	int8		Total number of WAL records generated by the statement
wal_fpi	int8		Total number of WAL full page images generated by the statement
wal_bytes	numeric		Total amount of WAL bytes generated by the statement
jit_functions	int8		Total number of functions JIT-compiled by the statement. In Postgres Pro versions lower than 15, contains zero.

Name	Type	References	Description
jit_generation_time	float8		Total time spent by the statement on generating JIT code, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_inlining_count	int8		Number of times functions used in the statement have been inlined. In Postgres Pro versions lower than 15, contains zero.
jit_inlining_time	float8		Total time spent by the statement on inlining functions, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_optimization_count	int8		Number of times the statement has been optimized. In Postgres Pro versions lower than 15, contains zero.
jit_optimization_time	float8		Total time spent by the statement on optimizing, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_emission_count	int8		Number of times code has been emitted by the statement. In Postgres Pro versions lower than 15, contains zero.
jit_emission_time	float8		Total time spent by the statement on emitting code, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_deform_count	int8		Total number of tuple deform functions JIT-compiled by the statement. In Postgres Pro versions lower than 17, contains zero.
jit_deform_time	float8		Total time spent by the statement on JIT-compiling tuple deform functions, in milliseconds. In Postgres Pro versions lower than 17, contains zero.

Name	Type	References	Description
wait_stats	jsonb		A jsonb object containing statistics on wait events, for each execution of the query that uses the corresponding plan. Each statistic is provided in milliseconds and is a multiple of the pgpro_stats.profile_period configuration parameter.
inval_msgs	pgpro_stats_inval_msgs		Number of cache invalidation messages by type generated by the statement (if this is supported by the server, otherwise zero).
stats_since	timestamp with time zone		Time at which statistics gathering started for this statement
minmax_stats_since	timestamp with time zone		Time at which min/max statistics gathering started for this statement (fields min_plan_time , max_plan_time , min_exec_time and max_exec_time)

Take into account that like pg_stat_statements, pgpro_stats normalizes into one record those DML queries (containing SELECT, INSERT, UPDATE, DELETE and MERGE commands) that have equivalent structures according to some internal hash value. Being compared this way, two queries are normally considered equal if they are semantically equivalent up to constants included in the queries. All the other commands are, however, compared strictly as query texts. When the value of a constant in a query is ignored for comparison with other queries, this constant is replaced in the pgpro_stats output with a symbol of a parameter, such as, $k, where k is a positive integer. If a query already contains parameters, the initial value of k equals the number following the last number of a $n parameter in the original query text. If there are no parameters, the initial value of k equals 1. Note that sometimes hidden parameter symbols affect this numbering. For example, PL/pgSQL uses such hidden symbols to insert values of function local variables into queries, so a PL/pgSQL statement SELECT i + 1 INTO j will be represented as SELECT i + $2 in the normalized query text.

pgpro_stats uses a similar technique to normalize plan texts. When doing so, an attempt is made to associate numbers of constants in the plan text with the corresponding numbers of constants in the query text. If such an attempt appears unsuccessful for a certain constant in the plan text, it is assigned the number following the maximum number of a constant replaced in the query text. For example, consider the query:

```
SELECT 1::int, 'abc'::VARCHAR(3), 2::int;
```

pgpro_stats will replace numbers of constants in the query text and in the text of the corresponding plan as follows:

```
postgres=# SELECT query, plan FROM pgpro_stats_statements;
                     query                      |                                plan
-----------------------------------------------
+-------------------------------------------------
```

```
SELECT $1::int, $2::VARCHAR(3), $3::int          | Result
            +
                                                 |   Output: $1, $4, $3
            +
```

In this plan text, it appeared possible to associate constants numbered 1 and 3 from the query text, but not the constant numbered 2, and the latter was replaced with the number following the maximum number in the query text, that is, number 4.

Replacement of numbers in plan texts has an exception for version numbers of XML documents. If in the original query such a number is represented with a constant, e.g., '1.0', it is retained as is in the plan text rather than replaced with `$k`. If the version number of an XML document is represented with an expression, replacement of constants follows usual rules.

G.3.4.2. The `pgpro_stats_totals` View

The aggregate statistics gathered by the module are made available via a view named `pgpro_stats_totals`. This view contains one row for each distinct object (up to the maximum number of distinct objects that the module can track). The columns of the view are shown in Table G.73.

Table G.73. `pgpro_stats_totals` Columns

Name	Type	Description
`object_type`	`text`	Type of the object for which aggregated statistics are collected: "cluster", "database", "user", "client_addr", "application", "backend", "session"
`object_id`	`bigint`	ID of the object: oid for databases and users, pid for backends, sid for sessions, NULL for others
`object_name`	`text`	Textual name of the object or NULL
`queries_planned`	`int8`	Number of queries planned
`total_plan_time`	`float8`	Total time spent in the planning of statements, in milliseconds
`total_plan_rusage`	pgpro_stats_rusage	Aggregate resource usage statistics of the statement planning
`queries_executed`	`int8`	Number of queries executed
`total_exec_time`	`float8`	Total time spent in the execution of statements, in milliseconds
`total_exec_rusage`	pgpro_stats_rusage	Aggregate resource usage statistics of the statement execution
`rows`	`int8`	Total number of rows retrieved or affected by the statements
`shared_blks_hit`	`int8`	Total number of shared block cache hits by the statements
`shared_blks_read`	`int8`	Total number of shared blocks read by the statements
`shared_blks_dirtied`	`int8`	Total number of shared blocks dirtied by the statements
`shared_blks_written`	`int8`	Total number of shared blocks written by the statements

Name	Type	Description
local_blks_hit	int8	Total number of local block cache hits by the statements
local_blks_read	int8	Total number of local blocks read by the statements
local_blks_dirtied	int8	Total number of local blocks dirtied by the statements
local_blks_written	int8	Total number of local blocks written by the statements
temp_blks_read	int8	Total number of temp blocks read by the statements
temp_blks_written	int8	Total number of temp blocks written by the statements
shared_blk_read_time	float8	Total time the statements spent reading shared blocks, in milliseconds (if track_io_timing is enabled, otherwise zero)
shared_blk_write_time	float8	Total time the statements spent writing shared blocks, in milliseconds (if track_io_timing is enabled, otherwise zero)
local_blk_read_time	float8	Total time the statements spent reading local blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 17, contains zero.
local_blk_write_time	float8	Total time the statements spent writing local blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 17, contains zero.
temp_blk_read_time	float8	Total time the statements spent reading temp blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 15, contains zero.
temp_blk_write_time	float8	Total time the statements spent writing temp blocks, in milliseconds (if track_io_timing is enabled, otherwise zero). In Postgres Pro versions lower than 15, contains zero.
wal_records	int8	Total number of WAL records generated by the statements
wal_fpi	int8	Total number of WAL full page images generated by the statements
wal_bytes	numeric	Total amount of WAL bytes generated by the statements

Name	Type	Description
jit_functions	int8	Total number of functions JIT-compiled by the statements. In Postgres Pro versions lower than 15, contains zero.
jit_generation_time	float8	Total time spent by the statements on generating JIT code, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_inlining_count	int8	Number of times functions used in the statements have been inlined. In Postgres Pro versions lower than 15, contains zero.
jit_inlining_time	float8	Total time spent by the statements on inlining functions, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_optimization_count	int8	Number of times the statements have been optimized. In Postgres Pro versions lower than 15, contains zero.
jit_optimization_time	float8	Total time spent by the statements on optimizing, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_emission_count	int8	Number of times code has been emitted by the statements. In Postgres Pro versions lower than 15, contains zero.
jit_emission_time	float8	Total time spent by the statements on emitting code, in milliseconds. In Postgres Pro versions lower than 15, contains zero.
jit_deform_count	int8	Total number of tuple deform functions JIT-compiled by the statements. In Postgres Pro versions lower than 17, contains zero.
jit_deform_time	float8	Total time spent by the statements on JIT-compiling tuple deform functions, in milliseconds. In Postgres Pro versions lower than 17, contains zero.
wait_stats	jsonb	A jsonb object containing statistics on wait events for each execution of the queries. Each statistic is provided in milliseconds and is a multiple of the pgpro_stats.profile_period configuration parameter.

Name	Type	Description
inval_msgs	pgpro_stats_inval_msgs	Number of cache invalidation messages by type generated by the statements (if this is supported by the server, otherwise zero).
cache_resets	int4	Number of shared cache resets (only for cluster, databases and backends). Gets incremented for a backend when it receives a full cache reset message.
stats_since	timestamp with time zone	Time at which statistics gathering started for the statements

G.3.4.3. The pgpro_stats_info View

The statistics of the pgpro_stats module itself are tracked and made available via a view named pgpro_stats_info. This view contains only a single row. The columns of the view are shown in Table G.74.

Table G.74. pgpro_stats_info Columns

Name	Type	Description
dealloc	bigint	Total number of times pgpro_stats_statements entries about the least-executed statements were deallocated because more distinct statements than pgpro_stats.max were observed
stats_reset	timestamp with time zone	Time at which all statistics in the pgpro_stats_statements view were last reset

G.3.4.4. The pgpro_stats_metrics View

The metrics gathered by pgpro_stats are displayed in the pgpro_stats_metrics view. The table below describes the columns of the view.

Table G.75. pgpro_stats_metrics Columns

Name	Type	Description
metric_number	int4	A unique ID of the collected metric assigned by user. This ID is included into parameter names that define the metric.
metric_name	text	The name of the metric defined by the pgpro_stats.metric_*N*_*name* parameter
db_name	text	The name of the database for which a particular metric was collected
ts	timestamptz	The time when the metric value got calculated
value	jsonb	The result of the query used for metric measurement. It is serialized in jsonb as an array of objects received via to_jsonb(

Name	Type	Description
		resulting_row). If an error occurs, a single object is returned that contains code, message, detail, and hint fields.

G.3.4.5. The pgpro_stats_archiver View

The pgpro_stats_archiver view will contain one row showing data about the archiver process of the cluster.

Table G.76. pgpro_stats_archiver Columns

Column	Type	Description
archived_count	bigint	Number of WAL files that have been successfully archived
last_archived_wal	text	Name of the last WAL file successfully archived
last_archived_time	timestamp with time zone	Time of the last successful archive operation
failed_count	bigint	Number of failed attempts for archiving WAL files
last_failed_wal	text	Name of the WAL file of the last failed archival operation
last_failed_time	timestamp with time zone	Time of the last failed archival operation
active_time	int8	Overall time that the archiver process was active
archive_command_time	int8	Overall execution time of the archive command
stats_reset	timestamp with time zone	Time at which these statistics were last reset

G.3.4.6. The pgpro_stats_vacuum_database View

> **Important**
>
> Starting with Postgres Pro 16, this view contains no data because the statistics to be displayed are available through the catalog view pg_stats_vacuum_database (see System Views for details).

The pgpro_stats_vacuum_database view will contain one row for each database in the current cluster, showing statistics about vacuuming that database. These statistics are collected by the core system as explained in Section 27.2. The table below describes the columns of the view.

Table G.77. pgpro_stats_vacuum_database Columns

Column	Type	Description
dbid	oid	OID of a database
total_blks_read	int8	Number of database blocks read by vacuum operations performed on this database
total_blks_hit	int8	Number of times database blocks were found in the buffer cache

Column	Type	Description
		by vacuum operations performed on this database
total_blks_dirtied	int8	Number of database blocks dirtied by vacuum operations performed on this database
total_blks_written	int8	Number of database blocks written by vacuum operations performed on this database
wal_records	int8	Total number of WAL records generated by vacuum operations performed on this database
wal_fpi	int8	Total number of WAL full page images generated by vacuum operations performed on this database
wal_bytes	numeric	Total amount of WAL bytes generated by vacuum operations performed on this database
blk_read_time	float8	Time spent reading database blocks by vacuum operations performed on this database, in milliseconds (if track_io_timing is enabled, otherwise zero)
blk_write_time	float8	Time spent writing database blocks by vacuum operations performed on this database, in milliseconds (if track_io_timing is enabled, otherwise zero)
delay_time	float8	Time spent sleeping in a vacuum delay point by vacuum operations performed on this database, in milliseconds (see Section 19.4.4 for details)
system_time	float8	System CPU time of vacuuming this database, in milliseconds
user_time	float8	User CPU time of vacuuming this database, in milliseconds
total_time	float8	Total time of vacuuming this database, in milliseconds
interrupts	int4	Number of times vacuum operations performed on this database were interrupted on any errors

G.3.4.7. The pgpro_stats_vacuum_tables View

Important

Starting with Postgres Pro 16, this view contains no data because the statistics to be displayed are available through the catalog view pg_stats_vacuum_tables (see System Views for details).

The pgpro_stats_vacuum_tables view will contain one row for each table in the current database (including TOAST tables), showing statistics about vacuuming that specific table. These statistics are collected by the core system as explained in Section 27.2. The table below describes the columns of the view.

Table G.78. pgpro_stats_vacuum_tables Columns

Column	Type	Description
relid	oid	OID of a table
schema	name	Name of the schema this table is in
relname	name	Name of this table
total_blks_read	int8	Number of database blocks read by vacuum operations performed on this table
total_blks_hit	int8	Number of times database blocks were found in the buffer cache by vacuum operations performed on this table
total_blks_dirtied	int8	Number of database blocks dirtied by vacuum operations performed on this table
total_blks_written	int8	Number of database blocks written by vacuum operations performed on this table
rel_blks_read	int8	Number of blocks vacuum operations read from this table
rel_blks_hit	int8	Number of times blocks of this table were already found in the buffer cache by vacuum operations, so that a read was not necessary (this only includes hits in the Postgres Pro buffer cache, not the operating system's file system cache)
pages_scanned	int8	Number of pages examined by vacuum operations performed on this table
pages_removed	int8	Number of pages removed from the physical storage by vacuum operations performed on this table
pages_frozen	int8	Number of times vacuum operations marked pages of this table as all-frozen in the visibility map
pages_all_visible	int8	Number of times vacuum operations marked pages of this table as all-visible in the visibility map
tuples_deleted	int8	Number of dead tuples vacuum operations deleted from this table
tuples_frozen	int8	Number of tuples of this table that vacuum operations marked as frozen

Column	Type	Description
dead_tuples	int8	Number of dead tuples vacuum operations left in this table due to their visibility in transactions
index_vacuum_count	int8	Number of times indexes on this table were vacuumed
rev_all_frozen_pages	int8	Number of times the all-frozen mark in the visibility map was removed for pages of this table
rev_all_visible_pages	int8	Number of times the all-visible mark in the visibility map was removed for pages of this table
wal_records	int8	Total number of WAL records generated by vacuum operations performed on this table
wal_fpi	int8	Total number of WAL full page images generated by vacuum operations performed on this table
wal_bytes	numeric	Total amount of WAL bytes generated by vacuum operations performed on this table
blk_read_time	float8	Time spent reading database blocks by vacuum operations performed on this table, in milliseconds (if track_io_timing is enabled, otherwise zero)
blk_write_time	float8	Time spent writing database blocks by vacuum operations performed on this table, in milliseconds (if track_io_timing is enabled, otherwise zero)
delay_time	float8	Time spent sleeping in a vacuum delay point by vacuum operations performed on this table, in milliseconds (see Section 19.4.4 for details)
system_time	float8	System CPU time of vacuuming this table, in milliseconds
user_time	float8	User CPU time of vacuuming this table, in milliseconds
total_time	float8	Total time of vacuuming this table, in milliseconds
interrupts	integer	Number of times vacuum operations performed on this table were interrupted on any errors

Columns `total_*`, `wal_*` and `blk_*` include data on vacuuming indexes on this table, while columns `system_time` and `user_time` only include data on vacuuming the heap.

G.3.4.8. The `pgpro_stats_vacuum_indexes` View

> **Important**
>
> Starting with Postgres Pro 16, this view contains no data because the statistics to be displayed are available through the catalog view `pg_stats_vacuum_indexes` (see System Views for details).

The `pgpro_stats_vacuum_indexes` view will contain one row for each index in the current database (including TOAST table indexes), showing statistics about vacuuming that specific index. These statistics are collected by the core system as explained in Section 27.2. The table below describes the columns of the view.

Table G.79. `pgpro_stats_vacuum_indexes` Columns

Column	Type	Description
`relid`	`oid`	OID of an index
`schema`	`name`	Name of the schema this index is in
`relname`	`name`	Name of this index
`total_blks_read`	`int8`	Number of database blocks read by vacuum operations performed on this index
`total_blks_hit`	`int8`	Number of times database blocks were found in the buffer cache by vacuum operations performed on this index
`total_blks_dirtied`	`int8`	Number of database blocks dirtied by vacuum operations performed on this index
`total_blks_written`	`int8`	Number of database blocks written by vacuum operations performed on this index
`rel_blks_read`	`int8`	Number of blocks vacuum operations read from this index
`rel_blks_hit`	`int8`	Number of times blocks of this index were already found in the buffer cache by vacuum operations, so that a read was not necessary (this only includes hits in the Postgres Pro buffer cache, not the operating system's file system cache)
`pages_deleted`	`int8`	Number of pages deleted by vacuum operations performed on this index
`tuples_deleted`	`int8`	Number of dead tuples vacuum operations deleted from this index
`wal_records`	`int8`	Total number of WAL records generated by vacuum operations performed on this index

Column	Type	Description
wal_fpi	int8	Total number of WAL full page images generated by vacuum operations performed on this index
wal_bytes	numeric	Total amount of WAL bytes generated by vacuum operations performed on this index
blk_read_time	float8	Time spent reading database blocks by vacuum operations performed on this index, in milliseconds (if track_io_timing is enabled, otherwise zero)
blk_write_time	float8	Time spent writing database blocks by vacuum operations performed on this index, in milliseconds (if track_io_timing is enabled, otherwise zero)
delay_time	float8	Time spent sleeping in a vacuum delay point by vacuum operations performed on this index, in milliseconds (see Section 19.4.4 for details)
system_time	float8	System CPU time of vacuuming this index, in milliseconds
user_time	float8	User CPU time of vacuuming this index, in milliseconds
total_time	float8	Total time of vacuuming this index, in milliseconds
interrupts	integer	Number of times vacuum operations performed on this index were interrupted on any errors

G.3.5. Data Types

G.3.5.1. The pgpro_stats_rusage Type

pgpro_stats_rusage is a record type that contains resource usage statistics of statement planning/execution. The fields of this type are shown in Table G.80.

Table G.80. pgpro_stats_rusage Fields

Name	Type	Description
reads	bigint	Number of bytes read by the filesystem layer
writes	bigint	Number of bytes written by the filesystem layer
user_time	double precision	User CPU time used
system_time	double precision	System CPU time used
minflts	bigint	Number of page reclaims (soft page faults)
majflts	bigint	Number of page faults (hard page faults)
nswaps	bigint	Number of swaps

Name	Type	Description
msgsnds	bigint	Number of IPC messages sent
msgrcvs	bigint	Number of IPC messages received
nsignals	bigint	Number of signals received
nvcsws	bigint	Number of voluntary context switches
nivcsws	bigint	Number of involuntary context switches

G.3.6. Functions

pgpro_stats_statements_reset(userid Oid, dbid Oid, queryid bigint, planid bigint, minmax_only boolean) returns timestamp with time zone

pgpro_stats_statements_reset discards statistics gathered so far by pgpro_stats corresponding to the specified userid, dbid, queryid, and planid. If any of the parameters are not specified, the default value 0(invalid) is used for each of them and the statistics that match with other parameters will be reset. If no parameter is specified or all the specified parameters are 0(invalid), it will discard all statistics. If all statistics in the pgpro_stats_statements view are discarded, it will also reset the statistics in the pgpro_stats_info view. When minmax_only is true only the values of minimum and maximum planning and execution time will be reset (i.e. min_plan_time, max_plan_time, min_exec_time and max_exec_time fields). The default value for minmax_only parameter is false. Time of last min/max reset performed is shown in minmax_stats_since field of the pgpro_stats_statements view. This function returns the time of a reset. This time is saved to stats_reset field of pgpro_stats_info view or to minmax_stats_since field of the pgpro_stats_statements view if the corresponding reset was actually performed. By default, this function can only be executed by superusers. Access may be granted to others using GRANT.

> **Note**
>
> As statistics in the pgpro_stats_vacuum_database, pgpro_stats_vacuum_tables, and pgpro_stats_vacuum_indexes views are collected by the core system, to reset them, call the pg_stat_reset() function (see Section 27.2.25 for details).

pgpro_stats_statements(showtext boolean) returns setof record

The pgpro_stats_statements view is defined in terms of a function also named pgpro_stats_statements. Users can also call the pgpro_stats_statements function directly, and by specifying showtext := false make query text be omitted (that is, the OUT argument that corresponds to the view's query column will return nulls). This feature is intended to support external tools that might wish to avoid the overhead of repeatedly retrieving query texts of indeterminate length. Such tools can instead cache the first query text observed for each entry themselves, since that is all pgpro_stats itself does, and then retrieve query texts only as needed. Since the server stores query texts in a file, this approach may reduce physical I/O for repeated examination of the pgpro_stats_statements data.

pgpro_stats_info() returns record

pgpro_stats_info view is defined in terms of a function also named pgpro_stats_info. Users can also call the pgpro_stats_info function directly.

pgpro_stats_totals_reset(type text, id bigint) returns timestamp with timezone

pgpro_stats_totals_reset discards statistics gathered so far by pgpro_stats corresponding to the specified object type and id. If no parameter is specified or the type parameter is set to 0, all statistics will be discarded. If type is set to a valid object type, then if id is specified, then statistics

will be discarded only for the specified object, else, statistics will be discarded for all objects of the specified type. Otherwise, no statistics will be discarded. This function returns the time of a reset. By default, this function can only be executed by superusers. Access may be granted to others using `GRANT`.

`pgpro_stats_totals() returns setof record`

The `pgpro_stats_totals` view is defined in terms of a function also named `pgpro_stats_totals`. Users can also call the `pgpro_stats_totals` function directly.

`pgpro_stats_metrics() returns setof record`

Defines the `pgpro_stats_metrics` view, which is described in detail in Table G.75.

`pgpro_stats_get_archiver() returns setof record`

Defines the `pgpro_stats_archiver` view, which is described in detail in Table G.76.

`pgpro_stats_wal_sender_crc_errors() returns bigint`

In Postgres Pro Enterprise, returns the number of errors detected by the WAL sender process when the `wal_sender_check_crc` parameter is `on`. In Postgres Pro Standard, returns zero. Note that this counter is reset to zero when the cluster restarts.

`pgpro_stats_vacuum_database(dboid oid) returns setof record`

Defines the row of the `pgpro_stats_vacuum_database` view, which is described in detail in Table G.77, for the database specified by *`dboid`*.

`pgpro_stats_vacuum_tables(dboid oid, relid oid) returns setof record`

Defines the row of the `pgpro_stats_vacuum_tables` view, which is described in detail in Table G.78, for the database specified by *`dboid`* and table specified by *`reloid`*. If *`reloid`* = 0, the statistics for each table in the specified database are returned.

`pgpro_stats_vacuum_indexes(dboid oid, relid oid) returns setof record`

Defines the row of the `pgpro_stats_vacuum_indexes` view, which is described in detail in Table G.79, for the database specified by *`dboid`* and index specified by *`reloid`*. If *`reloid`* = 0, the statistics for each index in the specified database are returned.

G.3.6.1. Functions for Creating Views that Emulate Other Extensions

pgpro_stats can create views similar to those available in pg_stat_statements and *pg_stat_kcache* extensions. Specifically, `pg_stat_statements`, `pg_stat_statements_info`, `pg_stat_kcache` and `pg_stat_kcache_detail` views can be created. Each view is only created in a Postgres Pro version if it is available in pg_stat_statements/pg_stat_kcache extension for the same version of Postgres Pro/PostgreSQL. For example, the `pg_stat_statements_info` view is only created in Postgres Pro versions starting with 14. The following functions enable creating these views:

`pgpro_stats_create_pg_stat_statements_compatible_views() returns void`

Creates `pg_stat_statements` and `pg_stat_statements_info` views.

`pgpro_stats_create_pg_stat_kcache_compatible_views() returns void`

Creates `pg_stat_kcache` and `pg_stat_kcache_detail` views.

By default, these functions can only be executed by superusers. Access may be granted to others using `GRANT`.

To create `pg_stat_statements*` views, drop the pg_stat_statements extension if it was previously installed and call the function:

```
select pgpro_stats_create_pg_stat_statements_compatible_views();
```

To create `pg_stat_kcache*` views, drop the pg_stat_kcache extension if it was previously installed and call the function:

```
select pgpro_stats_create_pg_stat_kcache_compatible_views();
```

Once the views are created, you can work with them as if the pg_stat_statements/pg_stat_kcache extension is installed.

If you need to remove the views created earlier, do it in a regular way:

```
drop view pg_stat_statements;
drop view pg_stat_statements_info;
drop view pg_stat_kcache;
drop view pg_stat_kcache_detail;
```

G.3.7. Configuration Parameters

G.3.7.1. General Settings

`pgpro_stats.max` (`integer`)

pgpro_stats only collects statistics about most frequent queries. The less frequently a query appears during the server opertaion, the less probable its inclusion in the statistics. Rare queries are almost immediately evicted from the statistics by more frequent queries. The `pgpro_stats.max` parameter defines the maximum number of unique pairs (normalized query text, normalized plan text) tracked by the module, (i.e., the maximum number of rows in the `pgpro_stats_statements` view). The larger this value, the larger the number of queries for which the information is stored. But this is achieved at the cost of reduced server performance when waiting for locks trying to access the statistics table in the shared memory and when periodically collecting garbage in the file with texts of queries and plans. The default value is 5000. This parameter can only be set at server start.

`pgpro_stats.max_totals` (`integer`)

`pgpro_stats.max_totals` is the maximum number of objects tracked by the module (i.e., the maximum number of rows in the `pgpro_stats_totals` view). If more distinct objects than that are observed, information about least-used objects is discarded. The default value is 1000. This parameter can only be set at server start.

`pgpro_stats.track` (`enum`)

`pgpro_stats.track` controls which statements are counted by the module. Specify `top` to track top-level statements (those issued directly by clients), `all` to also track nested statements (such as statements invoked within functions) with nesting level not greater than 100, or `none` to disable statement statistics collection. The default value is `top`. Only superusers can change this setting.

`pgpro_stats.track_utility` (`boolean`)

`pgpro_stats.track_utility` controls whether utility commands are tracked by the module. Utility commands are all those other than `SELECT`, `INSERT`, `UPDATE` and `DELETE`. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_planning` (`boolean`)

`pgpro_stats.track_planning` controls whether planning operations and duration are tracked by the module. Enabling this parameter may incur a noticeable performance penalty, especially when statements with identical query structure are executed by many concurrent connections which compete to update a small number of `pgpro_stats_statements` entries. The default value is `off`. Only superusers can change this setting.

`pgpro_stats.track_totals` (`boolean`)

`pgpro_stats.track_totals` controls whether aggregate statistics for objects (cluster, users, databases etc.) are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_cluster` (`boolean`)

`pgpro_stats.track_cluster` controls whether aggregate statistics for the cluster are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_databases` (`boolean`)

`pgpro_stats.track_databases` controls whether aggregate statistics for the databases are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_users` (`boolean`)

`pgpro_stats.track_users` controls whether aggregate statistics for the users are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_applications` (`boolean`)

`pgpro_stats.track_applications` controls whether aggregate statistics for the applications (whose names are set by application_name) are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_client_addr` (`boolean`)

`pgpro_stats.track_client_addr` controls whether aggregate statistics for the client IP addresses are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_backends` (`boolean`)

`pgpro_stats.track_backends` controls whether aggregate statistics for the backends are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.track_sessions` (`boolean`)

`pgpro_stats.track_sessions` controls whether aggregate statistics for the sessions are tracked by the module. The default value is `on`. Only superusers can change this setting.

`pgpro_stats.save` (`boolean`)

`pgpro_stats.save` specifies whether to save statement statistics across server shutdowns. If it is `off` then statistics are neither saved at shutdown nor reloaded at server start. The default value is `on`. This parameter can only be set in the `postgresql.conf` file or on the server command line.

`pgpro_stats.plan_format` (`text`)

`pgpro_stats.plan_format` selects the `EXPLAIN` format for the query plan. Possible values are `text`, `xml`, `json`, and `yaml`. The default value is `text`. Changing this parameter requires a server restart.

`pgpro_stats.enable_profile` (`boolean`)

`pgpro_stats.enable_profile` enables sampling of wait events for separate statements. The default value is `true`. Changing this parameter requires a server restart.

`pgpro_stats.query_sample_rate` (`float`)

As pgpro_stats only collects statistics about most frequent queries, and rare queries are not included in the statistics, you can reduce the effect of the statistics collection on the server performance. This is possible because some time later than the statistics collection starts, almost all the statistics collected by the module will contain queries that are not very infrequent, and the set of types of the collected queries will not further change much if the value of pgpro_stats.max is sufficient and the average frequency for most of the frequent queries has no significant changes with the periods larger than the observation time. Such a stationary distribution of collected queries can also be achieved by increasing the time of the statistics collection, for example, twice, but only adding each second query to the statistics instead of every query, or considering each query, but adding queries to the statistics randomly, with a given probability. In this example, it equals 0.5. This allows you to considerably reduce the server load at the cost of increasing the time of the statistics collection. `pgpro_stats.query_sample_rate` is the parameter to implement this approach. For example: if `pgpro_stats.query_sample_rate` is set to 0.2 (1/5), in five hours of the server operation under the above conditions, the statistics will be collected that is similar to the statistics collected with `pgpro_stats.query_sample_rate` = 1 in an hour.

You can set up `pgpro_stats.query_sample_rate` by experiment. Choose the observation time depending on the environment of the server operation, for example: one hour. Look at the collected statistics an hour after the start and then an hour later without resetting the statistics. If the main difference appears to be in the increased number of collected queries (`calls`) rather than in the type of the queries, you can safely reduce `pgpro_stats.query_sample_rate` twice. In the case of a considerable difference in the types of the collected queries, increase the observtion time and/or the `pgpro_stats.max` parameter.

The default value is `1.0`. Changing this parameter requires a server restart.

`pgpro_stats.profile_period` (`integer`)

`pgpro_stats.profile_period` specifies the period, in milliseconds, during which to sample wait events. The default value is `10`. Only superusers can change this setting.

`pgpro_stats.metrics_buffer_size` (`integer`)

`pgpro_stats.metrics_buffer_size` specifies the size of the ring buffer used for collecting statistical metrics. The default value is `16kB`. Changing this parameter requires a server restart.

`pgpro_stats.metrics_workers` (`integer`)

`pgpro_stats.metrics_workers` specifies the number of workers used to collect statistical metrics. If this parameter is set to 2 or higher, one of the workers serves as the primary worker distributing queries to other workers. If only one worker is available, it gets reloaded to connect to different databases. Setting this parameter to `0` disables metrics collection. The default value is `2`. Changing this parameter requires a server restart.

`pgpro_stats.stats_temp_directory` (`string`)

`pgpro_stats.stats_temp_directory` specifies the directory with the external file to store query texts. This can be a path relative to the data directory or an absolute path. Changing this parameter requires a server restart.

G.3.7.2. Metrics Settings

The following parameters can be used to define a custom metric to collect. The *N* placeholder in the parameter name serves as a unique identifier of the metric to which this setting should apply; it must be set to a non-negative integer for each metric.

When you add these parameters for a new metric, you have to restart the server for the changes to take effect. Once the new metric is added, its parameters can be changed without a server restart by simply reloading the `postgresql.conf` configuration file.

`pgpro_stats.metric_`*N*`_name` (`text`)

The name of metric *N*. This name will be displayed in the `metric_name` column of the `pgpro_stats_metrics` view.

`pgpro_stats.metric_`*N*`_query` (`text`)

The query statement that defines the metric to collect.

`pgpro_stats.metric_`*N*`_period` (`integer`)

The time interval at which to collect metric *N*, in milliseconds. Default: 60000 ms

`pgpro_stats.metric_`*N*`_db` (`text`)

The list of databases for which to collect metric *N*. Database names must be separated by commas. You can specify the `*` character to select all databases in the cluster except the template databases. If you need to analyze the template databases as well, you have to specify them explicitly.

`pgpro_stats.metric_`*N*`_user` (`text`)

The name of the user on behalf of which to collect metric *N*. This user must have access to the database for which the metric is collected.

G.3.8. Tracing of Application Sessions

In pgpro_stats, tracing of application sessions is implemented. It is based on filters, which trigger logging the execution of queries that match filtering conditions. Queries and their `EXPLAIN` output are logged in so-called *trace files* specified by the user or in the system log file (if the trace file is not specified). Filters are stored in a table located in the shared memory. The rows of this table represent filters, and the columns contain filtering conditions and `EXPLAIN` options to be used (see EXPLAIN for details). You should fill this table with filters to start tracing of queries.

Once a database administrator adds a filter in any session, all subsequent executions of queries that match the filter conditions will be traced by all sessions of the instance without a need in the server restart. In other words, filters can be added, deleted, or updated “on the fly”, and tracing with these filters immediately starts for existing and future sessions.

> **Note**
>
> Operations of adding, deleting, or updating filters are not transactional. Changes to the table of filters are not rolled back together with the transaction where these changes were made.

Columns of the table that stores filters are also called *filter attributes*. They are described in Table G.81.

Table G.81. Filter Attributes

Name	Type	Description
`filter_id`	`integer`	Unique filter ID, which is automatically assigned to a filter when it is created, numbered from 1.
`active`	`boolean`	With the value of `false`, the filter is not active, which means that queries matching this filter are not logged. Default: `true`.
`alias`	`name`	Filter name, which can be specified for convenience. Only shown in the output of the `pgpro_stats_trace_show()` function. Default: empty string.
`tracefile`	`name`	Name of the trace file, where queries matching the filter and their `EXPLAIN` output are logged. If this filename if not specified, logging is done to the system log with the log level specified by pgpro_stats.trace_log_level. Trace files are created in `PGDATA/pg_stat` directory and have `trace` extension.
`pid`	`integer`	Process ID of the backend that executes the statement
`database_name`	`name`	Name of the database where the statement is executed
`client_addr`	`name`	IP address of the client connected to this backend
`application_name`	`name`	Name of the application that invoked execution of the statement

Name	Type	Description
username	name	Name of the user who executes the statement
queryid	bigint	Internal hash code, computed from the statement's parse tree
planid	bigint	Internal hash code, computed from the statement's plan tree
duration	float8	Time spent in the planning and execution of the statement, in milliseconds
plan_time	float8	Time spent in the planning of the statement, in milliseconds
exec_time	float8	Time spent in the execution of the statement, in milliseconds
user_time	float8	User CPU time used in planning and execution of the statement
system_time	float8	System CPU time used in planning and execution of the statement
rows	int8	Total number of rows retrieved or affected by the statement
shared_blks_hit	int8	Total number of shared block cache hits by the statement
shared_blks_read	int8	Total number of shared blocks read by the statement
shared_blks_fetched	int8	Total number of shared blocks fetched from buffers by the statement
shared_blks_dirtied	int8	Total number of shared blocks dirtied by the statement
shared_blks_written	int8	Total number of shared blocks written by the statement
local_blks_hit	int8	Total number of local block cache hits by the statement
local_blks_read	int8	Total number of local blocks read by the statement
local_blks_fetched	int8	Total number of local blocks fetched from buffers by the statement
local_blks_dirtied	int8	Total number of local blocks dirtied by the statement
local_blks_written	int8	Total number of local blocks written by the statement
temp_blks_read	int8	Total number of temp blocks read by the statement
temp_blks_written	int8	Total number of temp blocks written by the statement
wal_bytes	numeric	Total amount of WAL bytes generated by the statement

Name	Type	Description
total_wait_time	float8	Total time execution of this statement spent waiting
total_inval_msgs	bigint	Total number of cache invalidation messages generated by the statement (if this is supported by the server)
explain_analyze	boolean	If true, the EXPLAIN output will be logged with the ANALYZE option. By default, defined by the pgpro_stats.explain_analyze_default configuration parameter.
explain_verbose	boolean	If true, the EXPLAIN output will be logged with the VERBOSE option. By default, defined by the pgpro_stats.explain_verbose_default configuration parameter.
explain_costs	boolean	If true, the EXPLAIN output will be logged with the COSTS option. By default, defined by the pgpro_stats.explain_costs_default configuration parameter.
explain_settings	boolean	If true, the EXPLAIN output will be logged with the SETTINGS option. By default, defined by the pgpro_stats.explain_settings_default configuration parameter.
explain_buffers	boolean	If true, the EXPLAIN output will be logged with the BUFFERS option. By default, defined by the pgpro_stats.explain_buffers_default configuration parameter.
explain_wal	boolean	If true, the EXPLAIN output will be logged with the WAL option. By default, defined by the pgpro_stats.explain_wal_default configuration parameter.
explain_timing	boolean	If true, the EXPLAIN output will be logged with the TIMING option. By default, defined by the pgpro_stats.explain_timing_default configuration parameter.
explain_format	text	The value of the FORMAT option of EXPLAIN to be logged, which can be TEXT, XML, JSON, or YAML. By default, defined by the pgpro_stats.plan_format configuration parameter.
time_info	boolean	If true, includes additional information in the session-tracing output in the format defined by explain_format : pid, duration in milliseconds, start time

Name	Type	Description
		— start time of the query execution, and `stop time` — end time of the query execution. See Example G.2 for details.

Filter attributes can be divided into the following groups:

- Control attributes, from `filter_id` to `tracefile` in Table G.81.
- Identification attributes, from `pid` to `planid` in Table G.81.
- Threshold attributes, from `duration` to `total_inval_msgs` in Table G.81.
- Attributes that only control the output to the trace file or system log file and do not affect filtering. Most of them specify the `EXPLAIN` options. These are the attributes starting with `explain_analyze` up to the end of Table G.81.

Query execution will be traced if both of these conditions are met:

- For all the specified identification attributes of the filter, the values of the respective characteristics of the query are the same as the values of these attributes.
- For all the specified threshold attributes of the filter, the values of the respective characteristics of the query are greater than or equal to the limits specified in these attributes.

It is allowed not to assign values to attributes. For all the attributes except `active`, you can also explicitly assign the value of NULL. If the value of a control attribute is undefined or it was expclicitly set to NULL, this attribute will be assigned the default value shown in Table G.81. For identification and threshold attributes, undefined or NULL values mean that queries will not be filtered by the respective characteristic. If no values are defined for all identification and all threshold attributes, all the queries are taken to be matching this filter and will be logged. If the attributes specifying `EXPLAIN` options are undefined, the default values defined by the configuration parameters will be used (see Section G.3.8.2 for details).

> **Warning**
>
> Although when specifying a filter, you can assign values to any combination of filter attributes, bear in mind that a too general filter will lead to an excessive size of the trace file and will affect the performance more than desired as the main performance overhead is associated with writing to the trace file rather than with checking the filter conditions.

G.3.8.1. Session-Tracing Functions

Specialized functions enable creation, update and deletion of query filters:

`pgpro_stats_trace_insert(VARIADIC "any") returns integer`

Adds a filter to the list of session-tracing filters. A filter must be passed as a sequence of alternating key-value pairs, where the key is the name of the filter attribute from Table G.81 except `filter_id`. For example:

```
pgpro_stats_trace_insert('pid', 42, 'database_name', 'main', 'explain_analyze',
 true)
```

Key-value pairs are position-independent: they can be provided in any order, independently of the order of attributes in Table G.81. Some of the attributes can be missing from the sequence. Such attributes will be assigned the default values. Returns the unique `filter_id`, which the function assigns to the added filter.

`pgpro_stats_trace_update(filter_id integer, VARIADIC "any") returns boolean`

Updates a session-tracing filter defined by *`filter_id`*. Filter attributes to update must be passed as a sequence of alternating key-value pairs, where the key is the name of the filter attribute from

Table G.81 except `filter_id`. Key-value pairs are position-independent: they can be provided in any order, independently of the order of attributes in Table G.81. Filter attributes whose values are not explicitly specified will not be changed. The value of NULL for identification and threshold attributes resets the values of these attributes, which means that a query will match the conditions of the updated filter regardless of the respective characteristics. Returns `true` on success and `false` otherwise.

`pgpro_stats_trace_delete(filter_id integer) returns boolean`

Deletes a session-tracing filter defined by *`filter_id`*. Returns `true` on success and `false` otherwise.

`pgpro_stats_trace_reset() returns integer`

Removes all session-tracing filters. Returns the number of removed filters. By default, this function can only be executed by superusers. Access may be granted to others using `GRANT`.

`pgpro_stats_trace_show() returns setof record`

Displays the contents of the table of filters, whose columns are shown in Table G.81.

G.3.8.2. Session-Tracing Configuration Parameters

The following parameters can be used to configure session-tracing logging. Note that `pgpro_stats.explain_*_default` settings define the logging behavior when the corresponding `explain_*` filter attributes (from Table G.81) are not specified or explicitly set to NULL.

`pgpro_stats.explain_analyze_default` (`boolean`)

If `true`, the `EXPLAIN` output will be logged with the `ANALYZE` option and without it if `false`. The default value is `false`. Only superusers can change this setting.

`pgpro_stats.explain_verbose_default` (`boolean`)

If `true`, the `EXPLAIN` output will be logged with the `VERBOSE` option and without it if `false`. The default value is `false`. Only superusers can change this setting.

`pgpro_stats.explain_costs_default` (`boolean`)

If `true`, the `EXPLAIN` output will be logged with the `COSTS` option and without it if `false`. The default value is `true`. Only superusers can change this setting.

`pgpro_stats.explain_settings_default` (`boolean`)

If `true`, the `EXPLAIN` output will be logged with the `SETTINGS` option and without it if `false`. The default value is `false`. Only superusers can change this setting.

`pgpro_stats.explain_buffers_default` (`boolean`)

If `true`, the `EXPLAIN` output will be logged with the `BUFFERS` option and without it if `false`. The default value is `false`. Only superusers can change this setting.

`pgpro_stats.explain_wal_default` (`boolean`)

If `true`, the `EXPLAIN` output will be logged with the `WAL` option and without it if `false`. The default value is `false`. Only superusers can change this setting.

`pgpro_stats.explain_timing_default` (`boolean`)

If `true`, the `EXPLAIN` output will be logged with the `TIMING` option and without it if `false`. The default value is `true`. Only superusers can change this setting.

`pgpro_stats.trace_log_level` (`enum`)

Defines the log level at which the `EXPLAIN` output will be logged to the system log file (when the trace file is not specified). Valid values are `DEBUG5`, `DEBUG4`, `DEBUG3`, `DEBUG2`, `DEBUG1`, `INFO`, `NOTICE`, `WARNING`, and `LOG`. The default value is `LOG`.

`pgpro_stats.trace_query_text_size` (`int`)

Defines the maximum size of query texts in the session-tracing output, in kilobytes. If the size of the query text in kilobytes is larger, it is trimmed to the maximum size. If this parameter is not specified, the default value of zero is used, which means that the whole query texts are output.

G.3.8.3. Examples Related to Session Tracing

Example G.1. Usage of Session-Tracing Functions

Let's add the filter `first`:

```
SELECT pgpro_stats_trace_insert('alias', 'first', 'pid', pg_backend_pid(),
 'explain_analyze', true);
```

Let's add the filter `second` and specify logging to the trace file `second_tf.trace`:

```
SELECT pgpro_stats_trace_insert('alias', 'second', 'database_name', current_database(),
 'explain_costs', false, 'tracefile', 'second_tf');
```

You can view the table with filters as follows:

```
\x auto
SELECT * from pgpro_stats_trace_show();
```

```
-[ RECORD 1 ]-------+----------
filter_id           | 1
active              | t
alias               | first
tracefile           |
pid                 | 243183
database_name       |
client_addr         |
application_name    |
username            |
queryid             |
planid              |
duration            |
plan_time           |
exec_time           |
user_time           |
system_time         |
rows                |
shared_blks_hit     |
shared_blks_read    |
shared_blks_fetched |
shared_blks_dirtied |
shared_blks_written |
local_blks_hit      |
local_blks_read     |
local_blks_fetched  |
local_blks_dirtied  |
local_blks_written  |
temp_blks_read      |
temp_blks_written   |
wal_bytes           |
total_wait_time     |
total_inval_msgs    |
explain_analyze     | t
explain_verbose     | f
explain_costs       | t
explain_settings    | f
explain_buffers     | f
```

```
explain_wal          | f
explain_timing       | t
explain_format       | text
time_info            | f
-[ RECORD 2 ]--------+----------
filter_id            | 2
active               | t
alias                | second
tracefile            | second_tf
pid                  |
database_name        | postgres
client_addr          |
application_name     |
username             |
queryid              |
planid               |
duration             |
plan_time            |
exec_time            |
user_time            |
system_time          |
rows                 |
shared_blks_hit      |
shared_blks_read     |
shared_blks_fetched  |
shared_blks_dirtied  |
shared_blks_written  |
local_blks_hit       |
local_blks_read      |
local_blks_fetched   |
local_blks_dirtied   |
local_blks_written   |
temp_blks_read       |
temp_blks_written    |
wal_bytes            |
total_wait_time      |
total_inval_msgs     |
explain_analyze      | f
explain_verbose      | f
explain_costs        | f
explain_settings     | f
explain_buffers      | f
explain_wal          | f
explain_timing       | f
explain_format       | text
time_info            | f
```

The following query matches the conditions of both filters, so it must be logged in the system log file and in the specified trace file:

```
SELECT 1 as result;
```

The following is the output to the system log file:

```
2023-04-18 04:52:53.242 MSK [63112] LOG:  Filter 1 triggered explain of the plan:
Query Text: SELECT 1 as result;
Result  (cost=0.00..0.01 rows=1 width=4) (actual time=0.003..0.003 rows=1 loops=1)
```

And the following is the output to the `second_tf.trace` trace file:

```
Query Text: SELECT 1 as result;
```

```
Result
```

Let's delete the first filter:

```
SELECT pgpro_stats_trace_delete(1);
```

Let's also change `pid` to 2 for the second filter

```
SELECT pgpro_stats_trace_update(2, 'pid', 2);
```

When you execute the query

```
SELECT 2 as result;
```

it does not get logged to `second_tf.trace`.

Now let's remove all filters from the table:

```
SELECT pgpro_stats_trace_reset();
```

Example G.2. Session-Tracing Output with `time_info` = `true`

The following is an example of the session-tracing output in the JSON format when `time_info` = `true`:

```
{
  "Pid": 123456,
  "Duration ms": 0.094691,
  "Start time": "2025-01-12 15:39:27.580447+03",
  "Stop time": "2025-01-12 15:39:27.587802+03",
  "Query Text": "SELECT 2 AS Result;",
  "Plan": {
    "Node Type": "Result",
    "Parallel Aware": false,
    "Async Capable": false,
    "Startup Cost": 0.00,
    "Total Cost": 0.01,
    "Plan Rows": 1,
    "Plan Width": 4
  }
}
```

G.3.9. Cache Invalidation Metrics

Among the rest, pgpro_stats can collect cache invalidation statistics. This section provides some background information needed to better understand related metrics.

Each backend has its local cache, which allows you to minimize accesses for meta information on tables, for example, to the system catalogs. If a backend changes the meta information, this information must be updated in other backends' caches. This is implemented by sending invalidation messages through a queue: the backend that changed the meta information on some object sends an appropriate message to the queue.

All backends get invalidation messages from the queue. Depending on whether the object for which the invalidation message was received is cached, the backend either ignores the message (when the object is not cached) or updates its cache (when the object is cached). In pgpro_stats, most invalidation message counters, unless explicitly stated otherwise for certain counters, are incremented when backends just generate messages, which will only be sent to the queue upon commit of the appropriate transaction. Note that the counters will remain incremented if the transaction is rolled back, although the message will not be sent to the queue.

When a backend that is adding messages to the queue figures out that the queue size reached a certain limit, it starts a cleanup by deleting messages already processed by all backends, and if backends are found that heavily fall behind and thus delay the cleanup, they get a reset signal, which forces them to reset all their caches.

G.3.9.1. The pgpro_stats_inval_status View

The pgpro_stats_inval_status view shows one row with the current status of the cache invalidation global queue. The columns of the view are shown in Table G.82.

Table G.82. pgpro_stats_inval_status Columns

Name	Type	Description
num_inval_messages	int8	Current number of invalidation messages in the queue
num_inval_queue_cleanups	int8	Number of invalidation queue cleanups done to prevent its overflow
num_inval_queue_resets	int4	Number of cache resets for backends that fail to process messages fast enough

In a working system, num_inval_messages usually approximately equals 4000, which means that the queue is pretty full. The speed of the num_inval_queue_cleanups growth is determined by how fast invalidation messages are generated. Growth of num_inval_queue_resets is normally zero, and non-zero growth indicates either too fast generation of messages or delays in processing messages by backends. Monitoring num_inval_queue_cleanups and num_inval_queue_resets may in some cases allow you to detect problematic backend/backeds as described below.

If for a certain time interval, num_inval_queue_cleanups considerably increased, while num_inval_queue_resets did not, this indicates that invalidation messages are generated faster and/or backends process them more slowly, but backends still manage to process messages before the queue overflows.

If for a time interval, num_inval_queue_cleanups did not considerably increase, while num_inval_queue_resets did, this definitely indicates a delay in processing messages by backend(s), and the cache_resets column of the pgpro_stats_totals view allows you to figure out which backend(s) to blame.

If for a time interval, both counters considerably increased, this also indicates that invalidation messages are generated faster and/or backends process them more slowly, but this time backends fail to process messages before the queue overflows. The cache_resets column of the pgpro_stats_totals view allows you detect which backend(s) delay message processing. In this case, it is not possible to definitely conclude whether too fast generation of messages or a delay in message processing accounts for the growth of num_inval_queue_resets. However, the totals counter of the pgpro_stats_inval_msgs view may help here. If the change of this counter for that interval is pretty the same as for a previous interval of the same length, you can definitely conclude that the growth is caused by backend delays.

The pgpro_stats_inval_status view can be defined in terms of a function:

```
pgpro_stats_inval_status() returns record
```

Defines the pgpro_stats_inval_status view, which is described in detail in Table G.82.

G.3.9.2. The pgpro_stats_inval_msgs Type

The pgpro_stats_statements and pgpro_stats_totals views for each corresponding object, show a record of the pgpro_stats_inval_msgs record type containing counters for cache invalidation messages. The fields of the type are shown in Table G.83.

Table G.83. pgpro_stats_inval_msgs Fields

Name	Type	Description
total	bigint	Total number of invalidation messages

Name	Type	Description
catcache	bigint	Number of selective catalog cache invalidation messages
catalog	bigint	Number of whole catalog cache invalidation messages
relcache	bigint	Number of selective relation cache invalidation messages
relcache_all	bigint	Number of whole relation cache invalidation messages
smgr	bigint	Number of invalidation messages of open relation files. Gets incremented when the messages are sent to the queue.
relmap	bigint	Number of relation map cache invalidation messages. Gets incremented when the messages are sent to the queue.
snapshot	bigint	Number of catalog snapshot invalidation messages

G.3.10. Authors

Postgres Professional, Moscow, Russia

Appendix H. Third-Party Modules and Extensions Shipped as Individual Packages

This appendix contains third-party modules and extensions that are made available in Postgres Pro Enterprise as individual packages. These packages are listed in Section 17.1.4.1, and the documentation for each module explains which package to choose to install it. Appendix F and Appendix G cover more modules and extensions included in the Postgres Pro Enterprise distribution. Note also the following extensions that are shipped as individual packages: orafce, pldebugger and plv8 (see Table 17.3 for details).

H.1. oracle_fdw

The oracle_fdw module is a Postgres Pro extension that provides a Foreign Data Wrapper for easy and efficient access to Oracle databases, including pushdown of `WHERE` conditions and required columns as well as comprehensive `EXPLAIN` support.

H.1.1. Installation

The oracle_fdw extension is provided with Postgres Pro Enterprise as a separate pre-built package `oracle-fdw-ent-14` (for the detailed installation instructions, see Chapter 17). oracle_fdw requires Oracle Instant Client version 19.5.

For RPM-based systems (RHEL, SUSE, Red OS, ROSA, ALT Linux), download the `oracle-instantclient` RPM and install it using `rpm`. If you use a Debian-based system (Ubuntu, Astra Linux), you have to either convert the RPM package to a Debian package using alien, and then install it using dpkg, or download the ZIP archive of the client and extract the contents of the archive into the `/opt/oracle` directory.

Once you have Postgres Pro Enterprise installed, create the oracle_fdw extension:

```
CREATE EXTENSION oracle_fdw;
```

That will define the required functions and create a foreign data wrapper.

Note that the extension version as shown by the psql `\dx` command or the system catalog `pg_available_extensions` is *not* the installed version of oracle_fdw. To get the oracle_fdw version, use the `oracle_diag` function.

H.1.2. Internals

oracle_fdw sets the `MODULE` of the Oracle session to `postgres` and the `ACTION` to the backend process number. This can help identifying the Oracle session and allows you to trace it with `DBMS_MONITOR.SERV_MOD_ACT_TRACE_ENABLE`.

oracle_fdw uses Oracle array interface to avoid unnecessary client-server round-trips. The batch size can be configured with the prefetch table option and is set to 50 by default.

Rather than using a `PLAN_TABLE` to explain an Oracle query (which would require such a table to be created in the Oracle database), oracle_fdw uses execution plans stored in the library cache. For that, an Oracle query is *explicitly described*, which forces Oracle to parse the query. The hard part is to find the `SQL_ID` and `CHILD_NUMBER` of the statement in `V$SQL` because the `SQL_TEXT` column contains only the first 1000 bytes of the query. Therefore, oracle_fdw adds a comment to the query that contains a hash of the query text. This is used to search in `V$SQL`. The actual execution plan or cost information is retrieved from `V$SQL_PLAN`.

oracle_fdw uses transaction isolation level `SERIALIZABLE` on the Oracle side, which corresponds to Postgres Pro's `REPEATABLE READ`. This is necessary because a single Postgres Pro statement can lead to multiple Oracle queries (e.g. during a nested loop join) and the results need to be consistent. Unfortunately, the Oracle implementation of `SERIALIZABLE` has certain quirks; see the Problems section for more.

The Oracle transaction is committed immediately before the local transaction commits, so that a completed Postgres Pro transaction guarantees that the Oracle transaction has completed. However, there is a small chance that the Postgres Pro transaction cannot complete even though the Oracle transaction is committed. This cannot be avoided without using two-phase transactions and a transaction manager, which is beyond what a foreign data wrapper can reasonably provide. Prepared statements involving Oracle are not supported for the same reason.

H.1.3. Short Simple Example

This is an example how to use oracle_fdw. More detailed information is provided in the sections Options and Usage. You should also read the documentation on foreign data and the commands referenced there.

For the sake of this example, let's assume you can connect to Oracle as the operating system user `postgres` (or whoever starts the Postgres Pro server) with the following command:

```
sqlplus orauser/orapwd@//dbserver.mydomain.com:1521/ORADB
```

That means that the Oracle client and the environment are set up correctly. It is also assumed that oracle_fdw has been installed (see the Installation section).

We want to access a table defined like this:

```
SQL> DESCRIBE oratab
 Name                           Null?    Type
 ------------------------------ -------- ------------
 ID                             NOT NULL NUMBER(5)
 TEXT                                    VARCHAR2(30)
 FLOATING                       NOT NULL NUMBER(7,2)
```

Then configure oracle_fdw as a Postgres Pro superuser like this:

```
pgdb=# CREATE EXTENSION oracle_fdw;
pgdb=# CREATE SERVER oradb FOREIGN DATA WRAPPER oracle_fdw
          OPTIONS (dbserver '//dbserver.mydomain.com:1521/ORADB');
```

You can use other naming methods or local connections, see the description of dbserver below.

It is a good idea to use a superuser only where really necessary, so let's allow a normal user to use the foreign server (this is not required for the example to work but recommended):

```
pgdb=# GRANT USAGE ON FOREIGN SERVER oradb TO pguser;
```

Then you can connect to Postgres Pro as `pguser` and define the following:

```
pgdb=> CREATE USER MAPPING FOR pguser SERVER oradb
          OPTIONS (user 'orauser', password 'orapwd');
```

You can use external authentication to avoid storing Oracle passwords.

```
pgdb=> CREATE FOREIGN TABLE oratab (
          id        integer           OPTIONS (key 'true')  NOT NULL,
          text      character varying(30),
          floating  double precision  NOT NULL
       ) SERVER oradb OPTIONS (schema 'ORAUSER', table 'ORATAB');
```

Remember that the table and schema name (the latter is optional) must normally be in uppercase.

Now you can use the table like a regular Postgres Pro table.

H.1.4. Usage

H.1.4.1. Oracle Permissions

The Oracle user will need the `CREATE SESSION` privilege and the right to select from the table or view in question. Note that oracle_fdw accesses the Oracle table at query planning time to get its definition. This happens *before* permissions on the foreign table are checked. Consequently, you may receive an Oracle error if you try to access a foreign table on which you have no permissions in Postgres Pro. This is expected and no security problem.

For `EXPLAIN VERBOSE`, the user will also need `SELECT` privileges on `V$SQL` and `V$SQL_PLAN`.

H.1.4.2. Connections

oracle_fdw caches Oracle connections because it is expensive to create an Oracle session for each individual query. All connections are automatically closed when the Postgres Pro session ends.

The `close_connections` function can be used to close all cached Oracle connections. This can be useful for long-running sessions that do not access foreign tables all the time and want to avoid blocking the resources needed by an open Oracle connection. You cannot call this function inside a transaction that modifies Oracle data.

H.1.4.3. Columns

When you define a foreign table, the columns of the Oracle table are mapped to the Postgres Pro columns in the order of their definition.

oracle_fdw will only include those columns in the Oracle query that are actually needed by the Postgres Pro query.

The Postgres Pro table can have more or less columns than the Oracle table. If it has more columns, and these columns are used, you will receive a warning and NULL values will be returned.

If you want to `UPDATE` or `DELETE`, make sure that the `key` option is set on all columns that belong to the table's primary key. Failure to do so will result in errors.

H.1.4.4. Data Types

You must define the Postgres Pro columns with data types that oracle_fdw can translate (see the conversion table below). This restriction is only enforced if the column actually gets used, so you can define "dummy" columns for untranslatable data types as long as you don't access them (this trick only works with `SELECT`, not when modifying foreign data). If an Oracle value exceeds the size of the Postgres Pro column (e.g., the length of a `varchar` column or the maximal `integer` value), you will receive a runtime error.

These conversions are automatically handled by oracle_fdw:

```
Oracle type              | Possible PostgreSQL types
-------------------------+--------------------------------------------------
CHAR                     | char, varchar, text
NCHAR                    | char, varchar, text
VARCHAR                  | char, varchar, text
VARCHAR2                 | char, varchar, text, json
NVARCHAR2                | char, varchar, text
CLOB                     | char, varchar, text, json
LONG                     | char, varchar, text
RAW                      | uuid, bytea
BLOB                     | bytea
```

```
BFILE                      | bytea (read-only)
LONG RAW                   | bytea
NUMBER                     | numeric, float4, float8, char, varchar, text
NUMBER(n,m) with m<=0      | numeric, float4, float8, int2, int4, int8,
                           |    boolean, char, varchar, text
FLOAT                      | numeric, float4, float8, char, varchar, text
BINARY_FLOAT               | numeric, float4, float8, char, varchar, text
BINARY_DOUBLE              | numeric, float4, float8, char, varchar, text
DATE                       | date, timestamp, timestamptz, char, varchar, text
TIMESTAMP                  | date, timestamp, timestamptz, char, varchar, text
TIMESTAMP WITH TIME ZONE   | date, timestamp, timestamptz, char, varchar, text
TIMESTAMP WITH             | date, timestamp, timestamptz, char, varchar, text
   LOCAL TIME ZONE         |
INTERVAL YEAR TO MONTH     | interval, char, varchar, text
INTERVAL DAY TO SECOND     | interval, char, varchar, text
XMLTYPE                    | xml, char, varchar, text
MDSYS.SDO_GEOMETRY         | geometry (see "PostGIS support" below)
```

If a `NUMBER` is converted to a `boolean`, 0 means `false`, everything else `true`.

Inserting or updating `XMLTYPE` only works with values that do not exceed the maximum length of the `VARCHAR2` data type (4000 or 32767, depending on the `MAX_STRING_SIZE` parameter).

`NCLOB` is currently not supported because Oracle cannot automatically convert it to the client encoding.

If you want to convert `TIMESTAMP WITH LOCAL TIME ZONE` to `timestamp`, consider setting the `set_time-zone` option on the foreign server.

If you need conversions exceeding the above, define an appropriate view in Oracle or Postgres Pro.

H.1.4.5. `WHERE` Conditions and `ORDER BY` Clauses

Postgres Pro will use all applicable parts of the `WHERE` clause as a filter for the scan. The Oracle query that oracle_fdw constructs will contain a `WHERE` clause corresponding to these filter criteria whenever such a condition can safely be translated to Oracle SQL. This feature, also known as *push-down* of `WHERE` clauses, can greatly reduce the number of rows retrieved from Oracle and may enable Oracle's optimizer to choose a good plan for accessing the required tables.

Similarly, `ORDER BY` clauses will be pushed down to Oracle wherever possible. Note that no `ORDER BY` condition that sorts by a character string will be pushed down as the sort orders in Postgres Pro and Oracle cannot be guaranteed to be the same.

To make use of that, try to use simple conditions for the foreign table. Choose Postgres Pro column data types that correspond to Oracle's types because otherwise conditions cannot be translated.

The expressions `now()`, `transaction_timestamp()`, `current_timestamp`, `current_date`, and `local-timestamp` will be translated correctly.

The output of `EXPLAIN` will show the Oracle query used so you can see which conditions were translated to Oracle and how.

H.1.4.6. Joins Between Foreign Tables

oracle_fdw can push down joins to the Oracle server, that is, a join between two foreign tables will lead to a single Oracle query that performs the join on the Oracle side.

There are some restrictions when this can happen:

- Both tables must be defined on the same foreign server.
- Joins between three or more tables won't be pushed down.

- The join must be in a SELECT statement.
- oracle_fdw must be able to push down all join conditions and WHERE clauses.
- Cross joins without join conditions are not pushed down.
- If a join is pushed down, ORDER BY clauses will not be pushed down.

It is important that table statistics for both foreign tables have been collected with ANALYZE for Postgres Pro to determine the best join strategy.

H.1.4.7. Modifying Foreign Data

oracle_fdw supports INSERT, UPDATE, and DELETE on foreign tables. This is allowed by default (also in databases upgraded from an earlier Postgres Pro release) and can be disabled by setting the readonly table option.

For UPDATE and DELETE to work, the columns corresponding to the primary key columns of the Oracle table must have the key column option set. These columns are used to identify a foreign table row, so make sure that the option is set on *all* columns that belong to the primary key.

If you omit a foreign table column during INSERT, that column is set to the value defined in the DEFAULT clause on the Postgres Pro foreign table (or NULL if there is no DEFAULT clause). DEFAULT clauses on the corresponding Oracle columns are not used. If the Postgres Pro foreign table does not include all columns of the Oracle table, the Oracle DEFAULT clauses will be used for the columns not included in the foreign table definition.

The RETURNING clause on INSERT, UPDATE and DELETE is supported except for columns with Oracle data types LONG and LONG RAW (Oracle doesn't support these data types in the RETURNING clause).

Triggers on foreign tables are supported. Triggers defined with AFTER and FOR EACH ROW require that the foreign table has no columns with Oracle data type LONG or LONG RAW. This is because such triggers make use of the RETURNING clause mentioned above.

While modifying foreign data works, the performance is not particularly good, specifically when many rows are affected, because (owing to the way foreign data wrappers work) each row has to be treated individually.

Transactions are forwarded to Oracle so BEGIN, COMMIT, ROLLBACK, and SAVEPOINT work as expected. Prepared statements involving Oracle are not supported. See the Internals section for details.

Since oracle_fdw uses serialized transactions by default, it is possible that data modifying statements lead to a serialization failure:

```
ORA-08177: can't serialize access for this transaction
```

This can happen if concurrent transactions modify the table and gets more likely in long running transactions. Such errors can be identified by their SQLSTATE (40001). An application using oracle_fdw should retry transactions that fail with this error.

It is possible to use a different transaction isolation level, see Foreign Server Options for a discussion.

H.1.4.8. EXPLAIN

Postgres Pro's EXPLAIN will show the query that is actually issued to Oracle. EXPLAIN VERBOSE will show Oracle's execution plan (that will not work with Oracle server 9i or older, see Problems).

H.1.4.9. ANALYZE

You can use ANALYZE to gather statistics on a foreign table. This is supported by oracle_fdw.

Without statistics, Postgres Pro has no way to estimate the row count for queries on a foreign table, which can cause bad execution plans to be chosen.

Postgres Pro will *not* automatically gather statistics for foreign tables with the autovacuum daemon like it does for normal tables, so it is particularly important to run `ANALYZE` on foreign tables after creation and whenever the remote table has changed significantly.

Keep in mind that analyzing an Oracle foreign table will result in a full sequential table scan. You can use the table option sample_percent to speed this up by using only a sample of the Oracle table.

H.1.4.10. PostGIS Support

The data type `geometry` is only available when PostGIS is installed.

The only supported geometry types are `POINT`, `LINE`, `POLYGON`, `MULTIPOINT`, `MULTILINE`, and `MULTIPOLYGON` in two and three dimensions. Empty PostGIS geometries are not supported because they have no equivalent in Oracle Spatial.

NULL values for Oracle `SRID` will be converted to 0 and vice versa. For other conversions between Oracle `SRID` and PostGIS `SRID`, create a file `srid.map` in the Postgres Pro `share` directory. Each line of this file shall contain an Oracle `SRID` and the corresponding PostGIS `SRID`, separated by a whitespace. Keep the file small for good performance.

H.1.4.11. Support for `IMPORT FOREIGN SCHEMA`

IMPORT FOREIGN SCHEMA is supported to bulk import table definitions for all tables in an Oracle schema. In addition to the documentation of `IMPORT FOREIGN SCHEMA`, consider the following:

- `IMPORT FOREIGN SCHEMA` will create foreign tables for all objects found in `ALL_TAB_COLUMNS`. That includes tables, views and materialized views, but not synonyms.
- These are the supported options for `IMPORT FOREIGN SCHEMA`:
  - `case` controls case folding for table and column names during import.

    The possible values are:

    - `keep`: leave the names as they are in Oracle, usually in upper case.
    - `lower`: translate all table and column names to lower case.
    - `smart`: only translate names that are all upper case in Oracle (this is the default).
  - `collation` is the collation used for case folding for the `lower` and `smart` options of `case`.

    The default value is `default`, which is the database's default collation. Only collations in the `pg_catalog` schema are supported. See the `collname` values in the `pg_collation` catalog for a list of possible values.
  - `dblink` is the Oracle database link through which the schema is accessed.

    This name must be written exactly as it occurs in Oracle's system catalog so normally consist of uppercase letters only.
  - `readonly` sets the readonly option on all imported tables.
  - `skip_tables` (default `false`): don't import tables.
  - `skip_views` (default `false`): don't import views.
  - `skip_matviews` (default `false`): don't import materialized views.
  - `max_long` sets the max_long option on all imported tables.
  - `sample_percent` sets the sample_percent option on all imported tables.
  - `prefetch` sets the prefetch option on all imported tables.
  - `lob_prefetch` sets the lob_prefetch option on all imported tables.
  - `nchar` sets the nchar option on all imported tables.

- `set_timezone` sets the set_timezone option on all imported tables.

- The Oracle schema name must be written exactly as it is in Oracle, so normally in upper case. Since Postgres Pro translates names to lower case before processing, you must protect the schema name with double quotes (for example, `"SCOTT"`).
- Table names in the `LIMIT TO` or `EXCEPT` clause must be written as they will appear in Postgres Pro after the case folding described above.

Note that `IMPORT FOREIGN SCHEMA` does not work with Oracle server 8i; see the Problems section for details.

H.1.5. Reference

H.1.5.1. Objects Created by the Extension

`oracle_fdw_handler() RETURNS fdw_handler`
`oracle_fdw_validator(text[], oid) RETURNS void`

These functions are the handler and validator functions necessary to create a foreign data wrapper.

```
FOREIGN DATA WRAPPER oracle_fdw
  HANDLER oracle_fdw_handler
  VALIDATOR oracle_fdw_validator
```

The extension automatically creates a foreign data wrapper named `oracle_fdw`. Normally, that's all you need, and you can proceed to define foreign servers. You can create additional Oracle foreign data wrappers, for example, if you need to set the nls_lang option (you can alter the existing `oracle_fdw` wrapper, but all modifications will be lost after a dump/restore).

`oracle_close_connections() RETURNS void`

This function can be used to close all open Oracle connections in this session. See Usage for further description.

`oracle_diag(name DEFAULT NULL) RETURNS text`

This function is useful for diagnostic purposes only. It will return the versions of oracle_fdw, Postgres Pro server, and Oracle client. If called with no argument or NULL, it will additionally return the values of some environment variables used for establishing Oracle connections. If called with the name of a foreign server, it will additionally return the Oracle server version.

`oracle_execute(server name, stmt text) RETURNS void`

This function can be used to execute arbitrary SQL statements on the remote Oracle server. That will only work with statements that do not return results (typically DDL statements).

Be careful when using this function since it might disturb the transaction management of oracle_fdw. Remember that running a DDL statement in Oracle will issue an implicit `COMMIT`. You are best advised to use this function outside of multi-statement transactions.

H.1.5.2. Options

H.1.5.2.1. Foreign Data Wrapper Options

Important

If you modify the default foreign data wrapper `oracle_fdw`, any changes will be lost upon dump/restore. Create a new foreign data wrapper if you want the options to be persistent. The SQL script shipped with the software contains a `CREATE FOREIGN DATA WRAPPER` statement you can use.

`[nls_lang]`

Sets the `NLS_LANG` environment variable for Oracle to this value. `NLS_LANG` is in the form *`language_territory.charset`* (for example, `AMERICAN_AMERICA.AL32UTF8`). This must match your database encoding. When this value is not set, oracle_fdw will automatically do the right thing if it can and issue a warning if it cannot. Set this only if you know what you are doing. See the Problems section.

H.1.5.2.2. Foreign Server Options

`dbserver`

The Oracle database connection string for the remote database. This can be in any of the forms that Oracle supports as long as your Oracle client is configured accordingly. Set this to an empty string for local (`BEQUEATH`) connections.

`[isolation_level]`

The transaction isolation level to use at the Oracle database. The value can be `serializable`, `read_committed`, or `read_only`. The default is `serializable`.

Note that the Oracle table can be queried more than once during a single Postgres Pro statement (for example, during a nested loop join). To make sure that no inconsistencies caused by race conditions with concurrent transactions can occur, the transaction isolation level must guarantee read stability. This is only guaranteed with Oracle's `SERIALIZABLE` or `READ ONLY` isolation levels.

Unfortunately Oracle's implementation of `SERIALIZABLE` is rather bad and causes serialization errors (ORA-08177) in unexpected situations, like inserts into the table. Using `READ COMMITTED` transactions works around this problem, but *there is a risk of inconsistencies*. If you want to use it, check your execution plans if the foreign scan could be executed more than once.

`[nchar]`

Setting this option to `on` chooses a more expensive character conversion on the Oracle side. This is required if Oracle tables have `NCHAR` or `NVARCHAR2` columns that contain characters that cannot be represented in the Oracle database character set. The default is `off`.

Setting `nchar` to `on` has a noticable performance impact, and it causes ORA-01461 errors with `UPDATE` statements that set strings over 2000 bytes (or 16383 if you have `MAX_STRING_SIZE = EXTENDED`). This error seems to be an Oracle bug.

`[set_timezone]`

Setting this option to `on` sets the Oracle session time zone to the current value of the Postgres Pro parameter `timezone` when the connection to Oracle is made. This is only useful if you plan to use Oracle columns of type `TIMESTAMP WITH LOCAL TIME ZONE` and want to translate them to `timestamp without time zone` in Postgres Pro. The default is `off`.

Note that if you change `timezone` after the Oracle connection has been established, oracle_fdw will not change the Oracle session time zone. You can call `oracle_close_connections() RETURNS void` in that case so that a new connection is opened the next time you access a foreign table.

If Oracle does not recognize the time zone, connections will fail with an error like “ORA-01882: timezone region not found”.

In that case, either use a different `timezone` or leave the option set to `off` and set the environment variable `ORA_SDTZ` to an appropriate value in the environment of the Postgres Pro server.

H.1.5.2.3. User Mapping Options

`user`

The Oracle user name for the session. Set this to an empty string for *external authentication* if you don't want to store Oracle credentials in the Postgres Pro database (one simple way is to use an *external password store*).

`password`

The password for the Oracle user.

H.1.5.2.4. Foreign Table Options

`table`

The Oracle table name. This name must be written exactly as it occurs in Oracle's system catalog so normally consist of uppercase letters only.

To define a foreign table based on an arbitrary Oracle query, set this option to the query enclosed in parentheses:

```
OPTIONS (table '(SELECT col FROM tab WHERE val = ''string'')')
```

Do not set the schema option in this case. `INSERT`, `UPDATE`, and `DELETE` will work on foreign tables defined on simple queries; if you want to avoid that (or confusing Oracle error messages for more complicated queries), use the table option readonly.

`dblink`

The Oracle database link through which the table is accessed. This name must be written exactly as it occurs in Oracle's system catalog so normally consist of uppercase letters only.

`[schema]`

The table's schema (or owner). Useful to access tables that do not belong to the connecting Oracle user. This name must be written exactly as it occurs in Oracle's system catalog so normally consist of uppercase letters only.

`[max_long]`

The maximal length of any `LONG`, `LONG RAW`, and `XMLTYPE` columns in the Oracle table. Possible values are integers between 1 and 1073741823 (the maximal size of a `bytea` in Postgres Pro). This amount of memory will be allocated at least twice so large values will consume a lot of memory. If max_long is less than the length of the longest value retrieved, you will receive the error message “ORA-01406: fetched column value was truncated”. The default is `32767`.

`[readonly]`

`INSERT`, `UPDATE`, and `DELETE` are only allowed on tables where this option is not set to yes/on/true. The default is `false`.

`[sample_percent]`

This option only influences `ANALYZE` processing and can be useful to `ANALYZE` very large tables in a reasonable time.

The value must be between 0.000001 and 100 and defines the percentage of Oracle table blocks that will be randomly selected to calculate Postgres Pro table statistics. This is accomplished using the `SAMPLE BLOCK (x)` clause in Oracle. The default is `100`.

`ANALYZE` will fail with ORA-00933 for tables defined with Oracle queries and may fail with ORA-01446 for tables defined with complex Oracle views.

`[prefetch]`

Sets the number of rows that will be fetched with a single round-trip between Postgres Pro and Oracle during a foreign table scan. The value must be between 1 and 1000, where a value of zero disables prefetching. The default is `50`.

Higher values can speed up performance but will use more memory on the Postgres Pro server.

Note that there is no prefetching if the Oracle table contains columns of the type MDSYS.SDO_GEOMETRY.

[lob_prefetch]

Sets the number of bytes that are prefetched for BLOB, CLOB, and BFILE values. LOBs that exceed that size will require additional round trips between Postgres Pro and Oracle so setting this value bigger than the size of your typical LOB will be good for performance. Choosing bigger values for this option can allocate more memory on the server side but will boost performance for large LOBs. The default is 1048576.

H.1.5.2.5. Column Options

[key]

If set to yes/on/true, the corresponding column on the foreign Oracle table is considered a primary key column. For UPDATE and DELETE to work, you must set this option on all columns that belong to the table's primary key. The default is false.

[strip_zeros]

If set to yes/on/true, ASCII 0 characters will be removed from the string during transfer. Such characters are valid in Oracle but not in Postgres Pro so they will cause an error when read by oracle_fdw. This option only makes sense for character, character varying, and text columns. The default is false.

H.1.6. Problems

H.1.6.1. Encoding

Characters stored in an Oracle database that cannot be converted to the Postgres Pro database encoding will silently be replaced by replacement characters, typically a normal or inverted question mark, by Oracle. You will get no warning or error messages.

If you use a Postgres Pro database encoding that Oracle does not know (currently these are EUC_CN, EUC_KR, LATIN10, MULE_INTERNAL, WIN874, and SQL_ASCII), non-ASCII characters cannot be translated correctly. You will get a warning in this case, and the characters will be replaced by replacement characters as described above.

You can set the nls_lang option of the foreign data wrapper to force a certain Oracle encoding, but the resulting characters will most likely be incorrect and lead to Postgres Pro error messages. This is probably only useful for SQL_ASCII encoding if you know what you are doing.

H.1.6.2. Limited Functionality in Old Oracle Versions

The definition of the Oracle system catalogs V$SQL and V$SQL_PLAN has changed with Oracle 10.1. Using EXPLAIN VERBOSE with older Oracle server versions will result in errors like:

```
ERROR:  error describing query: OCIStmtExecute failed to execute
        remote query for sql_id
DETAIL:  ORA-00904: "LAST_ACTIVE_TIME": invalid identifier
```

There is no plan to fix this, since Oracle 9i has been out of Extended Support since 2010 and the functionality is not essential.

IMPORT FOREIGN SCHEMA throws the following error with Oracle server 8i:

```
ERROR:  error importing foreign schema: OCIStmtExecute failed to execute
        column query
DETAIL:  ORA-00904: invalid column name
```

This is because the view ALL_TAB_COLUMNS lacks the column CHAR_LENGTH, which was added in Oracle 9i.

H.1.6.3. LDAP Libraries

The Oracle client shared library comes with its own LDAP client implementation conforming to *RFC 1823* so these functions have the same names as OpenLDAP's. This will lead to a name collision when the Postgres Pro server was configured `--with-ldap`.

The name collision will not be detected because oracle_fdw is loaded at runtime, but trouble will happen if anybody calls an LDAP function. Typically, OpenLDAP is loaded first so if Oracle calls an LDAP function (for example, if you use *directory naming* name resolution), the backend will crash. This can lead to messages like the following (seen on Linux) in the Postgres Pro server log:

```
../../../libraries/libldap/getentry.c:29: ldap_first_entry:
 Assertion `( (ld)->ld_options.ldo_valid == 0x2 )' failed.
```

Since Postgres Pro is built `--with-ldap`, it may work as long as you don't use any LDAP client functionality in Oracle. On some platforms, you can force Oracle's client shared library to be loaded before the Postgres Pro server is started (`LD_PRELOAD` on Linux). Then Oracle's LDAP functions should get used. In that case, Oracle may be able to use LDAP functionality, but using LDAP from Postgres Pro will crash the backend.

You cannot use LDAP functionality both in Postgres Pro and in Oracle.

H.1.6.4. Serialization Errors

In Oracle 11.2 or above, inserting the first row into a newly created Oracle table with oracle_fdw will lead to a serialization error.

This is because of an Oracle feature called *deferred segment creation*, which defers allocation of storage space for a new table until the first row is inserted. This causes a serialization failure with serializable transactions.

This is no serious problem; you can work around it by either ignoring that first error or creating the table with `SEGMENT CREATION IMMEDIATE`.

A much nastier problem is that concurrent inserts can sometimes cause serialization errors when an index page is split concurrently with a modifying serializable transaction.

Oracle claims that this is not a bug, and the suggested solution is to retry the transaction that got a serialization error.

H.1.6.5. Oracle Bugs

This is the list of Oracle bugs that affect or have affected oracle_fdw in the past.

Bug 2728408 can cause “ORA-8177 cannot serialize access for this transaction” even if no modification of remote data is attempted. It can occur with Oracle server 8.1.7.4 (install one-off patch 2728408) or Oracle server 9.2 (install Patch Set 9.2.0.4 or better).

Oracle client 21c is known not to work for `CLOB` columns (they appear empty). There is no ultimate proof that that is an Oracle bug, but other versions are working fine.

H.1.7. Authors

Laurenz Albe, with notable contributions from Vincent Mora of Oslandia and Tatsuro Yamada of the NTT OSS Center.

H.2. tds_fdw

The `tds_fdw` module provides the foreign data wrapper tds_fdw, which can connect to databases that use the Tabular Data Stream (TDS) protocol, such as *Sybase* databases and *Microsoft SQL Server*.

This foreign data wrapper requires a library that implements the DB-Library interface, such as FreeTDS. This has been tested with FreeTDS, but not the proprietary implementations of DB-Library.

H.2.1. Limitations

Unlike `WHERE` and column pushdowns, which are supported when `match_column_names` is enabled, `JOIN` pushdown or write operations are not supported.

H.2.2. Installing tds_fdw

tds_fdw is provided with Postgres Pro Enterprise as a separate pre-built package `tds-fdw` (for the detailed installation instructions, see Chapter 17).

Install the `tds_fdw` extension using CREATE EXTENSION.

H.2.3. Configuring tds_fdw

H.2.3.1. Managing Character Sets/Encoding

Although many newer versions of the TDS protocol will only use USC-2 to communicate with the server, FreeTDS converts the UCS-2 to the client character set of your choice. To set the client character set, you can set `client charset` in `freetds.conf`. See *The `freetds.conf` File* and *Localization and TDS 7.0* for details.

You may need more configuring in case you get an error like this with Microsoft SQL Server when working with Unicode data:

```
NOTICE: DB-Library notice: Msg #: 4004, Msg state: 1, Msg: Unicode data in a Unicode-only
collation or ntext data cannot be sent to clients using DB-Library (such as ISQL) or ODBC
version 3.7 or earlier., Server: PILLIUM\SQLEXPRESS, Process: , Line: 1, Level: 16

ERROR: DB-Library error: DB #: 4004, DB Msg: General SQL Server error: Check messages
from the SQL Server, OS #: -1, OS Msg: (null), Level: 16
```

In this case, you may have to manually set tds version in `freetds.conf` to 7.0 or higher. See *The `freetds.conf` File* and *Choosing a TDS protocol version* for details.

H.2.3.2. Configuring Encrypted Connections to MSSQL

This needs to be configured at the `freetds.conf`. See *The `freetds.conf` File* and under `freetds.conf settings`, look for encryption.

H.2.4. Usage

To prepare for database access using tds_fdw:

1. Create a foreign server object, using CREATE SERVER, to represent each database you want to connect to.
2. Create a user mapping, using CREATE USER MAPPING, for each database user you want to allow to access each foreign server.
3. Create a foreign table, using CREATE FOREIGN TABLE or IMPORT FOREIGN SCHEMA, for each table you want to access.

H.2.4.1. Creating a Foreign Server

To create a foreign server, execute the CREATE SERVER command providing the following options:

`servername`

The servername, address or hostname of the foreign server. This can be a DSN, as specified in `freetds.conf`. See *FreeTDS name lookup* for details. You can set this option to a comma-separated list of server names, then each server is tried until the first connection succeeds. This is useful for automatic failover to a secondary server.

Required: Yes

Default: 127.0.0.1

`port`

The port of the foreign server. Instead of providing a port here, it can be specified in `freetds.conf` (if `servername` is a DSN).

Required: No

`database`

The database to connect to for this server

Required: No

`dbuse`

If `dbuse` is 0, tds_fdw will connect directly to `database`. If `dbuse` is not 0, tds_fdw will connect to the server's default database and then select the database by calling the DB-Library's `dbuse()` function. For Azure, `dbuse` currently needs to be set to 0.

Required: No

Default: 0

`language`

The language to use for messages and the locale to use for date formats. FreeTDS may default to U.S. English on most systems. You can probably also change this in `freetds.conf`. For information related to this for MS SQL Server, see *`SET LANGUAGE` in MS SQL Server*. For information related to Sybase ASE, see *Sybase ASE login options* and *`SET LANGUAGE` in Sybase ASE*.

Required: No

`character_set`

The client character set to use for the connection if you need to set this for some reason. For TDS protocol versions 7.0+, the connection always uses UCS-2, so this parameter does nothing in those cases. See *Localization and TDS 7.0* for details.

Required: No

`tds_version`

The version of the TDS protocol to use for this server. See *Choosing a TDS protocol version* and *History of TDS Versions* for details.

Required: No

`msg_handler`

The function used for the TDS message handler. Can be one of the following values:

- `notice`: TDS messages are turned into PostgreSQL notices
- `blackhole`: TDS messages are ignored

Required: No

Default: `blackhole`

`fdw_startup_cost`

A cost that is used in query planning to represent the overhead of using this foreign data wrapper.

Required: No

`fdw_tuple_cost`

A cost that is used in query planning to represent the overhead of fetching rows from this server.

Required: No

`sqlserver_ansi_mode`

A cost that is used to represent the overhead of fetching rows from this server used in query planning.

This option is supported for SQL Server only. Setting this to `true` will enable the following server-side settings after a successful connection to the foreign server:

- `CONCAT_NULLS_YIELDS_NULL ON`
- `ANSI_NULLS ON`
- `ANSI_WARNINGS ON`
- `QUOTED_IDENTIFIER ON`
- `ANSI_PADDING ON`
- `ANSI_NULL_DFLT_ON ON`

Those parameters in summary are comparable to the SQL Server option `ANSI_DEFAULTS`. In contrast, `sqlserver_ansi_mode` currently does not activate the following options:

- `CURSOR_CLOSE_ON_COMMIT`
- `IMPLICIT_TRANSACTIONS`

This follows the behavior of the native ODBC and OLEDB driver for SQL servers, which explicitly turn them off if not configured otherwise.

Required: No

Default: `false`

Some foreign table options can also be set at the server level. Those include:

- `use_remote_estimate`
- `row_estimate_method`

Example H.1. Create a Foreign Server

```
CREATE SERVER mssql_svr
    FOREIGN DATA WRAPPER tds_fdw
    OPTIONS (servername '127.0.0.1', port '1433', database 'tds_fdw_test', tds_version
 '7.1');
```

H.2.4.2. Creating a User Mapping

To create a user mapping, execute the CREATE USER MAPPING command providing the following options:

`username`

The username of the account on the foreign server

> **Important**
>
> If you are using Azure SQL, then your username for the foreign server will need to be in the format `username@servername`. If you only use the username, the authentication will fail.

Required: Yes

`password`

The password of the account on the foreign server

Required: Yes

Example H.2. Create a User Mapping

```
CREATE USER MAPPING FOR postgres
    SERVER mssql_svr
    OPTIONS (username 'sa', password '');
```

H.2.4.3. Creating a Foreign Table

To create a foreign table, execute the CREATE FOREIGN TABLE command providing the following options:

`query`

The query string to use to query the foreign table

Required: Yes (mutually exclusive with `table_name`)

`schema_name`

The schema that the table is in. The schema name can also be included in `table_name`.

Required: No

`table_name`

The table on the foreign server to query

Aliases: *table*

Required: Yes (mutually exclusive with `query`)

`match_column_names`

Match local columns with remote columns by comparing their table names instead of using the order in which they appear in the result set. Required for `WHERE` and column pushdowns.

Required: No

`use_remote_estimate`

Estimate the size of the table by performing some operation on the remote server, as defined by `row_estimate_method`, instead of using the local estimate, as defined by `local_tuple_estimate`

Required: No

`local_tuple_estimate`

A locally set estimate of the number of tuples that is used when `use_remote_estimate` is disabled

Required: No

`row_estimate_method`

Can be one of the following values:

- `execute`: Execute the query on the remote server and get the actual number of rows in the query
- `showplan_all`: Get the estimated number of rows using *MS SQL Server's* *`SET SHOWPLAN_ALL`*

Required: No

Default: `execute`

Example H.3. Create a Foreign Table

Using a `table_name` definition:

```
CREATE FOREIGN TABLE mssql_table (
    id integer,
    data varchar)
    SERVER mssql_svr
    OPTIONS (table_name 'dbo.mytable', row_estimate_method 'showplan_all');
```

Using a `schema_name` and `table_name` definition:

```
CREATE FOREIGN TABLE mssql_table (
    id integer,
    data varchar)
    SERVER mssql_svr
    OPTIONS (schema_name 'dbo', table_name 'mytable', row_estimate_method
 'showplan_all');
```

Using a `query` definition:

```
CREATE FOREIGN TABLE mssql_table (
    id integer,
    data varchar)
    SERVER mssql_svr
    OPTIONS (query 'SELECT * FROM dbo.mytable', row_estimate_method 'showplan_all');
```

Setting a remote column name:

```
CREATE FOREIGN TABLE mssql_table (
    id integer,
    col2 varchar OPTIONS (column_name 'data'))
    SERVER mssql_svr
    OPTIONS (schema_name 'dbo', table_name 'mytable', row_estimate_method
 'showplan_all');
```

H.2.4.4. Importing a Foreign Schema

To import a foreign schema, execute the IMPORT FOREIGN SCHEMA command providing the following options:

`import_default`

Controls whether column `DEFAULT` expressions are included in the definitions of foreign tables

Required: No

Default: false

`import_not_null`

Controls whether column `NOT NULL` constraints are included in the definitions of foreign tables

Required: No

Default: true

Example H.4. Import a Foreign Schema

```
IMPORT FOREIGN SCHEMA dbo
    EXCEPT (mssql_table)
    FROM SERVER mssql_svr
```

```
    INTO public
    OPTIONS (import_default 'true');
```

H.2.4.5. Setting Variables

To set a variable, execute the SET command.

The following variables are available:

`tds_fdw.show_before_row_memory_stats`

Print memory context stats to the Postgres Pro log before each row is fetched

`tds_fdw.show_after_row_memory_stats`

Print memory context stats to the Postgres Pro log after each row is fetched

`tds_fdw.show_finished_memory_stats`

Print memory context stats to the Postgres Pro log when a query is finished

Example H.5. Set a Variable

```
postgres=# SET tds_fdw.show_finished_memory_stats=1;
SET
```

H.2.4.6. Viewing the Query Issued on the Remote System

To view the query issued on the remote system, execute the EXPLAIN `[ VERBOSE ]` command.

H.2.5. Author

Geoff Montee

Appendix I. Additional Supplied Programs

This appendix, Appendix F, and Appendix G contain information regarding additional modules available in the Postgres Pro Enterprise distribution. See Appendix F and Appendix G for more information about the server extensions and plug-ins.

This appendix covers the utility programs. Once installed, they are found in the `bin` directory of the Postgres Pro Enterprise installation and can be used like any other program.

I.1. Additional PostgreSQL/Postgres Pro Client Applications

This section covers PostgreSQL/Postgres Pro additional client applications included in the Postgres Pro Enterprise distribution. They can be run from anywhere, independent of where the database server resides. See also Postgres Pro Client Applications for information about client applications that are part of the core Postgres Pro Enterprise distribution.

oid2name

oid2name — resolve OIDs and file nodes in a Postgres Pro data directory

Synopsis

`oid2name` [*option*...]

Description

oid2name is a utility program that helps administrators to examine the file structure used by Postgres Pro. To make use of it, you need to be familiar with the database file structure, which is described in Chapter 70.

> **Note**
>
> The name “oid2name” is historical, and is actually rather misleading, since most of the time when you use it, you will really be concerned with tables' filenode numbers (which are the file names visible in the database directories). Be sure you understand the difference between table OIDs and table filenodes!

oid2name connects to a target database and extracts OID, filenode, and/or table name information. You can also have it show database OIDs or tablespace OIDs.

Options

oid2name accepts the following command-line arguments:

`-f` *`filenode`*
`--filenode=`*`filenode`*

show info for table with filenode *`filenode`*.

`-i`
`--indexes`

include indexes and sequences in the listing.

`-o` *`oid`*
`--oid=`*`oid`*

show info for table with OID *`oid`*.

`-q`
`--quiet`

omit headers (useful for scripting).

`-s`
`--tablespaces`

show tablespace OIDs.

`-S`
`--system-objects`

include system objects (those in `information_schema`, `pg_toast` and `pg_catalog` schemas).

`-t` *`tablename_pattern`*
`--table=`*`tablename_pattern`*

show info for table(s) matching *`tablename_pattern`*.

`-V`
`--version`

Print the oid2name version and exit.

`-x`
`--extended`

display more information about each object shown: tablespace name, schema name, and OID.

`-?`
`--help`

Show help about oid2name command line arguments, and exit.

oid2name also accepts the following command-line arguments for connection parameters:

`-d` *database*
`--dbname=`*database*

database to connect to.

`-h` *host*
`--host=`*host*

database server's host.

`-H` *host*

database server's host. Use of this parameter is *deprecated* as of Postgres Pro 12.

`-p` *port*
`--port=`*port*

database server's port.

`-U` *username*
`--username=`*username*

user name to connect as.

To display specific tables, select which tables to show by using `-o`, `-f` and/or `-t`. `-o` takes an OID, `-f` takes a filenode, and `-t` takes a table name (actually, it's a `LIKE` pattern, so you can use things like `foo%`). You can use as many of these options as you like, and the listing will include all objects matched by any of the options. But note that these options can only show objects in the database given by `-d`.

If you don't give any of `-o`, `-f` or `-t`, but do give `-d`, it will list all tables in the database named by `-d`. In this mode, the `-S` and `-i` options control what gets listed.

If you don't give `-d` either, it will show a listing of database OIDs. Alternatively you can give `-s` to get a tablespace listing.

Environment

`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

oid2name requires a running database server with non-corrupt system catalogs. It is therefore of only limited use for recovering from catastrophic database corruption situations.

Examples

```
$ # what's in this database server, anyway?
$ oid2name
All databases:
    Oid  Database Name  Tablespace
----------------------------------
  17228       alvherre  pg_default
  17255     regression  pg_default
  17227      template0  pg_default
      1      template1  pg_default

$ oid2name -s
All tablespaces:
     Oid  Tablespace Name
-------------------------
    1663       pg_default
    1664        pg_global
  155151         fastdisk
  155152          bigdisk

$ # OK, let's look into database alvherre
$ cd $PGDATA/base/17228

$ # get top 10 db objects in the default tablespace, ordered by size
$ ls -lS * | head -10
-rw-------  1 alvherre alvherre 136536064 sep 14 09:51 155173
-rw-------  1 alvherre alvherre  17965056 sep 14 09:51 1155291
-rw-------  1 alvherre alvherre   1204224 sep 14 09:51 16717
-rw-------  1 alvherre alvherre    581632 sep  6 17:51 1255
-rw-------  1 alvherre alvherre    237568 sep 14 09:50 16674
-rw-------  1 alvherre alvherre    212992 sep 14 09:51 1249
-rw-------  1 alvherre alvherre    204800 sep 14 09:51 16684
-rw-------  1 alvherre alvherre    196608 sep 14 09:50 16700
-rw-------  1 alvherre alvherre    163840 sep 14 09:50 16699
-rw-------  1 alvherre alvherre    122880 sep  6 17:51 16751

$ # I wonder what file 155173 is ...
$ oid2name -d alvherre -f 155173
From database "alvherre":
  Filenode  Table Name
----------------------
    155173    accounts

$ # you can ask for more than one object
$ oid2name -d alvherre -f 155173 -f 1155291
From database "alvherre":
  Filenode     Table Name
------------------------
    155173       accounts
   1155291  accounts_pkey

$ # you can mix the options, and get more details with -x
$ oid2name -d alvherre -t accounts -f 1155291 -x
```

```
From database "alvherre":
  Filenode     Table Name      Oid  Schema  Tablespace
-----------------------------------------------------
    155173       accounts   155173  public  pg_default
   1155291  accounts_pkey  1155291  public  pg_default

$ # show disk space for every db object
$ du [0-9]* |
> while read SIZE FILENODE
> do
>   echo "$SIZE       `oid2name -q -d alvherre -i -f $FILENODE`"
> done
16            1155287  branches_pkey
16            1155289  tellers_pkey
17561            1155291  accounts_pkey
...

$ # same, but sort by size
$ du [0-9]* | sort -rn | while read SIZE FN
> do
>   echo "$SIZE   `oid2name -q -d alvherre -f $FN`"
> done
133466             155173    accounts
17561            1155291  accounts_pkey
1177              16717  pg_proc_proname_args_nsp_index
...

$ # If you want to see what's in tablespaces, use the pg_tblspc directory
$ cd $PGDATA/pg_tblspc
$ oid2name -s
All tablespaces:
     Oid  Tablespace Name
------------------------
    1663       pg_default
    1664        pg_global
  155151         fastdisk
  155152          bigdisk

$ # what databases have objects in tablespace "fastdisk"?
$ ls -d 155151/*
155151/17228/  155151/PG_VERSION

$ # Oh, what was database 17228 again?
$ oid2name
All databases:
    Oid  Database Name  Tablespace
----------------------------------
  17228       alvherre  pg_default
  17255     regression  pg_default
  17227      template0  pg_default
      1      template1  pg_default

$ # Let's see what objects does this database have in the tablespace.
$ cd 155151/17228
$ ls -l
total 0
-rw-------  1 postgres postgres 0 sep 13 23:20 155156
```

```
$ # OK, this is a pretty small table ... but which one is it?
$ oid2name -d alvherre -f 155156
From database "alvherre":
  Filenode  Table Name
----------------------
    155156         foo
```

Author

B. Palmer <bpalmer@crimelabs.net>

pg_probackup

pg_probackup — manage backup and recovery of Postgres Pro Enterprise database clusters

Synopsis

pg_probackup version

pg_probackup help [*command*]

pg_probackup init -B *backup_dir* --skip-if-exists

pg_probackup add-instance -B *backup_dir* -D *data_dir* --instance *instance_name* --skip-if-exists

pg_probackup del-instance -B *backup_dir* --instance *instance_name*

pg_probackup set-config -B *backup_dir* --instance *instance_name* [*option*...]

pg_probackup set-backup -B *backup_dir* --instance *instance_name* -i *backup_id* [*option*...]

pg_probackup show-config -B *backup_dir* --instance *instance_name* [*option*...]

pg_probackup show -B *backup_dir* [*option*...]

pg_probackup backup -B *backup_dir* --instance *instance_name* -b *backup_mode* [*option*...]

pg_probackup restore -B *backup_dir* --instance *instance_name* [*option*...]

pg_probackup checkdb -B *backup_dir* --instance *instance_name* -D *data_dir* [option...]

pg_probackup validate -B *backup_dir* [*option*...]

pg_probackup merge -B *backup_dir* --instance *instance_name* -i *backup_id* [*option*...]

pg_probackup delete -B *backup_dir* --instance *instance_name* { -i *backup_id* | --delete-wal | --delete-expired | --merge-expired } [*option*...]

pg_probackup archive-push -B *backup_dir* --instance *instance_name* --wal-file-path *wal_file_path* --wal-file-name *wal_file_name* [*option*...]

pg_probackup archive-get -B *backup_dir* --instance *instance_name* --wal-file-path *wal_file_path* --wal-file-name *wal_file_name* [*option*...]

pg_probackup catchup -b *catchup_mode* --source-pgdata=*path_to_pgdata_on_remote_server* --destination-pgdata=*path_to_local_dir* [*option*...]

pg_probackup maintain -B *backup_dir* --instance *instance-name* [--backup-id *backup_id*] --status-sync [*option*...]

Description

pg_probackup is a utility to manage backup and recovery of Postgres Pro database clusters. It is designed to perform periodic backups of the Postgres Pro instance that enable you to restore the server in case of a failure. pg_probackup supports PostgreSQL 11 or higher. In Postgres Pro Enterprise, pg_probackup provides S3 (Simple Storage Service) support for storing data in private clouds.

> **Note**
>
> pg_probackup provides complete processing of S3 interface logging.

- Overview
- Quick Start
- Installation and Setup
- Command-Line Reference
- Usage

Overview

As compared to other backup solutions, pg_probackup offers the following benefits that can help you implement different backup strategies and deal with large amounts of data:

- S3 support for storing data in private clouds using MinIO object storage, Amazon S3 storage, and VK Cloud storage: provided in Postgres Pro Enterprise. Backup data is transferred to and from S3 without saving it in intermediate locations thus eliminating the need of having a large temporary storage.
- Incremental backup: with three different incremental modes, you can plan the backup strategy in accordance with your data flow. Incremental backups allow you to save disk space and speed up backup as compared to taking full backups. It is also faster to restore the cluster by applying incremental backups than by replaying WAL files.
- Incremental restore: speed up restore from a backup by reusing valid unchanged pages available in PGDATA.
- CFS (Compressed File System) support for incremental backups in `DELTA`, `PAGE`, and `PTRACK` (the fastest) modes: provided in Postgres Pro Enterprise.
- Validation: automatic data consistency checks and on-demand backup validation without actual data recovery.
- Verification: on-demand verification of Postgres Pro instance with the `checkdb` command.
- Retention: managing WAL archive and backups in accordance with retention policy. You can configure retention policy based on recovery time or the number of backups to keep, as well as specify time to live (TTL) for a particular backup. Expired backups can be merged or deleted.
- Parallelization: running `backup`, `restore`, `merge`, `delete`, `validate`, and `checkdb` processes on multiple parallel threads.
- Compression: storing backup data in a compressed state to save disk space.
- Deduplication: saving disk space by excluding non-data files (such as `_vm` or `_fsm`) from incremental backups if these files have not changed since they were copied into one of the previous backups in this incremental chain.
- Remote operations: backing up Postgres Pro instance located on a remote system or restoring a backup remotely.
- Backups from a standby: avoiding extra load on the primary by taking backups from a standby server.
- External directories: backing up files and directories located outside of the Postgres Pro data directory (`PGDATA`), such as scripts, configuration files, logs, or SQL dump files.
- Backup catalog: getting the list of backups and the corresponding meta information in plain text or JSON formats.
- Archive catalog: getting the list of all WAL timelines and the corresponding meta information in plain text or JSON formats.
- Partial restore: restoring only the specified databases.
- Catchup: cloning a Postgres Pro instance for a fallen-behind standby server to “catch up” with the primary.

To manage backup data, pg_probackup creates a *backup catalog*. This is a directory that stores all backup files with additional meta information, as well as WAL archives required for point-in-time recovery. You can store backups for different instances in separate subdirectories of a single backup catalog.

Using pg_probackup, you can take full or incremental backups:

- FULL backups contain all the data files required to restore the database cluster.
- Incremental backups operate at the page level, only storing the data that has changed since the previous backup. It allows you to save disk space and speed up the backup process as compared to

taking full backups. It is also faster to restore the cluster by applying incremental backups than by replaying WAL files. pg_probackup supports the following modes of incremental backups:

- DELTA backup. In this mode, pg_probackup reads all data files in the data directory and copies only those pages that have changed since the previous backup. This mode can impose read-only I/O pressure equal to a full backup.
- PAGE backup. In this mode, pg_probackup scans all WAL files in the archive from the moment the previous full or incremental backup was taken. Newly created backups contain only the pages that were mentioned in WAL records. This requires all the WAL files since the previous backup to be present in the WAL archive. If the size of these files is comparable to the total size of the database cluster files, speedup is smaller, but the backup still takes less space. You have to configure WAL archiving as explained in Setting up continuous WAL archiving to make PAGE backups.
- PTRACK backup. In this mode, Postgres Pro tracks page changes on the fly. Continuous archiving is not necessary for it to operate. Each time a relation page is updated, this page is marked in a special PTRACK bitmap. Tracking implies some minor overhead on the database server operation, but speeds up incremental backups significantly.

> **Warning**
>
> After promoting a standby server to primary and switching timelines, take the first backup in **either FULL or DELTA mode**. Using other backup modes in this case may result in data corruption.

pg_probackup can take only physical online backups, and online backups require WAL for consistent recovery. So regardless of the chosen backup mode (FULL, PAGE or DELTA), any backup taken with pg_probackup must use one of the following *WAL delivery modes*:

- ARCHIVE. Such backups rely on continuous archiving to ensure consistent recovery. This is the default WAL delivery mode.
- STREAM. Such backups include all the files required to restore the cluster to a consistent state at the time the backup was taken. Regardless of continuous archiving having been set up or not, the WAL segments required for consistent recovery are streamed via replication protocol during backup and included into the backup files. That's why such backups are called *autonomous*, or *standalone*.

Limitations

pg_probackup currently has the following limitations:

- The remote mode is not supported on Windows systems.
- On Unix systems, for Postgres Pro, a backup can be made only by the same OS user that has started the Postgres Pro server. For example, if Postgres Pro server is started by user `postgres`, the `backup` command must also be run by user `postgres`. To satisfy this requirement when taking backups in the remote mode using SSH, you must set `--remote-user` option to `postgres`.
- The Postgres Pro server from which the backup was taken and the restored server must be compatible by the block_size and wal_block_size parameters and have the same major release number. Depending on cluster configuration, Postgres Pro itself may apply additional restrictions, such as CPU architecture or libc/icu versions.
- Special limitations of pg_probackup in Postgres Pro Enterprise:
  - Incremental backup and restore for CFS tablespaces require ptrack 2.4.0 or higher.
  - Only the following commands can be launched in the remote mode: add-instance, backup, restore, delete, catchup, archive-push, and archive-get.

Quick Start

To quickly get started with pg_probackup, complete the steps below. This will set up FULL and DELTA backups in the remote mode and demonstrate some basic pg_probackup operations. In the following, these terms are used:

- `backup` — Postgres Pro role used to connect to the Postgres Pro cluster.
- `backupdb` — database used to connect to the Postgres Pro cluster.
- `backup_host` — host with the backup catalog.
- `backup_user` — user on `backup_host` running all pg_probackup operations.
- `/mnt/backups` — directory on `backup_host` where the backup catalog is stored.
- `postgres_host` — host with the Postgres Pro cluster.
- `postgres` — user on `postgres_host` under which Postgres Pro cluster processes are running.
- `/var/lib/pgpro/std-16/data` — Postgres Pro data directory on `postgres_host`.

Steps to perform:

1. Install pg_probackup on both `backup_host` and `postgres_host`.
2. Set up an SSH connection from `backup_host` to `postgres_host`.
3. Configure your database cluster for STREAM backups.
4. Initialize the backup catalog:

```
backup_user@backup_host:~$ pg_probackup init -B /mnt/backups
INFO: Backup catalog '/mnt/backups' successfully initialized
```

5. Add a backup instance called `mydb` to the backup catalog:

```
backup_user@backup_host:~$ pg_probackup add-instance \
    -B /mnt/backups \
    -D /var/lib/pgpro/std-16/data \
    --instance=node \
    --remote-host=postgres_host \
    --remote-user=postgres
INFO: Instance 'node' successfully initialized
```

6. Make a FULL backup:

```
backup_user@backup_host:~$ pg_probackup backup \
    -B /mnt/backups \
    -b FULL \
    --instance=node \
    --stream \
    --compress-algorithm=zstd \
    --remote-host=postgres_host \
    --remote-user=postgres \
    -U backup \
    -d backupdb
INFO: Backup start, pg_probackup version: 2.7.3, instance: node, backup ID: SBOL6J,
 backup mode: FULL, wal mode: STREAM, remote: true, compress-algorithm: zstd,
 compress-level: 1
WARNING:  pgpro_edition() function is old-style and will be removed in future major
 release, use pgpro_edition GUC variable instead.
INFO: This PostgreSQL instance was initialized with data block checksums. Data
 block corruption will be detected
INFO: Database backup start
INFO: wait for pg_backup_start()
INFO: PGDATA size: 96MB
INFO: Current Start LSN: 0/8000028, TLI: 1
INFO: Start transferring data files
INFO: Data files are transferred, time elapsed: 2s
INFO: wait for pg_stop_backup()
INFO: pg_stop_backup() successfully executed
INFO: stop_stream_lsn 0/9000000 currentpos 0/9000000
INFO: backup->stop_lsn 0/8004E40
INFO: Getting the Recovery Time from WAL
```

```
INFO: Syncing backup files to disk
INFO: Backup files are synced, time elapsed: 1s
INFO: Validating backup SBOL6J
INFO: Backup SBOL6J data files are valid
INFO: Backup SBOL6J resident size: 53MB
INFO: Backup SBOL6J completed
```

7. List the backups of the instance:

```
backup_user@backup_host:~$ pg_probackup show \
        -B /mnt/backups \
        --instance=node
========================================================================================
 Instance  Version  ID      Recovery Time                  Mode  WAL Mode  TLI
 Time  Data   WAL  Zalg  Zratio  Start LSN  Stop LSN   Status
========================================================================================
 node      17       SBOL6J  2024-04-09 18:18:21.970314+03  FULL  STREAM    1/0
 4s  37MB  16MB  zstd    2.57  0/8000028  0/8004E40  OK
```

8. Make an incremental backup in the DELTA mode:

```
backup_user@backup_host:~$ pg_probackup backup \
    -B /mnt/backups \
    -b DELTA \
    --instance=node \
    --stream \
    --compress-algorithm=zstd \
    --remote-host=postgres_host \
    --remote-user=postgres \
    -U backup \
    -d backupdb
INFO: Backup start, pg_probackup version: 2.7.3, instance: node, backup ID: SBOL6N,
 backup mode: DELTA, wal mode: STREAM, remote: true, compress-algorithm: zstd,
 compress-level: 1
WARNING:  pgpro_edition() function is old-style and will be removed in future major
 release, use pgpro_edition GUC variable instead.
INFO: This PostgreSQL instance was initialized with data block checksums. Data
 block corruption will be detected
INFO: Database backup start
INFO: wait for pg_backup_start()
INFO: Parent backup: SBOL6J
INFO: PGDATA size: 96MB
INFO: Current Start LSN: 0/9000028, TLI: 1
INFO: Parent Start LSN: 0/8000028, TLI: 1
INFO: Start transferring data files
INFO: Data files are transferred, time elapsed: 1s
INFO: wait for pg_stop_backup()
INFO: pg_stop_backup() successfully executed
INFO: stop_stream_lsn 0/A000000 currentpos 0/A000000
INFO: backup->stop_lsn 0/9000190
INFO: Getting the Recovery Time from WAL
INFO: Syncing backup files to disk
INFO: Backup files are synced, time elapsed: 0
INFO: Validating backup SBOL6N
INFO: Backup SBOL6N data files are valid
INFO: Backup SBOL6N resident size: 17MB
INFO: Backup SBOL6N completed
```

9. Add or modify some parameters in the pg_probackup configuration file, so that you do not have to specify them each time on the command line:

```
backup_user@backup_host:~$ pg_probackup set-config \
    -B /mnt/backups \
    --instance=node \
    --remote-host=postgres_host \
    --remote-user=postgres \
    -U backup \
    -d backupdb
```

10. Check the configuration of the instance:

```
backup_user@backup_host:~$ pg_probackup show-config \
    -B /mnt/backups \
    --instance=node
# Backup instance information
pgdata = /var/lib/pgpro/std-16/data
system-identifier = 7355886958826772732
xlog-seg-size = 16777216
# Connection parameters
pgdatabase = backupdb
pghost = postgres_host
pguser = backup
# Archive parameters
archive-timeout = 5min
# Logging parameters
log-level-console = INFO
log-level-file = OFF
log-format-console = PLAIN
log-format-file = PLAIN
log-filename = pg_probackup.log
log-rotation-size = 0TB
log-rotation-age = 0d
# Retention parameters
retention-redundancy = 0
retention-window = 0
wal-depth = 0
# Compression parameters
compress-algorithm = none
compress-level = 1
# Remote access parameters
remote-proto = ssh
remote-host = postgres_host
remote-user = postgres
```

Note that the parameters not modified via `set-config` retain their default values.

11. Make another incremental backup in the DELTA mode, omitting the parameters stored in the configuration file earlier:

```
backup_user@backup_host:~$ pg_probackup backup \
    -B /mnt/backups \
    -b DELTA \
    --instance=node \
    --stream \
    --compress-algorithm=zstd
INFO: Backup start, pg_probackup version: 2.7.3, instance: node, backup ID: SBOL6P,
 backup mode: DELTA, wal mode: STREAM, remote: true, compress-algorithm: zstd,
 compress-level: 1
WARNING:  pgpro_edition() function is old-style and will be removed in future major
 release, use pgpro_edition GUC variable instead.
```

```
INFO: This PostgreSQL instance was initialized with data block checksums. Data
 block corruption will be detected
INFO: Database backup start
INFO: wait for pg_backup_start()
INFO: Parent backup: SBOL6N
INFO: PGDATA size: 96MB
INFO: Current Start LSN: 0/A000028, TLI: 1
INFO: Parent Start LSN: 0/9000028, TLI: 1
INFO: Start transferring data files
INFO: Data files are transferred, time elapsed: 1s
INFO: wait for pg_stop_backup()
INFO: pg_stop_backup() successfully executed
INFO: stop_stream_lsn 0/B000000 currentpos 0/B000000
INFO: backup->stop_lsn 0/A000190
INFO: Getting the Recovery Time from WAL
INFO: Syncing backup files to disk
INFO: Backup files are synced, time elapsed: 0
INFO: Validating backup SBOL6P
INFO: Backup SBOL6P data files are valid
INFO: Backup SBOL6P resident size: 17MB
INFO: Backup SBOL6P completed
```

12. List the backups of the instance again:

```
backup_user@backup_host:~$ pg_probackup show \
    -B /mnt/backups \
    --instance=node
========================================================================================
 Instance  Version  ID      Recovery Time                  Mode   WAL Mode  TLI
 Time    Data   WAL  Zalg  Zratio  Start LSN  Stop LSN   Status
========================================================================================
 node      17       SBOL6P  2024-04-09 18:18:26.630175+03  DELTA  STREAM    1/1
 1s  1147kB  16MB  zstd    1.00  0/A000028  0/A000190  OK
 node      17       SBOL6N  2024-04-09 18:18:25.015713+03  DELTA  STREAM    1/1
 2s  1160kB  16MB  zstd    1.04  0/9000028  0/9000190  OK
 node      17       SBOL6J  2024-04-09 18:18:21.970314+03  FULL   STREAM    1/0
 4s    37MB  16MB  zstd    2.57  0/8000028  0/8004E40  OK
```

13. Restore the data from the latest available backup to an arbitrary location:

```
backup_user@backup_host:~$ pg_probackup restore \
    -B /mnt/backups \
    -D /var/lib/pgpro/std-16/staging-data \
    --instance=node
INFO: Validating parents for backup SBOL6P
INFO: Validating backup SBOL6J
INFO: Backup SBOL6J data files are valid
INFO: Validating backup SBOL6N
INFO: Backup SBOL6N data files are valid
INFO: Validating backup SBOL6P
INFO: Backup SBOL6P data files are valid
INFO: Backup SBOL6P WAL segments are valid
INFO: Backup SBOL6P is valid.
INFO: Restoring the database from the backup starting at 2024-04-09 18:18:25+03 on
 localhost
INFO: Start restoring backup files. PGDATA size: 112MB
INFO: Backup files are restored. Transferred bytes: 112MB, time elapsed: 2s
INFO: Restore incremental ratio (less is better): 100% (112MB/112MB)
INFO: Syncing restored files to disk
```

```
INFO: Restored backup files are synced, time elapsed: 1s
INFO: Restore of backup SBOL6P completed.
```

Installation and Setup

Once you have pg_probackup installed, complete the following setup:

- Initialize the backup catalog.
- Add a new backup instance to the backup catalog.
- Configure the database cluster to enable pg_probackup backups.
- Optionally, configure SSH for running pg_probackup operations in the remote mode.
- Optionally, configure S3 for running pg_probackup connected to the S3 storage.

Initializing the Backup Catalog

pg_probackup stores all WAL and backup files in the corresponding subdirectories of the backup catalog.

To initialize the backup catalog, run the following command:

```
pg_probackup init -B backup_dir
```

where *backup_dir* is the path to the backup catalog. If the *backup_dir* already exists, it must be empty. Otherwise, pg_probackup returns an error.

The user launching pg_probackup must have full access to the *backup_dir* directory.

pg_probackup creates the *backup_dir* backup catalog, with the following subdirectories:

- `wal/` — directory for WAL files.
- `backups/` — directory for backup files.

Once the backup catalog is initialized, you can add a new backup instance.

Adding a New Backup Instance

pg_probackup can store backups for multiple database clusters in a single backup catalog. To set up the required subdirectories, you must add a backup instance to the backup catalog for each database cluster you are going to back up.

To add a new backup instance, run the following command:

```
pg_probackup add-instance -B backup_dir -D data_dir --instance=instance_name
 [remote_options]
```

Where:

- *data_dir* is the data directory of the cluster you are going to back up. To set up and use pg_probackup, write access to this directory is required.
- *instance_name* is the name of the subdirectories that will store WAL and backup files for this cluster.
- remote_options are optional parameters that need to be specified only if *data_dir* is located on a remote system.

pg_probackup creates the *instance_name* subdirectories under the `backups/` and `wal/` directories of the backup catalog. The `backups/`*instance_name* directory contains the `pg_probackup.conf` configuration file that controls pg_probackup settings for this backup instance. If you run this command with the remote_options, the specified parameters will be added to `pg_probackup.conf`.

For details on how to fine-tune pg_probackup configuration, see the section called “Configuring pg_probackup”.

The user launching pg_probackup must have full access to *backup_dir* directory and at least read-only access to *data_dir* directory. If you specify the path to the backup catalog in the `BACKUP_PATH` environment variable, you can omit the corresponding option when running pg_probackup commands.

> **Note**
>
> For Postgres Pro 11 or higher, it is recommended to use the group access feature, so that backups can be done by any OS user in the same group as the cluster owner. In this case, the user should have read permissions for the cluster directory.

Configuring the Database Cluster

Although pg_probackup can be used by a superuser, it is recommended to create a separate role with the minimum permissions required for the chosen backup strategy. In these configuration instructions, the `backup` role is used as an example.

For security reasons, it is recommended to run the configuration SQL queries below in a separate database.

```
postgres=# CREATE DATABASE backupdb;
postgres=# \c backupdb
```

To perform a backup, the following permissions for role `backup` are required only in the database **used for connection** to the Postgres Pro server.

For Postgres Pro versions 11 — 14:

```
BEGIN;
CREATE ROLE backup WITH LOGIN;
GRANT USAGE ON SCHEMA pg_catalog TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.current_setting(text) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.set_config(text, text, boolean) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_is_in_recovery() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_start_backup(text, boolean, boolean) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_stop_backup(boolean, boolean) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_create_restore_point(text) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_switch_wal() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_last_wal_replay_lsn() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.txid_current() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.txid_current_snapshot() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.txid_snapshot_xmax(txid_snapshot) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_control_checkpoint() TO backup;
COMMIT;
```

For Postgres Pro 15 or higher:

```
BEGIN;
CREATE ROLE backup WITH LOGIN;
GRANT USAGE ON SCHEMA pg_catalog TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.current_setting(text) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.set_config(text, text, boolean) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_is_in_recovery() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_backup_start(text, boolean) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_backup_stop(boolean) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_create_restore_point(text) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_switch_wal() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_last_wal_replay_lsn() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.txid_current() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.txid_current_snapshot() TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.txid_snapshot_xmax(txid_snapshot) TO backup;
GRANT EXECUTE ON FUNCTION pg_catalog.pg_control_checkpoint() TO backup;
COMMIT;
```

In the pg_hba.conf file, allow connection to the database cluster on behalf of the `backup` role.

Since pg_probackup needs to read cluster files directly, pg_probackup must be started by (or connected to, if used in the remote mode) the OS user that has read access to all files and directories inside the data directory (PGDATA) you are going to back up.

Depending on whether you plan to take standalone or archive backups, Postgres Pro cluster configuration will differ, as specified in the sections below. To back up the database cluster from a standby server, run pg_probackup in the remote mode, or create PTRACK backups, additional setup is required.

For details, see the sections Setting up STREAM Backups, Setting up continuous WAL archiving, Setting up Backup from Standby, Configuring the Remote Mode, Setting up Partial Restore, and Setting up PTRACK Backups.

Setting up STREAM Backups

To set up the cluster for STREAM backups, complete the following steps:

- If the backup role does not exist, create it with the REPLICATION privilege when Configuring the Database Cluster:

  ```
  CREATE ROLE backup WITH LOGIN REPLICATION;
  ```

- If the backup role already exists, grant it with the REPLICATION privilege:

  ```
  ALTER ROLE backup WITH REPLICATION;
  ```

- In the pg_hba.conf file, allow replication on behalf of the backup role.
- Make sure the parameter max_wal_senders is set high enough to leave at least one session available for the backup process.
- Set the parameter wal_level to be higher than minimal.

If you are planning to take PAGE backups in the STREAM mode or perform PITR with STREAM backups, you still have to configure WAL archiving, as explained in the section Setting up continuous WAL archiving.

Once these steps are complete, you can start taking FULL, PAGE, DELTA, and PTRACK backups in the STREAM WAL mode.

> **Note**
>
> If you are planning to rely on .pgpass for authentication when running backup in STREAM mode, then .pgpass must contain credentials for replication database, used to establish connection via replication protocol. Example: pghost:5432:replication:backup_user:my_strong_password

Setting up Continuous WAL Archiving

Making backups in the PAGE backup mode, performing PITR and making backups with the ARCHIVE WAL delivery mode require continuous WAL archiving to be enabled. To set up continuous archiving in the cluster, complete the following steps:

- Make sure the wal_level parameter is higher than minimal.
- If you are configuring archiving on the primary, archive_mode must be set to on or always. To perform archiving on a standby, set this parameter to always.
- Set the archive_command parameter, as follows:

  ```
  archive_command = '"install_dir/pg_probackup" archive-push -B "backup_dir" --
  instance=instance_name --wal-file-name=%f [remote_options]'
  ```

where *install_dir* is the installation directory of the pg_probackup version you are going to use, *backup_dir* and *instance_name* refer to the already initialized backup catalog instance for this database cluster, and remote_options only need to be specified to archive WAL on a remote host. For details about all possible archive-push parameters, see the section archive-push.

Once these steps are complete, you can start making backups in the ARCHIVE WAL mode, backups in the PAGE backup mode, as well as perform PITR.

You can view the current state of the WAL archive using the show command. For details, see the section called “Viewing WAL Archive Information”.

If you are planning to make PAGE backups and/or backups with ARCHIVE WAL mode from a standby server that generates a small amount of WAL traffic, without long waiting for WAL segment to fill up, consider setting the archive_timeout Postgres Pro parameter **on the primary**. The value of this parameter should be slightly lower than the `--archive-timeout` setting (5 minutes by default), so that there is enough time for the rotated segment to be streamed to a standby and sent to WAL archive before the backup is aborted because of `--archive-timeout`.

> **Note**
>
> Instead of using the archive-push command provided by pg_probackup, you can use any other tool to set up continuous archiving as long as it delivers WAL segments into *backup_dir*`/wal/`*instance_name* directory. If compression is used, it should be `gzip`, and `.gz` suffix in filename is mandatory.

> **Note**
>
> Instead of configuring continuous archiving by setting the `archive_mode` and `archive_command` parameters, you can opt for using the pg_receivewal utility. In this case, pg_receivewal `-D` *directory* option should point to *backup_dir*`/wal/`*instance_name* directory. pg_probackup supports WAL compression that can be done by pg_receivewal. “Zero Data Loss” archive strategy can be achieved only by using pg_receivewal.

Setting up Backups from a Standby

pg_probackup can take backups from a standby server. This requires the following additional setup:

- On the standby server, set the hot_standby parameter to `on`.
- On the primary server, set the full_page_writes parameter to `on`.
- To perform standalone backups on a standby, complete all the steps in section Setting up STREAM Backups.
- To perform archive backups on a standby, complete all steps in section Setting up continuous WAL archiving.

Once these steps are complete, you can start taking FULL, PAGE, DELTA, or PTRACK backups with appropriate WAL delivery mode: ARCHIVE or STREAM, from the standby server.

Backups from a standby server have the following limitations:

- If a standby is promoted to a primary during the backup process, the backup fails.
- All WAL records required for the backup must contain sufficient full-page writes. This requires you to enable `full_page_writes` on the primary, and not to use tools like pg_compresslog as archive_command to remove full-page writes from WAL files.

Setting up Cluster Verification

Logical verification of a database cluster requires the following additional setup. Role `backup` is used as an example:

- Install the amcheck or *amcheck_next* extension **in every database** of the cluster:

  ```
  CREATE EXTENSION amcheck;
  ```

- Grant the following permissions to the `backup` role **in every database** of the cluster:

```
GRANT SELECT ON TABLE pg_catalog.pg_am TO backup;
GRANT SELECT ON TABLE pg_catalog.pg_class TO backup;
GRANT SELECT ON TABLE pg_catalog.pg_database TO backup;
GRANT SELECT ON TABLE pg_catalog.pg_namespace TO backup;
GRANT SELECT ON TABLE pg_catalog.pg_extension TO backup;
GRANT EXECUTE ON FUNCTION bt_index_check(regclass) TO backup;
GRANT EXECUTE ON FUNCTION bt_index_check(regclass, bool) TO backup;
GRANT EXECUTE ON FUNCTION bt_index_check(regclass, bool, bool) TO backup;
```

Setting up Partial Restore

If you are planning to use partial restore, complete the following additional step:

- Grant the read-only access to `pg_catalog.pg_database` to the `backup` role only in the database **used for connection** to Postgres Pro server:

  ```
  GRANT SELECT ON TABLE pg_catalog.pg_database TO backup;
  ```

Configuring the Remote Mode

pg_probackup supports the remote mode that allows you to perform backup, restore and WAL archiving operations remotely. In this mode, the backup catalog is stored on a local system, while Postgres Pro instance to backup and/or to restore is located on a remote system. Currently the only supported remote protocol is SSH.

Set up SSH

If you are going to use pg_probackup in remote mode via SSH, complete the following steps:

1. Install pg_probackup on both systems: `backup_host` and `postgres_host`.
2. For communication between the hosts set up a passwordless SSH connection between the `backup_user` user on `backup_host` and the `postgres` user on `postgres_host`:

   ```
   backup_user@backup_host:~$ ssh-copy-id postgres@postgres_host
   ```

   Where:

   - `backup_host` is the system with *backup catalog*.
   - `postgres_host` is the system with the Postgres Pro cluster.
   - `backup_user` is the OS user on `backup_host` used to run pg_probackup.
   - `postgres` is the user on `postgres_host` under which Postgres Pro cluster processes are running. For Postgres Pro 11 or higher a more secure approach can be used thanks to group access feature.
3. If you are going to rely on continuous WAL archiving, set up a passwordless SSH connection between the `postgres` user on `postgres_host` and the `backup` user on `backup_host`:

   ```
   postgres@postgres_host:~$ ssh-copy-id backup_user@backup_host
   ```
4. Make sure pg_probackup on `postgres_host` can be located when a connection via SSH is made. For example, for Bash, you can modify `PATH` in `~/.bashrc` of the `postgres` user (above the line in `bashrc` that exits the script for non-interactive shells). Alternatively, for pg_probackup commands, specify the path to the directory containing the pg_probackup binary on `postgres_host` via the --remote-path option.

pg_probackup in the remote mode via SSH works as follows:

- Only the following commands can be launched in the remote mode: add-instance, backup, restore, delete, catchup, archive-push, and archive-get.
- Operating in remote mode requires pg_probackup binary to be installed on both local and remote systems. The versions of local and remote binary must be the same.
- When started in the remote mode, the main pg_probackup process on the local system connects to the remote system via SSH and launches one or more agent processes on the remote system, which are called *remote agents*. The number of remote agents is equal to the `-j`/`--threads` setting.

- The main pg_probackup process uses remote agents to access remote files and transfer data between local and remote systems.
- Remote agents try to minimize the network traffic and the number of round-trips between hosts.
- The main process is usually started on *backup_host* and connects to *postgres_host*, but in case of `archive-push` and `archive-get` commands the main process is started on *postgres_host* and connects to *backup_host*.
- Once data transfer is complete, remote agents are terminated and SSH connections are closed.
- If an error condition is encountered by a remote agent, then all agents are terminated and error details are reported by the main pg_probackup process, which exits with an error.
- Compression is always done on *postgres_host*, while decompression is always done on *backup_host*.

> **Note**
>
> You can impose *additional restrictions* on SSH settings to protect the system in the event of account compromise.

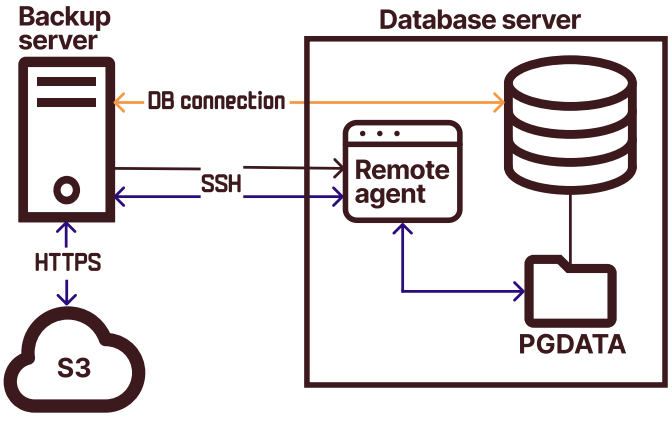
> **Note**
>
> Setting the number of threads (`-j`/`--threads` option) to a value greater than 10 for pg_probackup working in the remote mode via SSH may result in the actual number of SSH connections exceeding the maximum allowed number of simultaneous SSH connections on the remote server and consequently lead to an "ERROR: Agent error: kex_exchange_identification: Connection closed by remote host" error. To correct the error, either reduce the number of pg_probackup threads or adjust the value of `MaxStartups` configuration parameter of the remote SSH server. If SSH is set up as a xinetd service on the remote server, adjust the value of the xinetd `per_source` configuration parameter rather than `MaxStartups`.

Configuring S3 Connectivity

pg_probackup supports S3 interface for storing backups. Backup data is transferred to and from S3 without saving it in intermediate locations thus eliminating the need of having a large temporary storage.

An example configuration with a remote agent and a cloud storage (S3) is shown in Figure I.1.

Figure I.1. pg_probackup setup with a remote agent and S3



In this figure, the following logical components are shown:

Backup server

A server where the main process of pg_probackup runs and where local backups are stored.

Database server

A server with a database instance that needs to be backed up or restored.

Remote agent

A secondary pg_probackup process running on the database server. Only applicable to the remote mode.

Cloud storage

A cloud storage for backups.

Set up Access to S3 Storage

If you are going to use pg_probackup with S3 interface, complete the following steps:

- Create a bucket with a unique and meaningful name in the S3 storage for you future backups.
- Create ACCESS_KEY and SECRET_ACCESS_KEY tokens to be used for secure connectivity instead of your username and password.
- For communication between pg_probackup and S3 server, set values of environment variables corresponding to your S3 server. For example:

```
export PG_PROBACKUP_S3_HOST=127.0.0.1
export PG_PROBACKUP_S3_PORT=9000
export PG_PROBACKUP_S3_REGION=ru-msk
export PG_PROBACKUP_S3_BUCKET_NAME=test1
export PG_PROBACKUP_S3_ACCESS_KEY=admin
export PG_PROBACKUP_S3_SECRET_ACCESS_KEY=password
export PG_PROBACKUP_S3_HTTPS=ON
```

Alternatively, you can provide S3 server settings in the S3 configuration file (see the `--s3-config-file` option in the section S3 Options for details).

It makes sense to specify S3 server settings if `--s3=minio`, as described in the section S3 Options.

The following environment variables can be specified:

`PG_PROBACKUP_S3_HOST`

Address or list of addresses of the S3 server. A list of one or several semicolon-delimited addresses. Do not add a semicolon after the last address in the list. Each address can include the port number, separated by a colon. If the port number is not specified, the value of `PG_PROBACKUP_S3_PORT` is assumed. Do not add a colon if the port number is not specified.

For example:

```
export PG_PROBACKUP_S3_PORT=80
export PG_PROBACKUP_S3_HOST="127.0.0.1:9000;10.4.13.56:443;172.17.0.1"
```

In this example, for the “127.0.0.1” address, the port 9000 is explicitly specified, for “10.4.13.56”, the port 443 is specified, while for the “172.17.0.1” address, port 80, specified through `PG_PROBACKUP_S3_PORT`, will be used.

If any of the specified addresses gets unavailable while pg_probackup is in operation, requests to the S3 storage are distribited between the rest of the specified addresses. That is, when several addresses are specified, pg_probackup performs load balancing of S3 requests.

`PG_PROBACKUP_S3_PORT`

The port of the S3 server.

`PG_PROBACKUP_S3_REGION`

The region of the S3 server.

`PG_PROBACKUP_S3_BUCKET_NAME`

The name of the bucket on the S3 server.

`PG_PROBACKUP_S3_ACCESS_KEY`
`PG_PROBACKUP_S3_SECRET_ACCESS_KEY`

Secure tokens on the S3 server.

`PG_PROBACKUP_S3_HTTPS`

The protocol to be used. Possible values:

- `ON` or `HTTPS` — use HTTPS
- Other than `ON` or `HTTPS` — use HTTP

`PG_PROBACKUP_S3_BUFFER_SIZE`

The size of the read/write buffer for communicating with S3, in MiB. The default is `16`.

`PG_PROBACKUP_S3_RETRIES`

The maximum number of attempts to execute an S3 request in case of failures. The default is `3`.

`PG_PROBACKUP_S3_TIMEOUT`

The maximum amount of time to execute an HTTP request to the S3 server, in seconds. The default is `300`.

`PG_PROBACKUP_S3_IGNORE_CERT_VER`

Don't verify the certificate host and peer. The default is `ON`.

`PG_PROBACKUP_S3_CA_CERTIFICATE`

Specify the path to file with trust Certificate Authority (CA) bundle.

`PG_PROBACKUP_S3_CA_PATH`

Specify the directory with trust CA certificates.

`PG_PROBACKUP_S3_CLIENT_CERT`

Setup SSL client certificate.

`PG_PROBACKUP_S3_CLIENT_KEY`

Setup private key file for TLS and SSL client certificate.

Setting up PTRACK Backups

> **Note**
>
> PTRACK versions lower than 2.0 are deprecated and not supported. Postgres Pro Standard and Postgres Pro Enterprise versions starting with 11.9.1 contain PTRACK 2.0. Upgrade your server to avoid issues in backups that you will take in future and be sure to take fresh backups of your clusters with the upgraded PTRACK since the backups taken with PTRACK 1.x might be corrupt.

If you are going to use PTRACK backups, complete the following additional steps.

> **Note**
>
> The permissions required for the role that will perform PTRACK backups (the `backup` role in the examples below) are listed in the section called “Configuring the Database Cluster”. The role must have permissions only in the database used for connection to the Postgres Pro server.

For Postgres Pro 11 or higher:

1. Create PTRACK extension in the database *used for connection* to the Postgres Pro server:

   ```
   CREATE EXTENSION ptrack;
   ```

2. To enable tracking page updates, set `ptrack.map_size` parameter to a positive integer and restart the server.

   For optimal performance, it is recommended to set `ptrack.map_size` to *`N / 1024`*, where *`N`* is the size of the Postgres Pro cluster, in MB. If you set this parameter to a lower value, PTRACK is more likely to map several blocks together, which leads to false-positive results when tracking changed blocks and increases the incremental backup size as unchanged blocks can also be copied into the incremental backup. Setting `ptrack.map_size` to a higher value does not affect PTRACK operation, but it is not recommended to set this parameter to a value higher than 1024.

> **Note**
>
> If you change the `ptrack.map_size` parameter value, the previously created PTRACK map file is cleared, and tracking newly changed blocks starts from scratch. Thus, you have to retake a full backup before taking incremental PTRACK backups after changing `ptrack.map_size`.

Usage

Creating a Backup

To create a backup, run the following command:

```
pg_probackup backup -B backup_dir --instance=instance_name -b backup_mode
```

Where *`backup_mode`* can take one of the following values: `FULL`, `DELTA`, `PAGE`, and `PTRACK`.

When restoring a cluster from an incremental backup, pg_probackup relies on the parent full backup and all the incremental backups between them, which is called “the backup chain”. Thus, to perform incremental backups, it is necessary to have the last parent full backup with the status `OK` or `DONE` in the directory. If the parent full backup has the `MERGING` or `MERGED` status, an incremental backup cannot be performed.

For example, if merge has already been launched with a single full backup, an attempt to perform an incremental backup will end with the following messages:

```
WARNING: Valid full backup on current timeline 1 is not found, trying to look up on
 previous timelines
WARNING: Cannot find valid backup on previous timelines
ERROR: Create new full backup before an incremental one
```

ARCHIVE Mode

ARCHIVE is the default WAL delivery mode.

For example, to make a FULL backup in ARCHIVE mode, run:

```
pg_probackup backup -B backup_dir --instance=instance_name -b FULL
```

ARCHIVE backups rely on continuous archiving to get WAL segments required to restore the cluster to a consistent state at the time the backup was taken.

When a backup is taken, pg_probackup ensures that WAL files containing WAL records between `Start LSN` and `Stop LSN` actually exist in *`backup_dir`*`/wal/`*`instance_name`* directory. pg_probackup also ensures that WAL records between `Start LSN` and `Stop LSN` can be parsed. This precaution eliminates the risk of silent WAL corruption.

STREAM Mode

STREAM is the optional WAL delivery mode.

For example, to make a FULL backup in the STREAM mode, add the `--stream` flag to the command from the previous example:

```
pg_probackup backup -B backup_dir --instance=instance_name -b FULL --stream --temp-slot
```

The optional `--temp-slot` flag ensures that the required segments remain available if the WAL is rotated before the backup is complete.

Unlike backups in ARCHIVE mode, STREAM backups include all the WAL segments required to restore the cluster to a consistent state at the time the backup was taken.

During backup pg_probackup streams WAL files containing WAL records between `Start LSN` and `Stop LSN` to *backup_dir*`/backups/`*instance_name*`/`*backup_id*`/database/pg_wal` directory. To eliminate the risk of silent WAL corruption, pg_probackup also checks that WAL records between `Start LSN` and `Stop LSN` can be parsed.

Even if you are using continuous archiving, STREAM backups can still be useful in the following cases:

- STREAM backups can be restored on the server that has no file access to WAL archive.
- STREAM backups enable you to restore the cluster state at the point in time for which WAL files in archive are no longer available.
- Backup in STREAM mode can be taken from a standby of a server that generates small amount of WAL traffic, without long waiting for WAL segment to fill up.

Page Validation

If data_checksums are enabled in the database cluster, pg_probackup uses this information to check correctness of data files during backup. While reading each page, pg_probackup checks whether the calculated checksum coincides with the checksum stored in the page header. This guarantees that the Postgres Pro instance and the backup itself have no corrupt pages. Note that pg_probackup reads database files directly from the filesystem, so under heavy write load during backup it can show false-positive checksum mismatches because of partial writes. If a page checksum mismatch occurs, the page is re-read and checksum comparison is repeated.

A page is considered corrupt if checksum comparison has failed more than 300 times. In this case, the backup is aborted.

Even if data checksums are not enabled, pg_probackup always performs sanity checks for page headers.

External Directories

To back up a directory located outside of the data directory, use the optional `--external-dirs` parameter that specifies the path to this directory. If you would like to add more than one external directory, you can provide several paths separated by colons on Linux systems or semicolons on Windows systems.

For example, to include `/etc/dir1` and `/etc/dir2` directories into the full backup of your *instance_name* instance that will be stored under the *backup_dir* directory on Linux, run:

```
pg_probackup backup -B backup_dir --instance=instance_name -b FULL --external-dirs=/
etc/dir1:/etc/dir2
```

Similarly, to include `C:\dir1` and `C:\dir2` directories into the full backup on Windows, run:

```
pg_probackup backup -B backup_dir --instance=instance_name -b FULL --external-dirs=C:
\dir1;C:\dir2
```

pg_probackup recursively copies the contents of each external directory into a separate subdirectory in the backup catalog. Since external directories included into different backups do not have to be the same, when you are restoring the cluster from an incremental backup, only those directories that belong to this particular backup will be restored. Any external directories stored in the previous backups will be ignored.

To include the same directories into each backup of your instance, you can specify them in the `pg_probackup.conf` configuration file using the set-config command with the `--external-dirs` option.

Performing Cluster Verification

To verify that Postgres Pro database cluster is not corrupt, run the following command:

```
pg_probackup checkdb [-B backup_dir [--instance=instance_name]] [-D data_dir]
 [connection_options]
```

This command performs physical verification of all data files located in the specified data directory by running page header sanity checks, as well as block-level checksum verification if checksums are enabled. If a corrupt page is detected, `checkdb` continues cluster verification until all pages in the cluster are validated.

By default, similar page validation is performed automatically while a backup is taken by pg_probackup. The `checkdb` command enables you to perform such page validation on demand, without taking any backup copies, even if the cluster is not backed up using pg_probackup at all.

To perform cluster verification, pg_probackup needs to connect to the cluster to be verified. In general, it is enough to specify the backup instance of this cluster for pg_probackup to determine the required connection options. However, if `-B` and `--instance` options are omitted, you have to provide connection options and *`data_dir`* via environment variables or command-line options.

Physical verification cannot detect logical inconsistencies, missing or nullified blocks and entire files, or similar anomalies. Extensions amcheck and *amcheck_next* provide a partial solution to these problems.

If you would like, in addition to physical verification, to verify all indexes in all databases using these extensions, you can specify the `--amcheck` flag when running the checkdb command:

```
pg_probackup checkdb -D data_dir --amcheck [connection_options]
```

You can skip physical verification by specifying the `--skip-block-validation` flag. In this case, you can omit *backup_dir* and *data_dir* options, only connection options are mandatory:

```
pg_probackup checkdb --amcheck --skip-block-validation [connection_options]
```

Logical verification can be done more thoroughly with the `--heapallindexed` flag by checking that all heap tuples that should be indexed are actually indexed, but at the higher cost of CPU, memory, and I/O consumption.

Validating a Backup

pg_probackup calculates checksums for each file in a backup during the backup process. The process of checking checksums of backup data files is called *the backup validation*. By default, validation is run immediately after the backup is taken and right before the restore, to detect possible backup corruption.

> **Note**
>
> The backup validation includes checking checksums for CFS files.

If you would like to skip backup validation, you can specify the `--no-validate` flag when running backup and restore commands.

To ensure that all the required backup files are present and can be used to restore the database cluster, you can run the validate command with the exact recovery target options you are going to use for recovery.

For example, to check that you can restore the database cluster from a backup copy up to transaction ID 4242, run this command:

```
pg_probackup validate -B backup_dir --instance=instance_name --recovery-target-xid=4242
```

If validation completes successfully, pg_probackup displays the corresponding message. If validation fails, you will receive an error message with the exact time, transaction ID, and LSN up to which the recovery is possible.

If you specify *backup_id* via `-i/--backup-id` option, then only the backup copy with specified backup ID will be validated. If *backup_id* is specified with recovery target options, the `validate` command will check whether it is possible to restore the specified backup to the specified recovery target.

For example, to check that you can restore the database cluster from a backup copy with the `SBOL6P` backup ID up to the specified timestamp, run this command:

```
pg_probackup validate -B backup_dir --instance=instance_name -i SBOL6P --recovery-
target-time="2024-04-10 18:18:26+03"
```

If you specify the *backup_id* of an incremental backup, all its parents starting from FULL backup will be validated.

If you omit all the parameters, all backups are validated.

Restoring a Cluster

To restore the database cluster from a backup, run the restore command with at least the following options:

```
pg_probackup restore -B backup_dir --instance=instance_name -i backup_id
```

Where:

- *backup_dir* is the backup catalog that stores all backup files and meta information.
- *instance_name* is the backup instance for the cluster to be restored.
- *backup_id* specifies the backup to restore the cluster from. If you omit this option, pg_probackup uses the latest valid backup available for the specified instance. If you specify an incremental backup to restore, pg_probackup automatically restores the underlying full backup and then sequentially applies all the necessary increments.

Once the `restore` command is complete, start the database service.

If you restore ARCHIVE backups, perform PITR, or specify the `--restore-as-replica` flag with the `restore` command to set up a standby server, pg_probackup creates a recovery configuration file once all data files are copied into the target directory. This file includes the minimal settings required for recovery, except for the password in the primary_conninfo parameter; you have to add the password manually or use the `--primary-conninfo` option, if required. For Postgres Pro 11, recovery settings are written into the `recovery.conf` file. Starting from Postgres Pro 12, pg_probackup writes these settings into the `probackup_recovery.conf` file and then includes it into `postgresql.auto.conf`.

If you are restoring a STREAM backup, the restore is complete at once, with the cluster returned to a self-consistent state at the point when the backup was taken. For ARCHIVE backups, Postgres Pro replays all available archived WAL segments, so the cluster is restored to the latest state possible within the current timeline. You can change this behavior by using the recovery target options with the `restore` command, as explained in the section called “Performing Point-in-Time (PITR) Recovery”.

If the cluster to restore contains tablespaces, pg_probackup restores them to their original location by default. To restore tablespaces to a different location, use the `--tablespace-mapping`/`-T` option. Otherwise, restoring the cluster on the same host will fail if tablespaces are in use, because the backup would have to be written to the same directories.

When using the `--tablespace-mapping`/`-T` option, you must provide absolute paths to the old and new tablespace directories. If a path happens to contain an equals sign (=), escape it with a backslash. This option can be specified multiple times for multiple tablespaces. For example:

```
pg_probackup restore -B backup_dir --instance=instance_name -D data_dir -j 4 -
i backup_id -T tablespace1_dir=tablespace1_newdir -T tablespace2_dir=tablespace2_newdir
```

To restore the cluster on a remote host, follow the instructions in the section called “Using pg_probackup in the Remote Mode”.

> **Note**
>
> By default, the restore command validates the specified backup before restoring the cluster. If you run regular backup validations and would like to save time when restoring the cluster, you can specify the `--no-validate` flag to skip validation and speed up the recovery.

Incremental Restore

The speed of restore from backup can be significantly improved by replacing only invalid and changed pages in already existing Postgres Pro data directory using incremental restore options with the restore command.

To restore the database cluster from a backup in incremental mode, run the restore command with the following options:

```
pg_probackup restore -B backup_dir --instance=instance_name -D data_dir -
I incremental_mode
```

Where *incremental_mode* can take one of the following values:

- CHECKSUM — read all data files in the data directory, validate header and checksum in every page and replace only invalid pages and those with checksum and LSN not matching with corresponding page in backup. This is the simplest, the most fool-proof incremental mode. Recommended to use by default.
- LSN — read the *pg_control* in the data directory to obtain redo LSN and redo TLI, which allows you to determine a point in history(shiftpoint), where data directory state shifted from target backup chain history. If shiftpoint is not within reach of backup chain history, then restore is aborted. If shiftpoint is within reach of backup chain history, then read all data files in the data directory, validate header and checksum in every page and replace only invalid pages and those with LSN greater than shiftpoint. This mode offers a greater speed up compared to CHECKSUM, but rely on two conditions to be met. First, data_checksums parameter must be enabled in data directory (to avoid corruption due to hint bits). This condition will be checked at the start of incremental restore and the operation will be aborted if checksums are disabled. Second, the *pg_control* file must be synched with state of data directory. This condition cannot checked at the start of restore, so it is a user responsibility to ensure that *pg_control* contain valid information. Therefore it is not recommended to use LSN mode in any situation, where pg_control cannot be trusted or has been tampered with: after *pg_resetxlog* execution, after restore from backup without recovery been run, etc.
- NONE — regular restore without any incremental optimizations.

Regardless of chosen incremental mode, pg_probackup will check, that postmaster in given destination directory is not running and `system-identifier` is the same as in the backup.

Suppose you want to return an old primary as a replica after switchover using incremental restore in LSN mode:

```
========================================================================================
 Instance  Version  ID      Recovery Time                  Mode    WAL Mode  TLI  Time
  Data    WAL  Zalg  Zratio  Start LSN    Stop LSN    Status
========================================================================================
 node       17       SBOL8S  2024-04-09 18:19:43.707720+03  DELTA   STREAM    16/15
 3s  114MB  64MB   lz4    1.42  0/3C003020  0/3E8D4930  OK
 node       17       SBOL8G  2024-04-09 18:19:32.594670+03  PTRACK  STREAM    15/15
 4s   30MB  16MB  zlib    2.23  0/31000028  0/310029E0  OK
 node       17       SBOL83  2024-04-09 18:19:22.269595+03  PAGE    STREAM    15/15
 7s   46MB  32MB  pglz    1.44  0/29000028  0/2A0000F8  OK
 node       17       SBOL7P  2024-04-09 18:19:06.557301+03  FULL    STREAM    15/0
 6s  144MB  16MB  zstd    2.47  0/22000028  0/220001C8  OK
```

```
backup_user@backup_host:~$ pg_probackup restore -B /mnt/backups --instance=node -R -I
 lsn
INFO: Destination directory and tablespace directories are empty, disable incremental
 restore
INFO: Validating parents for backup SBOL8S
INFO: Validating backup SBOL7P
INFO: Backup SBOL7P data files are valid
INFO: Validating backup SBOL83
INFO: Backup SBOL83 data files are valid
INFO: Validating backup SBOL8G
INFO: Backup SBOL8G data files are valid
INFO: Validating backup SBOL8S
INFO: Backup SBOL8S data files are valid
INFO: Backup SBOL8S WAL segments are valid
INFO: Backup SBOL8S is valid.
INFO: Restoring the database from the backup starting at 2024-04-09 18:19:40+03
INFO: Start restoring backup files. PGDATA size: 616MB
INFO: Backup files are restored. Transferred bytes: 616MB, time elapsed: 2s
INFO: Restore incremental ratio (less is better): 100% (616MB/616MB)
INFO: Syncing restored files to disk
INFO: Restored backup files are synced, time elapsed: 2s
INFO: Restore of backup SBOL8S completed.
```

> **Note**
>
> Incremental restore is possible only for backups with `program_version` equal or greater than 2.4.0.

Partial Restore

If you have enabled partial restore before taking backups, you can restore only some of the databases using partial restore options with the restore commands.

To restore the specified databases only, run the restore command with the following options:

```
pg_probackup restore -B backup_dir --instance=instance_name --db-include=database_name
```

The `--db-include` option can be specified multiple times. For example, to restore only databases `db1` and `db2`, run the following command:

```
pg_probackup restore -B backup_dir --instance=instance_name --db-include=db1 --db-
include=db2
```

To exclude one or more databases from restore, use the `--db-exclude` option:

```
pg_probackup restore -B backup_dir --instance=instance_name --db-exclude=database_name
```

The `--db-exclude` option can be specified multiple times. For example, to exclude the databases `db1` and `db2` from restore, run the following command:

```
pg_probackup restore -B backup_dir --instance=instance_name --db-exclude=db1 --db-
exclude=db2
```

Partial restore relies on lax behavior of Postgres Pro recovery process toward truncated files. For recovery to work properly, files of excluded databases are restored as files of zero size. After the Postgres Pro cluster is successfully started, you must drop the excluded databases using `DROP DATABASE` command.

To decouple a single cluster containing multiple databases into separate clusters with minimal downtime, you can do partial restore of the cluster as a standby using the `--restore-as-replica` option for specific databases.

> **Note**
>
> The `template0` and `template1` databases are always restored.

> **Note**
>
> Due to recovery specifics of Postgres Pro versions earlier than 12, it is advisable that you set the hot_standby parameter to `off` when running partial restore of a Postgres Pro cluster of version earlier than 12. Otherwise the recovery may fail.

Performing Point-in-Time (PITR) Recovery

If you have enabled continuous WAL archiving before taking backups, you can restore the cluster to its state at an arbitrary point in time (recovery target) using recovery target options with the restore command.

You can use both STREAM and ARCHIVE backups for point in time recovery as long as the WAL archive is available at least starting from the time the backup was taken. If `-i`/`--backup-id` option is omitted, pg_probackup automatically chooses the backup that is the closest to the specified recovery target and starts the restore process, otherwise pg_probackup will try to restore the specified backup to the specified recovery target.

- To restore the cluster state at the exact time, specify the `--recovery-target-time` option, in the timestamp format. For example:

  ```
  pg_probackup restore -B backup_dir --instance=instance_name --recovery-target-time="2024-04-10 18:18:26+03"
  ```

- To restore the cluster state up to a specific transaction ID, use the `--recovery-target-xid` option:

  ```
  pg_probackup restore -B backup_dir --instance=instance_name --recovery-target-xid=687
  ```

- To restore the cluster state up to the specific LSN, use `--recovery-target-lsn` option:

  ```
  pg_probackup restore -B backup_dir --instance=instance_name --recovery-target-lsn=16/B374D848
  ```

- To restore the cluster state up to the specific named restore point, use `--recovery-target-name` option:

  ```
  pg_probackup restore -B backup_dir --instance=instance_name --recovery-target-name="before_app_upgrade"
  ```

- To restore the backup to the latest state available in the WAL archive, use `--recovery-target` option with `latest` value:

  ```
  pg_probackup restore -B backup_dir --instance=instance_name --recovery-target="latest"
  ```

- To restore the cluster to the earliest point of consistency, use `--recovery-target` option with the `immediate` value:

  ```
  pg_probackup restore -B backup_dir --instance=instance_name --recovery-target='immediate'
  ```

Using pg_probackup in the Remote Mode

pg_probackup supports the remote mode that allows you to perform `backup` and `restore` operations remotely via SSH. In this mode, the backup catalog is stored on a local system, while Postgres Pro instance to be backed up is located on a remote system. You must have pg_probackup installed on both systems.

> **Note**
>
> pg_probackup relies on passwordless SSH connection for communication between the hosts.

> **Note**
>
> In addition to SSH connection, pg_probackup uses a regular connection to the database to manage the remote operation. See the section Configuring the Database Cluster for details of how to set up a database connection.

The typical workflow is as follows:

- On your backup host, configure pg_probackup as explained in the section Installation and Setup. For the add-instance and set-config commands, make sure to specify remote mode options that point to the database host with the Postgres Pro instance.
- If you would like to take remote backups in PAGE mode, or rely on ARCHIVE WAL delivery mode, or use PITR, configure continuous WAL archiving from the database host to the backup host as explained in the section Setting up continuous WAL archiving. For the archive-push and archive-get commands, you must specify the remote mode options that point to the backup host with the backup catalog.
- Run backup or restore commands with remote mode options **on the backup host**. pg_probackup connects to the remote system via SSH and creates a backup locally or restores the previously taken backup on the remote system, respectively.

For example, to create an archive full backup of a Postgres Pro cluster located on a remote system with host address `192.168.0.2` on behalf of the `postgres` user via SSH connection through port `2302`, run:

```
pg_probackup backup -B backup_dir --instance=instance_name -b FULL --remote-
user=postgres --remote-host=192.168.0.2 --remote-port=2302
```

To restore the latest available backup on a remote system with host address `192.168.0.2` on behalf of the `postgres` user via SSH connection through port `2302`, run:

```
pg_probackup restore -B backup_dir --instance=instance_name --remote-user=postgres --
remote-host=192.168.0.2 --remote-port=2302
```

Restoring an ARCHIVE backup or performing PITR in the remote mode require additional information: destination address, port and username for establishing an SSH connection **from** the host with database **to** the host with the backup catalog. This information will be used by the `restore_command` to copy WAL segments from the archive to the Postgres Pro `pg_wal` directory.

To solve this problem, you can use Remote WAL Archive Options.

For example, to restore latest backup on remote system using remote mode through SSH connection to user `postgres` on host with address `192.168.0.2` via port `2302` and user `backup` on backup catalog host with address `192.168.0.3` via port `2303`, run:

```
pg_probackup restore -B backup_dir --instance=instance_name --remote-user=postgres
 --remote-host=192.168.0.2 --remote-port=2302 --archive-host=192.168.0.3 --archive-
port=2303 --archive-user=backup
```

Provided arguments will be used to construct the `restore_command`:

```
restore_command = '"install_dir/pg_probackup" archive-get -B "backup_dir" --
instance=instance_name --wal-file-path=%p --wal-file-name=%f --remote-host=192.168.0.3
 --remote-port=2303 --remote-user=backup'
```

Alternatively, you can use the `--restore-command` option to provide the entire *restore_command*:

```
pg_probackup restore -B backup_dir --instance=instance_name --remote-user=postgres
 --remote-host=192.168.0.2 --remote-port=2302 --restore-command='"install_dir/
```

```
pg_probackup" archive-get -B "backup_dir" --instance=instance_name --wal-file-path=%p
 --wal-file-name=%f --remote-host=192.168.0.3 --remote-port=2303 --remote-user=backup'
```

> **Note**
>
> The remote mode is currently unavailable for Windows systems.

Running pg_probackup on Parallel Threads

backup, restore, merge, delete, catchup, checkdb, and validate processes can be executed on several parallel threads. This can significantly speed up pg_probackup operation given enough resources (CPU cores, disk, and network bandwidth).

Parallel execution is controlled by the `-j/--threads` command-line option. For example, to create a backup using four parallel threads, run:

```
pg_probackup backup -B backup_dir --instance=instance_name -b FULL -j 4
```

> **Note**
>
> Parallel restore applies only to copying data from the backup catalog to the data directory of the cluster. When Postgres Pro server is started, WAL records need to be replayed, and this cannot be done in parallel.

> **Important**
>
> A technique is implemented that prevents repeatable copying of one file when pg_probackup runs on multiple threads. With this technique, however, when disks are slow or the system is overloaded, parallel copying might fail. To handle this situation, resolve issues with your system resources.

Configuring pg_probackup

Once the backup catalog is initialized and a new backup instance is added, you can use the `pg_probackup.conf` configuration file located in the *backup_dir*`/backups/`*instance_name* directory to fine-tune pg_probackup configuration.

For example, backup and checkdb commands use a regular Postgres Pro connection. To avoid specifying connection options each time on the command line, you can set them in the `pg_probackup.conf` configuration file using the set-config command.

> **Note**
>
> It is **not recommended** to edit `pg_probackup.conf` manually.

Initially, `pg_probackup.conf` contains the following settings:

- `PGDATA` — the path to the data directory of the cluster to back up.
- `system-identifier` — the unique identifier of the Postgres Pro instance.

Additionally, you can define remote mode, retention, logging, and compression settings using the `set-config` command:

```
pg_probackup set-config -B backup_dir --instance=instance_name
[--external-dirs=external_directory_path] [remote_options] [connection_options]
 [retention_options] [logging_options]
```

To view the current settings, run the following command:

```
pg_probackup show-config -B backup_dir --instance=instance_name
```

You can override the settings defined in `pg_probackup.conf` when running pg_probackup commands via the corresponding environment variables and/or command line options.

Specifying Connection Settings

If you define connection settings in the `pg_probackup.conf` configuration file, you can omit connection options in all the subsequent pg_probackup commands. However, if the corresponding environment variables are set, they get higher priority. The options provided on the command line overwrite both environment variables and configuration file settings.

If nothing is given, the default values are taken. By default pg_probackup tries to use local connection via Unix domain socket (`localhost` on Windows) and tries to get the database name and the user name from the `PGUSER` environment variable or the current OS user name.

Managing the Backup Catalog

With pg_probackup, you can manage backups from the command line:

- View backup information
- View WAL Archive Information
- Validate backups
- Merge backups
- Delete backups

Viewing Backup Information

To view the list of existing backups for every instance, run the command:

```
pg_probackup show -B backup_dir
```

pg_probackup displays the list of all the available backups. For example:

```
BACKUP INSTANCE 'node'
============================================================================================================
 Instance  Version  ID      Recovery Time                  Mode    WAL Mode  TLI  Time
  Data    WAL  Zalg  Zratio  Start LSN    Stop LSN    Status
============================================================================================================
 node       17       SBOL94  2024-04-09 18:19:56.603355+03  FULL    ARCHIVE   1/0    6s
 377MB  16MB   lz4    1.46  0/41000028   0/420000C0  OK
 node       17       SBOL8S  2024-04-09 18:19:43.707720+03  DELTA   STREAM    1/1    3s
 114MB  64MB   lz4    1.42  0/3C003020   0/3E8D4930  OK
 node       17       SBOL8G  2024-04-09 18:19:32.594670+03  PTRACK  STREAM    1/1    4s
  30MB  16MB  zlib    2.23  0/31000028   0/310029E0  OK
 node       17       SBOL83  2024-04-09 18:19:22.269595+03  PAGE    STREAM    1/1    7s
  46MB  32MB  pglz    1.44  0/29000028   0/2A0000F8  OK
 node       17       SBOL7P  2024-04-09 18:19:06.557301+03  FULL    STREAM    1/0    6s
 144MB  16MB  zstd    2.47  0/22000028   0/220001C8  OK
```

For each backup, the following information is provided:

- `Instance` — the instance name.
- `Version` — Postgres Pro major version.
- `ID` — the backup identifier.
- `Recovery time` — the earliest moment for which you can restore the state of the database cluster.
- `Mode` — the method used to take this backup. Possible values: `FULL`, `PAGE`, `DELTA`, `PTRACK`.
- `WAL Mode` — WAL delivery mode. Possible values: `STREAM` and `ARCHIVE`.
- `TLI` — timeline identifiers of the current backup and its parent.
- `Time` — the time it took to perform the backup.

- `Data` — the size of the data files in this backup. This value does not include the size of WAL files. For STREAM backups, the total size of the backup can be calculated as `Data` + `WAL`.
- `WAL` — the uncompressed size of WAL files that need to be applied during recovery for the backup to reach a consistent state.
- `compress-alg` — compression algorithm used during backup. Possible values: `zlib`, `pglz`, `lz4`, `zstd`, `none`.
- `Zratio` — compression ratio calculated as “uncompressed-bytes” / “data-bytes”.
- `Start LSN` — WAL log sequence number corresponding to the start of the backup process. REDO point for Postgres Pro recovery process to start from.
- `Stop LSN` — WAL log sequence number corresponding to the end of the backup process. Consistency point for Postgres Pro recovery process.
- `Status` — backup status. Possible values:
  - `OK` — the backup is complete and valid.
  - `DONE` — the backup is complete, but was not validated.
  - `RUNNING` — the backup is in progress.
  - `MERGING` — the backup is being merged.
  - `MERGED` — the backup data files were successfully merged, but its metadata is in the process of being updated. Only full backups can have this status.
  - `DELETING` — the backup files are being deleted.
  - `CORRUPT` — some of the backup files are corrupt.
  - `ERROR` — the backup was aborted because of an unexpected error.
  - `ORPHAN` — the backup is invalid because one of its parent backups is corrupt or missing.
  - `HIDDEN_FOR_TEST` — a test script marked the backup as nonexistent. (pg_probackup never sets this status by itself.)

You can restore the cluster from the backup only if the backup status is `OK` or `DONE`.

To get more detailed information about the backup, run the `show` command with the backup ID:

```
pg_probackup show -B backup_dir --instance=instance_name -i backup_id
```

The sample output is as follows:

```
#Configuration
backup-mode = FULL
stream = false
compress-alg = lz4
compress-level = 1
from-replica = false

#Compatibility
block-size = 8192
xlog-block-size = 8192
checksum-version = 1
program-version = 2.7.3
server-version = 17

#Result backup info
timelineid = 1
start-lsn = 0/41000028
stop-lsn = 0/420000C0
start-time = '2024-04-09 18:19:52+03'
end-time = '2024-04-09 18:19:58+03'
end-validation-time = '2024-04-09 18:19:59+03'
recovery-xid = 757
recovery-time = '2024-04-09 18:19:56.603355+03'
```

```
data-bytes = 395651278
wal-bytes = 16777216
uncompressed-bytes = 578552566
pgdata-bytes = 578552248
status = OK
primary_conninfo = 'user=backup channel_binding=prefer host=localhost
 port=5432 sslmode=prefer sslcompression=0 sslcertmode=allow sslsni=1
 ssl_min_protocol_version=TLSv1.2 gssencmode=prefer krbsrvname=postgres gssdelegation=0
 target_session_attrs=any load_balance_hosts=disable'
content-crc = 3862224379
```

Detailed output has additional attributes:

- `compress-alg` — compression algorithm used during backup. Possible values: `zlib`, `pglz`, `lz4`, `zstd`, `none`.
- `compress-level` — compression level used during backup.
- `from-replica` — was this backup taken on a standby? Possible values: `1`, `0`.
- `block-size` — the block_size setting of Postgres Pro cluster at the backup start.
- `checksum-version` — are data_checksums enabled in the backed up Postgres Pro cluster? Possible values: `1`, `0`.
- `program-version` — full version of pg_probackup binary used to create the backup.
- `start-time` — the backup start time.
- `end-time` — the backup end time.
- `end-validation-time` — the backup validation end time.
- `expire-time` — the point in time when a pinned backup can be removed in accordance with retention policy. This attribute is only available for pinned backups.
- `uncompressed-bytes` — the size of data files before adding page headers and applying compression. You can evaluate the effectiveness of compression by comparing `uncompressed-bytes` to `data-bytes` if compression if used.
- `pgdata-bytes` — the size of Postgres Pro cluster data files at the time of backup. You can evaluate the effectiveness of an incremental backup by comparing `pgdata-bytes` to `uncompressed-bytes`.
- `recovery-xid` — transaction ID at the backup end time.
- `parent-backup-id` — ID of the parent backup. Available only for incremental backups.
- `primary_conninfo` — libpq connection parameters used to connect to the Postgres Pro cluster to take this backup. The password is not included.
- `note` — text note attached to backup.
- `content-crc` — CRC32 checksum of `backup_content.control` file. It is used to detect corruption of backup metainformation.

You can also get the detailed information about the backup in the JSON format:

```
pg_probackup show -B backup_dir --instance=instance_name --format=json -i backup_id
```

The sample output is as follows:

```
[
    {
        "instance": "node",
        "backups": [
            {
                "id": "SBOL94",
                "status": "OK",
                "start-time": "2024-04-09 18:19:52+03",
                "backup-mode": "FULL",
                "wal": "ARCHIVE",
                "compress-alg": "lz4",
                "compress-level": 1,
                "from-replica": "false",
                "block-size": 8192,
                "xlog-block-size": 8192,
```

```
                "checksum-version": 1,
                "program-version": "2.7.3",
                "server-version": "17",
                "current-tli": 16,
                "parent-tli": 2,
                "start-lsn": "0/41000028",
                "stop-lsn": "0/420000C0",
                "end-time": "2024-04-09 18:19:58+03",
                "end-validation-time": "2024-04-09 18:19:59+03",
                "recovery-xid": 757,
                "recovery-time": "2024-04-09 18:19:56.603355+03",
                "data-bytes": 395651278,
                "wal-bytes": 16777216,
                "uncompressed-bytes": 578552566,
                "pgdata-bytes": 578552248,
                "primary_conninfo": "user=backup channel_binding=prefer
 host=localhost port=5432 sslmode=prefer sslcompression=0 sslcertmode=allow sslsni=1
 ssl_min_protocol_version=TLSv1.2 gssencmode=prefer krbsrvname=postgres gssdelegation=0
 target_session_attrs=any load_balance_hosts=disable",
                "content-crc": 3862224379
            }
        ]
    }
]
```


Viewing WAL Archive Information

To view the information about WAL archive for every instance, run the command:

```
pg_probackup show -B backup_dir [--instance=instance_name] --archive
```

pg_probackup displays the list of all the available WAL files grouped by timelines. For example:

```
ARCHIVE INSTANCE 'node'
================================================================================================
 TLI  Parent TLI  Switchpoint  Min Segno                 Max Segno                 N
 segments  Size   Zratio  N backups  Status
================================================================================================
 1    0           0/0          000000010000000000000001B  000000010000000000000042  40
        640MB  1.00    5          OK
```

For each timeline, the following information is provided:

- `TLI` — timeline identifier.
- `Parent TLI` — identifier of the timeline from which this timeline branched off.
- `Switchpoint` — LSN of the moment when the timeline branched off from its parent timeline.
- `Min Segno` — the first WAL segment belonging to the timeline.
- `Max Segno` — the last WAL segment belonging to the timeline.
- `N segments` — number of WAL segments belonging to the timeline.
- `Size` — the size that files take on disk.
- `Zalg` — compression algorithm used during backup. Possible values: `zlib`, `pglz`, `lz4`, `zstd`, `none`.
- `Zratio` — compression ratio calculated as `N segments` * *`wal_segment_size`* * *`wal_block_size`* / `Size`.
- `N backups` — number of backups belonging to the timeline. To get the details about backups, use the JSON format.
- `Status` — status of the WAL archive for this timeline. Possible values:
  - `OK` — all WAL segments between `Min Segno` and `Max Segno` are present.
  - `DEGRADED` — some WAL segments between `Min Segno` and `Max Segno` are missing. To find out which files are lost, view this report in the JSON format. This status may appear if several WAL files (in the middle of the sequence) were deleted by the delete command with the `--delete-wal`

option according to the retention policy. This status does not affect the restore correctness, but it can be impossible to perform PITR of the cluster to some recovery targets.

To get more detailed information about the WAL archive in the JSON format, run the command:

```
pg_probackup show -B backup_dir [--instance=instance_name] --archive --format=json
```

The sample output is as follows:


```
[
    {
        "instance": "node",
        "timelines": [
            {
                "tli": 1,
                "parent-tli": 0,
                "switchpoint": "0/0",
                "min-segno": "000000010000000000000001B",
                "max-segno": "000000010000000000000042",
                "n-segments": 40,
                "size": 671088640,
                "zratio": 1.00,
                "closest-backup-id": "",
                "status": "OK",
                "lost-segments": [],
                "backups": [
                    {
                        "id": "SBOL94",
                        "status": "OK",
                        "start-time": "2024-04-09 18:19:52+03",
                        "backup-mode": "FULL",
                        "wal": "ARCHIVE",
                        "compress-alg": "lz4",
                        "compress-level": 1,
                        "from-replica": "false",
                        "block-size": 8192,
                        "xlog-block-size": 8192,
                        "checksum-version": 1,
                        "program-version": "2.7.3",
                        "server-version": "17",
                        "current-tli": 2,
                        "parent-tli": 0,
                        "start-lsn": "0/41000028",
                        "stop-lsn": "0/420000C0",
                        "end-time": "2024-04-09 18:19:58+03",
                        "end-validation-time": "2024-04-09 18:19:59+03",
                        "recovery-xid": 757,
                        "recovery-time": "2024-04-09 18:19:56.603355+03",
                        "data-bytes": 395651278,
                        "wal-bytes": 16777216,
                        "uncompressed-bytes": 578552566,
                        "pgdata-bytes": 578552248,
                        "primary_conninfo": "user=backup channel_binding=prefer
host=localhost port=5432 sslmode=prefer sslcompression=0 sslcertmode=allow sslsni=1
ssl_min_protocol_version=TLSv1.2 gssencmode=prefer krbsrvname=postgres gssdelegation=0
target_session_attrs=any load_balance_hosts=disable",
                        "content-crc": 3862224379
                    },
                    {
                        "id": "SBOL8S",
```

```
                        "status": "OK",
                        "start-time": "2024-04-09 18:19:40+03",
                        "parent-backup-id": "SBOL8G",
                        "backup-mode": "DELTA",
                        "wal": "STREAM",
                        "compress-alg": "lz4",
                        "compress-level": 1,
                        "from-replica": "false",
                        "block-size": 8192,
                        "xlog-block-size": 8192,
                        "checksum-version": 1,
                        "program-version": "2.7.3",
                        "server-version": "17",
                        "current-tli": 1,
                        "parent-tli": 1,
                        "start-lsn": "0/3C003020",
                        "stop-lsn": "0/3E8D4930",
                        "end-time": "2024-04-09 18:19:43+03",
                        "end-validation-time": "2024-04-09 18:19:44+03",
                        "recovery-xid": 757,
                        "recovery-time": "2024-04-09 18:19:43.707720+03",
                        "data-bytes": 119350434,
                        "wal-bytes": 67108864,
                        "uncompressed-bytes": 170044286,
                        "pgdata-bytes": 578552248,
                        "primary_conninfo": "user=backup channel_binding=prefer
host=localhost port=5432 sslmode=prefer sslcompression=0 sslcertmode=allow sslsni=1
ssl_min_protocol_version=TLSv1.2 gssencmode=prefer krbsrvname=postgres gssdelegation=0
target_session_attrs=any load_balance_hosts=disable",
                        "content-crc": 1259851036
                    },
                    {
                        "id": "SBOL8G",
                        "status": "OK",
                        "start-time": "2024-04-09 18:19:28+03",
                        "parent-backup-id": "SBOL83",
                        "backup-mode": "PTRACK",
                        "wal": "STREAM",
                        "compress-alg": "zlib",
                        "compress-level": 1,
                        "from-replica": "false",
                        "block-size": 8192,
                        "xlog-block-size": 8192,
                        "checksum-version": 1,
                        "program-version": "2.7.3",
                        "server-version": "17",
                        "current-tli": 1,
                        "parent-tli": 1,
                        "start-lsn": "0/31000028",
                        "stop-lsn": "0/310029E0",
                        "end-time": "2024-04-09 18:19:32+03",
                        "end-validation-time": "2024-04-09 18:19:33+03",
                        "recovery-xid": 756,
                        "recovery-time": "2024-04-09 18:19:32.594670+03",
                        "data-bytes": 31218302,
                        "wal-bytes": 16777216,
                        "uncompressed-bytes": 69610366,
                        "pgdata-bytes": 510263736,
```

```
                        "primary_conninfo": "user=backup channel_binding=prefer
host=localhost port=5432 sslmode=prefer sslcompression=0 sslcertmode=allow sslsni=1
ssl_min_protocol_version=TLSv1.2 gssencmode=prefer krbsrvname=postgres gssdelegation=0
target_session_attrs=any load_balance_hosts=disable",
                        "content-crc": 2293248595
                    },
                    {
                        "id": "SBOL83",
                        "status": "OK",
                        "start-time": "2024-04-09 18:19:15+03",
                        "parent-backup-id": "SBOL7P",
                        "backup-mode": "PAGE",
                        "wal": "STREAM",
                        "compress-alg": "pglz",
                        "compress-level": 1,
                        "from-replica": "false",
                        "block-size": 8192,
                        "xlog-block-size": 8192,
                        "checksum-version": 1,
                        "program-version": "2.7.3",
                        "server-version": "17",
                        "current-tli": 1,
                        "parent-tli": 1,
                        "start-lsn": "0/29000028",
                        "stop-lsn": "0/2A0000F8",
                        "end-time": "2024-04-09 18:19:22+03",
                        "end-validation-time": "2024-04-09 18:19:22+03",
                        "recovery-xid": 755,
                        "recovery-time": "2024-04-09 18:19:22.269595+03",
                        "data-bytes": 48394744,
                        "wal-bytes": 33554432,
                        "uncompressed-bytes": 69577598,
                        "pgdata-bytes": 441975224,
                        "primary_conninfo": "user=backup channel_binding=prefer
host=localhost port=5432 sslmode=prefer sslcompression=0 sslcertmode=allow sslsni=1
ssl_min_protocol_version=TLSv1.2 gssencmode=prefer krbsrvname=postgres gssdelegation=0
target_session_attrs=any load_balance_hosts=disable",
                        "content-crc": 343227200
                    },
                    {
                        "id": "SBOL7P",
                        "status": "OK",
                        "start-time": "2024-04-09 18:19:01+03",
                        "backup-mode": "FULL",
                        "wal": "STREAM",
                        "compress-alg": "zstd",
                        "compress-level": 1,
                        "from-replica": "false",
                        "block-size": 8192,
                        "xlog-block-size": 8192,
                        "checksum-version": 1,
                        "program-version": "2.7.3",
                        "server-version": "17",
                        "current-tli": 1,
                        "parent-tli": 0,
                        "start-lsn": "0/22000028",
                        "stop-lsn": "0/220001C8",
                        "end-time": "2024-04-09 18:19:07+03",
```

```
                        "end-validation-time": "2024-04-09 18:19:09+03",
                        "recovery-xid": 754,
                        "recovery-time": "2024-04-09 18:19:06.557301+03",
                        "data-bytes": 151177272,
                        "wal-bytes": 16777216,
                        "uncompressed-bytes": 373695222,
                        "pgdata-bytes": 373694904,
                        "primary_conninfo": "user=backup channel_binding=prefer
 host=localhost port=5432 sslmode=prefer sslcompression=0 sslcertmode=allow sslsni=1
 ssl_min_protocol_version=TLSv1.2 gssencmode=prefer krbsrvname=postgres gssdelegation=0
 target_session_attrs=any load_balance_hosts=disable",
                        "content-crc": 1636300818
                    }
                ]
            }
        ]
    }
]
```

Most fields are consistent with the plain format, with some exceptions:

- The size is in bytes.
- The `closest-backup-id` attribute contains the ID of the most recent valid backup that belongs to one of the previous timelines. You can use this backup to perform point-in-time recovery to this timeline. If such a backup does not exist, this string is empty.
- The `lost-segments` array provides with information about intervals of missing segments in `DEGRADED` timelines. In `OK` timelines, the `lost-segments` array is empty.
- The `backups` array lists all backups belonging to the timeline. If the timeline has no backups, this array is empty.

Configuring Retention Policy

With pg_probackup, you can configure retention policy to remove redundant backups, clean up unneeded WAL files, as well as pin specific backups to ensure they are kept for the specified time, as explained in the sections below. All these actions can be combined together in any way.

Removing Redundant Backups

By default, all backup copies created with pg_probackup are stored in the specified backup catalog. To save disk space, you can configure retention policy to remove redundant backup copies.

To configure retention policy, set one or more of the following variables in the `pg_probackup.conf` file via set-config:

`--retention-redundancy=`*`redundancy`*

Specifies **the number of full backup copies** to keep in the backup catalog.

`--retention-window=`*`window`*

Defines the earliest point in time for which pg_probackup can complete the recovery. This option is set in **the number of days** from the current moment. For example, if `retention-window=7`, pg_probackup must keep at least one backup copy that is older than seven days, with all the corresponding WAL files, and all the backups that follow.

If both `--retention-redundancy` and `--retention-window` options are set, both these conditions have to be taken into account when purging the backup catalog. For example, if you set `--retention-redundancy=2` and `--retention-window=7`, pg_probackup has to keep two full backup copies, as well as all the backups required to ensure recoverability for the last seven days:

```
pg_probackup set-config -B backup_dir --instance=instance_name --retention-redundancy=2
 --retention-window=7
```

It is recommended to always keep at least two last parent full backups to avoid errors when creating incremental backups.

To clean up the backup catalog in accordance with retention policy, you have to run the delete command with retention flags, as shown below, or use the backup command with these flags to process the outdated backup copies right when the new backup is created.

For example, to remove all backup copies that no longer satisfy the defined retention policy, run the following command with the `--delete-expired` flag:

```
pg_probackup delete -B backup_dir --instance=instance_name --delete-expired
```

If you would like to also remove the WAL files that are no longer required for any of the backups, you should also specify the `--delete-wal` flag:

```
pg_probackup delete -B backup_dir --instance=instance_name --delete-expired --delete-
wal
```

You can also set or override the current retention policy by specifying `--retention-redundancy` and `--retention-window` options directly when running `delete` or `backup` commands:

```
pg_probackup delete -B backup_dir --instance=instance_name --delete-expired --
retention-window=7 --retention-redundancy=2
```

Since incremental backups require that their parent full backup and all the preceding incremental backups are available, if any of such backups expire, they still cannot be removed while at least one incremental backup in this chain satisfies the retention policy. To avoid keeping expired backups that are still required to restore an active incremental one, you can merge them with this backup using the `--merge-expired` flag when running backup or delete commands.

Suppose you have backed up the *node* instance in the *backup_dir* directory, with the `--retention-window` option set to `6` and `--retention-redundancy` option set to `2`, and you have the following backups available on August 01, 2024:

```
BACKUP INSTANCE 'node'
============================================================================================
 Instance  Version  ID      Recovery Time           Mode   WAL Mode  TLI  Time    Data
  WAL  Zalg  Zratio  Start LSN   Stop LSN    Status
============================================================================================
 node      17       SHJ1N9  2024-08-01 09:50:00+03  FULL   ARCHIVE   1/0    5s    13MB
 16MB  zstd    2,81  0/1D000028  0/1E0000C0  OK
 node      17       SHJ1N8  2024-08-01 09:49:59+03  DELTA  ARCHIVE   1/1    5s  6432kB
 16MB  zstd    1,06  0/1A000028  0/1B0000C0  OK
 node      17       SHH6Z8  2024-07-31 09:49:59+03  PAGE   ARCHIVE   1/1    5s  6431kB
 16MB  zstd    1,06  0/17000028  0/180000C0  OK
 node      17       SHFCB6  2024-07-30 09:49:57+03  FULL   ARCHIVE   1/0    5s    12MB
 16MB  zstd    2,83  0/14000028  0/150000C0  OK
 node      17       SH9SB5  2024-07-27 09:49:56+03  PAGE   ARCHIVE   1/1    5s  6432kB
 16MB  zstd    1,06  0/11000028  0/120000C0  OK
 ------------------------------------------------------------retention
 window------------------------------------------------------------
 node      17       SH62Z5  2024-07-25 09:49:56+03  DELTA  ARCHIVE   1/1    5s  6431kB
 16MB  zstd    1,06  0/E000028   0/F0000C0   OK
 node      17       SH48B3  2024-07-24 09:49:54+03  FULL   ARCHIVE   1/0    5s    12MB
 16MB  zstd    2,86  0/B000028   0/C0000C0   OK
 node      17       SGWTN3  2024-07-20 09:49:54+03  PAGE   ARCHIVE   1/1    5s  6432kB
 16MB  zstd    1,06  0/8000028   0/90000C0   OK
 node      17       SGUYZ2  2024-07-19 09:49:53+03  DELTA  ARCHIVE   1/1    5s  6442kB
 16MB  zstd    1,07  0/5000028   0/60000C0   OK
 node      17       SGT4B1  2024-07-18 09:49:52+03  FULL   ARCHIVE   1/0    5s    11MB
 16MB  zstd    2,89  0/2000028   0/3003A28   OK
```

If you run the delete command with the `--delete-expired` flag, the backups with IDs `SGT4B1`, `SGUYZ2`, and `SGWTN3` will be removed as they are expired both according to the retention window and due to redundancy (the required set of full backups has already been retained). `SGUYZ2` and `SGWTN3` will also be removed since the base full backup is expired.

Running the delete command with the `--merge-expired` flag will merge backups `SH48B3` and `SH62Z5` with `SH9SB5`. The merge will occur with `SH9SB5` as it is the first non-expired delta backup, which can be merged with expired delta backups `SH62Z5` and expired full backup `SH48B3`.

```
pg_probackup delete -B backup_dir --instance=node --delete-expired --merge-expired
pg_probackup show -B backup_dir
```

```
BACKUP INSTANCE 'node'
================================================================================================================
 Instance  Version  ID      Recovery Time           Mode    WAL Mode  TLI  Time    Data
  WAL  Zalg  Zratio  Start LSN    Stop LSN    Status
================================================================================================================
 node      17       SHJ1N9  2024-08-01 09:50:00+03  FULL    ARCHIVE   1/0    5s    13MB
 16MB  zstd    2,81  0/1D000028   0/1E0000C0  OK
 node      17       SHJ1N8  2024-08-01 09:49:59+03  DELTA   ARCHIVE   1/1    5s  6432kB
 16MB  zstd    1,06  0/1A000028   0/1B0000C0  OK
 node      17       SHH6Z8  2024-07-31 09:49:59+03  PAGE    ARCHIVE   1/1    5s  6431kB
 16MB  zstd    1,06  0/17000028   0/180000C0  OK
 node      17       SHFCB6  2024-07-30 09:49:57+03  FULL    ARCHIVE   1/0    5s    12MB
 16MB  zstd    2,83  0/14000028   0/150000C0  OK
 node      17       SH9SB5  2024-07-27 09:49:56+03  FULL    ARCHIVE   1/0    1s    12MB
 16MB  zstd    2,84  0/11000028   0/120000C0  OK
```

The `Time` field for the merged backup displays the time required for the merge.

Pinning Backups

If you need to keep certain backups longer than the established retention policy allows, you can pin them for arbitrary time. For example:

```
pg_probackup set-backup -B backup_dir --instance=instance_name -i backup_id --ttl=30d
```

This command sets the expiration time of the specified backup to 30 days starting from the time indicated in its `recovery-time` attribute.

You can also explicitly set the expiration time for a backup using the `--expire-time` option. For example:

```
pg_probackup set-backup -B backup_dir --instance=instance_name -i backup_id --expire-
time="2027-04-09 18:21:32+00"
```

Alternatively, you can use the `--ttl` and `--expire-time` options with the backup command to pin the newly created backup:

```
pg_probackup backup -B backup_dir --instance=instance_name -b FULL --ttl=30d
pg_probackup backup -B backup_dir --instance=instance_name -b FULL --expire-
time="2027-04-09 18:21:32+00"
```

To check if the backup is pinned, run the show command:

```
pg_probackup show -B backup_dir --instance=instance_name -i backup_id
```

If the backup is pinned, it has the `expire-time` attribute that displays its expiration time:

```
...
recovery-time = '2024-04-09 18:21:32+00'
expire-time = '2027-04-09 18:21:32+00'
data-bytes = 22288792
...
```

You can unpin the backup by setting the `--ttl` option to zero:

```
pg_probackup set-backup -B backup_dir --instance=instance_name -i backup_id --ttl=0
```

> **Note**
>
> A pinned incremental backup implicitly pins all its parent backups. If you unpin such a backup later, its implicitly pinned parents will also be automatically unpinned.

Configuring WAL Archive Retention Policy

When continuous WAL archiving is enabled, archived WAL segments can take a lot of disk space. Even if you delete old backup copies from time to time, the `--delete-wal` flag can purge only those WAL segments that do not apply to any of the remaining backups in the backup catalog. However, if point-in-time recovery is critical only for the most recent backups, you can configure WAL archive retention policy to keep WAL archive of limited depth and win back some more disk space.

To configure WAL archive retention policy, you have to run the set-config command with the `--wal-depth` option that specifies the number of backups that can be used for PITR. This setting applies to all the timelines, so you should be able to perform PITR for the same number of backups on each timeline, if available. Pinned backups are not included into this count: if one of the latest backups is pinned, pg_probackup ensures that PITR is possible for one extra backup.

To remove WAL segments that do not satisfy the defined WAL archive retention policy, you simply have to run the delete or backup command with the `--delete-wal` flag. For archive backups, WAL segments between `Start LSN` and `Stop LSN` are always kept intact, so such backups remain valid regardless of the `--wal-depth` setting and can still be restored, if required.

You can also use the `--wal-depth` option with the delete and backup commands to override the previously defined WAL archive retention policy and purge old WAL segments on the fly.

Suppose you have backed up the `node` instance in the *backup_dir* directory and configured continuous WAL archiving:

```
pg_probackup show -B backup_dir --instance=node
```

```
========================================================================================================
 Instance  Version  ID      Recovery Time                  Mode   WAL Mode  TLI  Time
  Data    WAL  Zalg  Zratio  Start LSN    Stop LSN    Status
========================================================================================================
 node       17       SBOLDA  2024-04-09 18:22:23.147138+03  DELTA  STREAM    1/1    1s
 1165kB  16MB  zstd    1.09  0/6F000028  0/6F000190  OK
 node       17       SBOLCY  2024-04-09 18:22:16.079841+03  FULL   STREAM    1/0   10s
 278MB   16MB  zstd    2.46  0/6D000028  0/6D000190  OK
 node       17       SBOLCW  2024-04-09 18:22:10.154022+03  DELTA  STREAM    1/1    2s
 1364kB  16MB  zstd    1.01  0/6B000028  0/6B000190  OK
 node       17       SBOLCS  2024-04-09 18:22:07.521646+03  DELTA  STREAM    1/1    4s
  78MB   16MB  zstd    2.41  0/69000028  0/69000190  OK
 node       17       SBOLCC  2024-04-09 18:21:55.830115+03  FULL   STREAM    1/0   15s
 278MB   96MB  zstd    2.46  0/600060C8  0/64FE6640  OK
 node       17       SBOLBW  2024-04-09 18:21:38.399702+03  FULL   STREAM    1/0   12s
 278MB   96MB  zstd    2.46  0/54001830  0/589E5908  OK
```

You can check the state of the WAL archive by running the show command with the `--archive` flag:

```
pg_probackup show -B backup_dir --instance=node --archive
```

```
ARCHIVE INSTANCE 'node'
========================================================================================================
 TLI  Parent TLI  Switchpoint  Min Segno                Max Segno                 N
 segments  Size   Zratio  N backups  Status
========================================================================================================
```

```
 1    0           0/0          000000010000000000000052  000000010000000000000006F  30
        480MB  1.00    6          OK
```

WAL purge without `--wal-depth` cannot achieve much, only one segment is removed:

```
pg_probackup delete -B backup_dir --instance=node --delete-wal
```

```
ARCHIVE INSTANCE 'node'
================================================================================================
 TLI  Parent TLI  Switchpoint  Min Segno                 Max Segno                 N
 segments  Size   Zratio  N backups  Status
================================================================================================
 1    0           0/0          000000010000000000000054  000000010000000000000006F  28
        448MB  1.00    6          OK
```

If you would like, for example, to keep only those WAL segments that can be applied to the latest valid backup, set the `--wal-depth` option to 1:

```
pg_probackup delete -B backup_dir --instance=node --delete-wal --wal-depth=1
```

```
ARCHIVE INSTANCE 'node'
================================================================================================
 TLI  Parent TLI  Switchpoint  Min Segno                 Max Segno                 N
 segments  Size  Zratio  N backups  Status
================================================================================================
 1    0           0/0          000000010000000000000006F  000000010000000000000006F  1
        16MB  1.00    6          OK
```

Alternatively, you can use the `--wal-depth` option with the backup command:

```
pg_probackup backup -B backup_dir --instance=node -b DELTA --wal-depth=1 --delete-wal
```

```
ARCHIVE INSTANCE 'node'
================================================================================================
 TLI  Parent TLI  Switchpoint  Min Segno                 Max Segno                 N
 segments  Size  Zratio  N backups  Status
================================================================================================
 1    0           0/0          000000010000000000000071  000000010000000000000071  1
        16MB  1.00    7          OK
```

Merging Backups

As you take more and more incremental backups, the total size of the backup catalog can substantially grow. To save disk space, you can merge incremental backups to their parent full backup by running the `merge` command, specifying the backup ID of the most recent incremental backup you would like to merge:

```
pg_probackup merge -B backup_dir --instance=instance_name -i backup_id
```

This command merges backups that belong to a common incremental backup chain. If you specify a full backup, it will be merged with its first incremental backup. If you specify an incremental backup, it will be merged to its parent full backup, together with all incremental backups between them. Once the merge is complete, the full backup takes in all the merged data, and the incremental backups are removed as redundant. Thus, the merge operation is virtually equivalent to retaking a full backup and removing all the outdated backups, but it allows you to save much time, especially for large data volumes, as well as I/O and network traffic if you are using pg_probackup in the remote mode.

Before the merge, pg_probackup validates all the affected backups to ensure that they are valid. You can check the current backup status by running the show command with the backup ID:

```
pg_probackup show -B backup_dir --instance=instance_name -i backup_id
```

If the merge is still in progress, the backup status is displayed as `MERGING`. For full backups, it can also be shown as `MERGED` while the metadata is being updated at the final stage of the merge. The merge is idempotent, so you can restart the merge if it was interrupted.

> **Warning**
>
> Avoid force-terminating the merge operation, as it may cause subsequent `merge` commands to fail and disrupt backup validation.

Deleting Backups

To delete a backup that is no longer required, run the following command:

```
pg_probackup delete -B backup_dir --instance=instance_name -i backup_id
```

This command will delete the backup with the specified *backup_id*, together with all the incremental backups that descend from *backup_id*, if any. This way you can delete some recent incremental backups, retaining the underlying full backup and some of the incremental backups that follow it.

To delete obsolete WAL files that are not necessary to restore any of the remaining backups, use the `--delete-wal` flag:

```
pg_probackup delete -B backup_dir --instance=instance_name --delete-wal
```

To delete backups that are expired according to the current retention policy, use the `--delete-expired` flag:

```
pg_probackup delete -B backup_dir --instance=instance_name --delete-expired
```

Expired backups cannot be removed while at least one incremental backup that satisfies the retention policy is based on them. If you would like to minimize the number of backups still required to keep incremental backups valid, specify the `--merge-expired` flag when running this command:

```
pg_probackup delete -B backup_dir --instance=instance_name --delete-expired --merge-expired
```

In this case, pg_probackup searches for the oldest incremental backup that satisfies the retention policy and merges this backup with the underlying full and incremental backups that have already expired, thus making it a full backup. Once the merge is complete, the remaining expired backups are deleted.

Before merging or deleting backups, you can run the `delete` command with the `--dry-run` flag, which displays the status of all the available backups according to the current retention policy, without performing any irreversible actions.

To delete all backups with specific status, use the `--status`:

```
pg_probackup delete -B backup_dir --instance=instance_name --status=ERROR
```

Deleting backups by status ignores established retention policies.

Cloning and Synchronizing Postgres Pro Instance

pg_probackup can create a copy of a Postgres Pro instance directly, without using the backup catalog. To do this, you can run the catchup command. It can be useful in the following cases:

- To add a new standby server.

  Usually, pg_basebackup is used to create a copy of a Postgres Pro instance. If the data directory of the destination instance is empty, the `catchup` command works similarly, but it can be faster if run in parallel mode.

- To have a fallen-behind standby server “catch up” with the primary.

  Under write-intensive load, replicas may fail to replay WAL fast enough to keep up with the primary and hence may lag behind. A usual solution to create a new replica and switch to it requires a lot of

extra space and data transfer. The `catchup` command allows you to update an existing replica much faster by bringing differences from the primary.

`catchup` is different from other pg_probackup operations:

- The backup catalog is not required.
- STREAM WAL delivery mode is only supported.
- Copying external directories is not supported.
- DDL commands CREATE TABLESPACE/DROP TABLESPACE cannot be run simultaneously with `catchup`.
- `catchup` takes configuration files, such as `postgresql.conf`, `postgresql.auto.conf`, or `pg_hba.conf`, from the source server and overwrites them on the target server. The `--exclude-path` option allows you to keep the configuration files intact.

To prepare for cloning/synchronizing a Postgres Pro instance, set up the source server as follows:

- Configure the database cluster for the instance to copy.
- To copy from a remote server, configure the remote mode.
- To use the PTRACK catchup mode, set up PTRACK backups.

Before cloning/synchronizing a Postgres Pro instance, ensure that the source server is running and accepting connections. To clone/sync a Postgres Pro instance, on the server with the destination instance, you can run the catchup command as follows:

```
pg_probackup catchup -b catchup_mode --source-pgdata=path_to_pgdata_on_remote_server --destination-pgdata=path_to_local_dir --stream [connection_options] [remote_options]
```

Where *catchup_mode* can take one of the following values:

- `FULL` — creates a full copy of the Postgres Pro instance. The data directory of the destination instance must be empty for this mode.
- `DELTA` — reads all data files in the data directory and creates an incremental copy for pages that have changed since the destination instance was shut down.
- `PTRACK` — tracking page changes on the fly, only reads and copies pages that have changed since the point of divergence of the source and destination instances.

> **Warning**
>
> PTRACK catchup mode requires PTRACK not earlier than 2.0 and hence, Postgres Pro not earlier than 11.

By specifying the `--stream` option, you can set STREAM WAL delivery mode of copying, which will include all the necessary WAL files by streaming them from the server via replication protocol.

You can use connection_options to specify the connection to the source database cluster. If it is located on a different server, also specify remote_options.

If the source database cluster contains tablespaces that must be located in a different directory, additionally specify the `--tablespace-mapping` option:

```
pg_probackup catchup -b catchup_mode --source-pgdata=path_to_pgdata_on_remote_server --destination-pgdata=path_to_local_dir --stream --tablespace-mapping=OLDDIR=NEWDIR
```

To run the `catchup` command on parallel threads, specify the number of threads with the `--threads` option:

```
pg_probackup catchup -b catchup_mode --source-pgdata=path_to_pgdata_on_remote_server --destination-pgdata=path_to_local_dir --stream --threads=num_threads
```

Before cloning/synchronising a Postgres Pro instance, you can run the `catchup` command with the `--dry-run` flag to estimate the size of data files to be transferred, but make no changes on disk:

```
pg_probackup catchup -b catchup_mode --source-pgdata=path_to_pgdata_on_remote_server --destination-pgdata=path_to_local_dir --stream --dry-run
```

For example, assume that a remote standby server with the Postgres Pro instance having `/replica-pgdata` data directory has fallen behind. To sync this instance with the one in `/master-pgdata` data directory, you can run the `catchup` command in the `PTRACK` mode on four parallel threads as follows:

```
pg_probackup catchup --source-pgdata=/master-pgdata --destination-pgdata=/replica-pgdata -p 5432 -d postgres -U remote-postgres-user --stream --backup-mode=PTRACK
 --remote-host=remote-hostname --remote-user=remote-unix-username -j 4 --exclude-path=postgresql.conf --exclude-path=postgresql.auto.conf --exclude-path=pg_hba.conf --exclude-path=pg_ident.conf
```

Note that in this example, the configuration files will not be overwritten during synchronization.

Another example shows how you can add a new remote standby server with the Postgres Pro data directory `/replica-pgdata` by running the `catchup` command in the `FULL` mode on four parallel threads:

```
pg_probackup catchup --source-pgdata=/master-pgdata --destination-pgdata=/replica-pgdata -p 5432 -d postgres -U remote-postgres-user --stream --backup-mode=FULL --remote-host=remote-hostname --remote-user=remote-unix-username -j 4
```

Command-Line Reference

Commands

This section describes pg_probackup commands. Optional parameters are enclosed in square brackets. For detailed parameter descriptions, see the section Options.

version

```
pg_probackup version [--format=json]
```

Prints pg_probackup version and edition, as well as Postgres Pro version and edition.

If `--format=json` is specified, the output is printed in the JSON format. This may be needed for native integration with JSON-based applications, such as PPEM. Example of a JSON output:

```
pg_probackup version --format=json
{
    "pg_probackup":
    {
        "version": "2.8.2",
        "edition": "enterprise"
    },
    "database":
    {
        "type": "Postgres Pro Enterprise",
        "version": "16.3.1"
    },
    "compressions": [zlib, pglz, lz4, zstd]
}
```

help

```
pg_probackup help [command]
```

Displays the synopsis of pg_probackup commands. If one of the pg_probackup commands is specified, shows detailed information about the options that can be used with this command.

init

```
pg_probackup init -B backup_dir [--skip-if-exists] [s3_options] [--help]
```

[*logging_options*]

Initializes the backup catalog in *backup_dir* that will store backup copies, WAL archive, and meta information for the backed up database clusters. If the specified *backup_dir* already exists, it must be empty. Otherwise, pg_probackup displays a corresponding error message. You can ignore this error by specifying the `--skip-if-exists` option. Although the backup will not be initialized, the application will return 0 code.

For details, see the section Initializing the Backup Catalog.

add-instance

```
pg_probackup add-instance -B backup_dir -D data_dir --instance=instance_name
[--skip-if-exists] [s3_options] [--help] [logging_options]
```

Initializes a new backup instance inside the backup catalog *backup_dir* and generates the `pg_probackup.conf` configuration file that controls pg_probackup settings for the cluster with the specified *data_dir* data directory.

`--skip-if-exists`

Allows skipping initialization without raising an error if an instance already exists.

For details, see the section Adding a New Backup Instance.

del-instance

```
pg_probackup del-instance -B backup_dir --instance=instance_name [s3_options] [--help]
[logging_options]
```

Deletes all backups and WAL files associated with the specified instance.

set-config

```
pg_probackup set-config -B backup_dir --instance=instance_name
[--help] [--pgdata=pgdata-path]
[--retention-redundancy=redundancy][--retention-window=window][--wal-depth=wal_depth]
[--compress-algorithm=compression_algorithm] [--compress-level=compression_level]
[-d dbname] [-h host] [-p port] [-U username]
[--archive-timeout=timeout] [--external-dirs=external_directory_path]
[--restore-command=cmdline]
[remote_options] [remote_wal_archive_options] [logging_options] [s3_options]
```

Adds the specified connection, compression, retention, logging, and external directory settings into the `pg_probackup.conf` configuration file, or modifies the previously defined values.

For all available settings, see the Options section.

It is **not recommended** to edit `pg_probackup.conf` manually.

set-backup

```
pg_probackup set-backup -B backup_dir --instance=instance_name -i backup_id
{--ttl=ttl | --expire-time=time}
[--note=backup_note] [s3_options] [--help] [logging_options]
```

Sets the provided backup-specific settings into the `backup.control` configuration file, or modifies the previously defined values.

`--note=backup_note`

Sets the text note for backup copy. If *backup_note* contains newline characters, then only the substring before the first newline character will be saved. The maximum size of a text note is 1 KB. The *'none'* value removes the current note.

For all available pinning settings, see the section Pinning Options.

show-config

```
pg_probackup show-config -B backup_dir --instance instance_name [--format=plain|json]
 [s3_options]
[--no-scale-units] [logging_options]
```

Displays all the current pg_probackup configuration settings, including those that are specified in the `pg_probackup.conf` configuration file located in the *backup_dir*`/backups/`*instance_name* directory and those that were provided on a command line. You can specify the `--format=json` option to get the result in the JSON format. By default, configuration settings are shown as plain text.

You can also specify the `--no-scale-units` option to display time and memory configuration settings in their base (unscaled) units. Otherwise, the values are scaled to larger units for optimal display. For example, if `archive-timeout` is 300, then `5min` is displayed, but if `archive-timeout` is 301, then `301s` is displayed. Also, if the `--no-scale-units` option is specified, configuration settings are displayed without units and for the JSON format, numeric and boolean values are not enclosed in quotes. This facilitates parsing the output.

To edit `pg_probackup.conf`, use the set-config command.

show

```
pg_probackup show -B backup_dir
[--help] [--instance=instance_name [-i backup_id | --archive]] [--format=plain|json]
 [--no-color] [--show-symlinks] [s3_options]
[logging_options]
```

Shows the contents of the backup catalog. If *instance_name* and *backup_id* are specified, shows detailed information about this backup. If the `--archive` option is specified, shows the contents of WAL archive of the backup catalog.

By default, the contents of the backup catalog is shown as plain text. You can specify the `--format=json` option to get the result in the JSON format. If `--no-color` flag is used, then the output is not colored.

If the `--show-symlinks` option is specified, the command also shows the links between merged backups and the original full backups that incremental backups were merged to.

For details on usage, see the sections Managing the Backup Catalog and Viewing WAL Archive Information.

backup

```
pg_probackup backup -B backup_dir -b backup_mode --instance=instance_name
[--help] [-j num_threads] [--progress]
[--backup-threads num_threads] [--validate-threads num_threads]
[-C] [--stream [-S slot_name] [--temp-slot[=true|false|on|off]]] [--backup-pg-log]
[--no-validate] [--skip-block-validation]
[-w --no-password] [-W --password] [--allow-group-access]
[--write-rate-limit=bitrate]
[--archive-timeout=timeout] [--external-dirs=external_directory_path]
[--no-sync] [--note=backup_note]
[connection_options] [compression_options] [remote_options]
[retention_options] [pinning_options] [logging_options] [s3_options]
```

Creates a backup copy of the Postgres Pro instance.

`-b` *mode*
`--backup-mode=`*mode*

Specifies the backup mode to use. Possible values are: `FULL`, `DELTA`, `PAGE`, and `PTRACK`.

`--backup-threads` *num_threads*

Specifies the number of threads for copying files. Overrides the `j`/`--threads` option for file copying.

`--validate-threads` *num_threads*

Specifies the number of threads for the backup validation. Overrides the `j`/`--threads` option for the backup validation.

`-C`
`--smooth-checkpoint`

Spreads out the checkpoint over a period of time. By default, pg_probackup tries to complete the checkpoint as soon as possible.

`--stream`

Makes a STREAM backup, which includes all the necessary WAL files by streaming them from the database server via replication protocol.

`--temp-slot[=true|false|on|off]`

Creates a *temporary* physical replication slot for streaming WAL from the backed up Postgres Pro instance. `--temp-slot` is enabled by default. It ensures that all the required WAL segments remain available if WAL is rotated while the backup is in progress. This flag can only be used together with the `--stream` flag. The default slot name is `pg_probackup_slot`. To change it, use the `--slot`/`-S` option and explicitly specify `--temp-slot` or `--temp-slot=true|on`.

`-S` *slot_name*
`--slot=`*slot_name*

Specifies the replication slot to connect to for WAL streaming. This option can only be used together with the `--stream` flag.

`--backup-pg-log`

Includes the log directory into the backup. This directory usually contains log messages. By default, log directory is excluded.

`-E` *external_directory_path*
`--external-dirs=`*external_directory_path*

Includes the specified directory into the backup by recursively copying its contents into a separate subdirectory in the backup catalog. This option is useful to back up scripts, SQL dump files, and configuration files located outside of the data directory. If you would like to back up several external directories, separate their paths by a colon on Unix and a semicolon on Windows.

`--allow-group-access`

Provides read access to backups stored on the backup host to any OS user in the same group as the OS user on the backup host who runs pg_probackup operations.

`--write-rate-limit=`*bitrate*

Sets the rate of writing data to disk, in MBps or GBps. The default unit is MBps. For example: `--write-rate-limit=1GBps` or `--write-rate-limit=100` (MBps). The default value is 0 — no limitation.

If this option is specified, the following information is displayed at the end of the backup:

- `written` — the amount of data written, in MB.
- `total time` — the time that elapsed between the first and last writes, in seconds. Note that this is not the total backup time.
- `sleep time` — the amount of forced delay time, in seconds.
- `average rate` — the actual average write rate, in MBps.

For example:

```
INFO: Rate limit: written 14975.445 MB, total time 17.163 s, sleep time 2.370 s,
 average rate 872.560715 MBps
```

`--archive-timeout=`*wait_time*

Sets the timeout for WAL segment archiving and streaming, in seconds. By default, pg_probackup waits 300 seconds.

`--skip-block-validation`

Disables block-level checksum verification to speed up the backup process.

`--no-validate`

Skips automatic validation after the backup is taken. You can use this flag if you validate backups regularly and would like to save time when running backup operations.

It is recommended to use this flag when creating a backup to an S3 storage. Due to some features of S3 storages, automatic validation may appear incorrect in this case. Skip automatic validation and then perform validation using a separate validate command.

`--no-sync`

Do not sync backed up files to disk. You can use this flag to speed up the backup process. Using this flag can result in data corruption in case of operating system or hardware crash. If you use this option, it is recommended to run the validate command once the backup is complete to detect possible issues.

`--note=`*backup_note*

Sets the text note for backup copy. If *backup_note* contain newline characters, then only substring before first newline character will be saved. Max size of text note is 1 KB. The *'none'* value removes current note.

For more details of the command settings, see sections Common Options, Connection Options, Retention Options, Pinning Options, Remote Mode Options, Compression Options, Logging Options, and S3 Options.

For details on usage, see the section Creating a Backup.

restore

```
pg_probackup restore -B backup_dir --instance=instance_name
[--help] [--dry-run] [-D data_dir] [-i backup_id]
[-j num_threads] [--progress]
[-T OLDDIR=NEWDIR] [--external-mapping=OLDDIR=NEWDIR] [--skip-external-dirs]
[-R | --restore-as-replica] [--no-validate] [--skip-block-validation]
[--force] [--no-sync] [--allow-group-access]
[--restore-command=cmdline]
[--primary-conninfo=primary_conninfo]
[-S | --primary-slot-name=slot_name]
[-X wal_dir | --waldir=wal_dir]
[recovery_target_options] [logging_options] [remote_options]
[partial_restore_options] [remote_wal_archive_options] [s3_options]
```

Restores the Postgres Pro instance from a backup copy located in the *backup_dir* backup catalog. If you specify a recovery target option, pg_probackup finds the closest backup and restores it to the specified recovery target. If neither the backup ID nor recovery target options are provided, pg_probackup uses the most recent backup to perform the recovery.

`-R`
`--restore-as-replica`

Creates a minimal recovery configuration file to facilitate setting up a standby server. If the replication connection requires a password, you must specify the password manually in the primary_con-

ninfo parameter as it is not included. For Postgres Pro 11 or lower, recovery settings are written into the `recovery.conf` file. Starting from Postgres Pro 12, pg_probackup writes these settings into the `probackup_recovery.conf` file in the data directory, and then includes them into the `postgresql.auto.conf` when the cluster is is started.

`--primary-conninfo=`*`primary_conninfo`*

Sets the primary_conninfo parameter to the specified value. This option will be ignored unless the `-R` flag is specified.

Example: `--primary-conninfo="host=192.168.1.50 port=5432 user=foo password=foopass"`

`-S`
`--primary-slot-name=`*`slot_name`*

Sets the primary_slot_name parameter to the specified value. This option will be ignored unless the `-R` flag is specified.

`-T` *`OLDDIR=NEWDIR`*
`--tablespace-mapping=`*`OLDDIR=NEWDIR`*

Relocates the tablespace from the *`OLDDIR`* to the *`NEWDIR`* directory at the time of recovery. Both *`OLDDIR`* and *`NEWDIR`* must be absolute paths. If the path contains the equals sign (=), escape it with a backslash. This option can be specified multiple times for multiple tablespaces.

`--external-mapping=`*`OLDDIR=NEWDIR`*

Relocates an external directory included into the backup from the *`OLDDIR`* to the *`NEWDIR`* directory at the time of recovery. Both *`OLDDIR`* and *`NEWDIR`* must be absolute paths. If the path contains the equals sign (=), escape it with a backslash. This option can be specified multiple times for multiple directories.

`--skip-external-dirs`

Skip external directories included into the backup with the `--external-dirs` option. The contents of these directories will not be restored.

`--skip-block-validation`

Disables block-level checksum verification to speed up validation. During automatic validation before the restore only file-level checksums will be verified.

`--no-validate`

Skips backup validation. You can use this flag if you validate backups regularly and would like to save time when running restore operations.

`--allow-group-access`

Provides any OS user in the same group as the cluster owner with the same access to the `PGDATA` directory on the database server as the cluster owner has. Running `restore` with this option will set the same permissions as when the cluster is created using the command

```
initdb --group access
```

`--restore-command=`*`cmdline`*

Sets the restore_command parameter to the specified command. For example: `--restore-command='cp /mnt/server/archivedir/%f "%p"'`

`--force`

Allows to ignore an invalid status of the backup. You can use this flag if you need to restore the Postgres Pro cluster from a corrupt or an invalid backup. Use with caution. If `PGDATA` contains a non-empty directory with system ID different from that of the backup being restored, incremental

restore with this flag overwrites the directory contents (while an error occurs without the flag). If tablespaces are remapped through the `--tablespace-mapping` option into non-empty directories, the contents of such directories will be deleted.

`--no-sync`

Do not sync restored files to disk. You can use this flag to speed up restore process. Using this flag can result in data corruption in case of operating system or hardware crash. If it happens, you have to run the restore command again.

`-X` *wal_dir*
`--waldir=`*wal_dir*

Sets the directory to write WAL files to. By default WAL files will be placed in the `pg_wal` subdirectory of the target directory, but this option can be used to place them elsewhere. *wal_dir* must be an absolute path, which must not already exist, but if it does, it must be empty.

For more details of the command settings, see sections Common Options, Recovery Target Options, Remote Mode Options, Remote WAL Archive Options, Logging Options, Partial Restore Options, and S3 Options.

For details on usage, see the section Restoring a Cluster.

checkdb

```
pg_probackup checkdb
[-B backup_dir] [--instance=instance_name] [-D data_dir]
[--help] [-j num_threads] [--progress]
[--amcheck [--skip-block-validation] [--checkunique] [--heapallindexed]]
[connection_options] [logging_options]
[s3_options]
```

Verifies the Postgres Pro database cluster correctness by detecting physical and logical corruption.

For the command to work correctly, when the backup instance is created in the S3 storage, you must specify S3 options on the command line or through environment variables.

`--amcheck`

Performs logical verification of indexes for the specified Postgres Pro instance if no corruption was found while checking data files. You must have the amcheck extension or the amcheck_next extension installed in the database to check its indexes. For databases without amcheck, index verification will be skipped. Additional options `--checkunique` and `--heapallindexed` are effective depending on the version of amcheck installed.

`--checkunique`

Verifies unique constraints during logical verification of indexes. You can use this flag only together with the `--amcheck` flag when the amcheck extension is installed in the database.

The verification of unique constraints is only possible if in the version of the amcheck extension you are using, the `bt_index_check` function takes the *checkunique* parameter.

`--heapallindexed`

Checks that all heap tuples that should be indexed are actually indexed. You can use this flag only together with the `--amcheck` flag.

This check is only possible if in the version of the amcheck/amcheck_next extension you are using, the `bt_index_check` function takes the *heapallindexed* parameter.

`--skip-block-validation`

Skip validation of data files. You can use this flag only together with the `--amcheck` flag, so that only logical verification of indexes is performed.

For more details of the command settings, see sections Common Options, Connection Options, Logging Options, and S3 Options.

For details on usage, see the section Verifying a Cluster.

validate

```
pg_probackup validate -B backup_dir
[--help] [--instance=instance_name] [-i backup_id]
[-j num_threads] [--progress] [--wal]
[--skip-block-validation]
[recovery_target_options] [logging_options] [s3_options]
```

Verifies that all the files required to restore the cluster are present and are not corrupt. If *instance_name* is not specified, pg_probackup validates all backups available in the backup catalog. If you specify the *instance_name* without any additional options, pg_probackup validates all the backups available for this backup instance. If you specify the *instance_name* with a recovery target option and/or a *backup_id*, pg_probackup checks whether it is possible to restore the cluster using these options. If the `--wal` option is specified, full check of the WAL archive will be performed instead of only checking WAL segments needed to restore the cluster.

For details, see the section Validating a Backup.

> **Note**
>
> The `TATLIN.OBJECT` S3 storage is an “eventually consistent” class system. In such systems, the reconciliation across nodes proceeds asynchronously. Therefore, if you are making a backup to the `TATLIN.OBJECT` S3 storage, perform backup validation not immediately after the backup, but some time later.

merge

```
pg_probackup merge -B backup_dir --instance=instance_name -i backup_id
[--dry-run] [--help] [-j num_threads] [--progress] [--no-validate] [--no-sync]
[logging_options]
```

Merges backups that belong to a common incremental backup chain. If you specify a full backup, it will be merged with its first incremental backup. If you specify an incremental backup, it will be merged to its parent full backup, together with all incremental backups between them. Once the merge is complete, the full backup takes in all the merged data, and the incremental backups are removed as redundant.

`--no-validate`

Skips automatic validation before and after merge.

`--no-sync`

Do not sync merged files to disk. You can use this flag to speed up the merge process. Using this flag can result in data corruption in case of operating system or hardware crash.

For more details of the command settings, see sections Common Options and Merging Backups.

delete

```
pg_probackup delete -B backup_dir --instance=instance_name
[--help] [-j num_threads] [--progress]
[--retention-redundancy=redundancy][--retention-window=window][--wal-depth=wal_depth]
 [--delete-wal]
{-i backup_id | --delete-expired [--merge-expired] | --merge-expired | --
status=backup_status}
[--dry-run] [--no-validate] [--no-sync] [logging_options] [s3_options]
```

Deletes backup with specified *backup_id* or launches the retention purge of backups and archived WAL that do not satisfy the current retention policies.

--no-validate

Skips automatic validation before and after retention merge.

--no-sync

Do not sync merged files to disk. You can use this flag to speed up the retention merge process. Using this flag can result in data corruption in case of operating system or hardware crash.

For details, see the sections Deleting Backups, Retention Options, and Configuring Retention Policy.

archive-push

```
pg_probackup archive-push -B backup_dir --instance=instance_name
--wal-file-name=wal_file_name [--wal-file-path=wal_file_path]
[--help] [--dry-run] [--no-sync] [--compress] [--no-ready-rename] [--overwrite]
[-j num_threads] [--batch-size=batch_size]
[--archive-timeout=timeout]
[--compress-algorithm=compression_algorithm]
[--compress-level=compression_level]
[remote_options] [logging_options] [s3_options]
```

Copies WAL files into the corresponding subdirectory of the backup catalog and validates the backup instance by *instance_name* and system-identifier. If parameters of the backup instance and the cluster do not match, this command fails with the following error message: `Refuse to push WAL segment segment_name into archive. Instance parameters mismatch.`

If the files to be copied already exists in the backup catalog, pg_probackup computes and compares their checksums. If the checksums match, archive-push skips the corresponding file and returns a successful execution code. Otherwise, archive-push fails with an error. If you would like to replace WAL files in the case of checksum mismatch, run the archive-push command with the --overwrite flag.

Each file is copied to a temporary file with the .part suffix. If the temporary file already exists, pg_probackup will wait archive_timeout seconds before discarding it. After the copy is done, atomic rename is performed. This algorithm ensures that a failed archive-push will not stall continuous archiving and that concurrent archiving from multiple sources into a single WAL archive has no risk of archive corruption.

The Postgres Pro server requests WAL segments one at a time. To speed up archiving, you can specify the --batch-size option to copy WAL segments in batches of the specified size. If --batch-size option is used, then you can also specify the -j option to copy the batch of WAL segments on multiple threads.

WAL segments copied to the archive are synced to disk unless the --no-sync flag is used.

You can use archive-push in the archive_command Postgres Pro parameter to set up continuous WAL archiving.

For more details of the command settings, see sections Common Options, Archiving Options, Compression Options, and S3 Options.

archive-get

```
pg_probackup archive-get -B backup_dir --instance=instance_name --wal-file-
path=wal_file_path --wal-file-name=wal_file_name
[-j num_threads] [--batch-size=batch_size]
[--prefetch-dir=prefetch_dir_path] [--no-validate-wal]
[--dry-run] [--help] [remote_options] [logging_options] [s3_options]
```

Copies WAL files from the corresponding subdirectory of the backup catalog to the cluster's write-ahead log location. This command is automatically set by pg_probackup as part of the restore_command when

restoring backups using a WAL archive. You do not need to set it manually if you use local storage for backups or remote mode.

If you use S3 interface, to ensure that the Postgres Pro server has access to S3 storage to fetch WAL files during restore, you can specify the `--s3-config-file` option that defines the S3 configuration file with appropriate configuration settings, as described in the section called "S3 Options".

The Postgres Pro server requests WAL segments one at a time. To speed up recovery, you can specify the `--batch-size` option to copy WAL segments in batches of the specified size. If `--batch-size` option is used, then you can also specify the `-j` option to copy the batch of WAL segments on multiple threads.

For more details of the command settings, see sections Common Options, Archiving Options, Compression Options, and S3 Options.

catchup

```
pg_probackup catchup -b catchup_mode
--source-pgdata=path_to_pgdata_on_remote_server
--destination-pgdata=path_to_local_dir
[--help] [-j | --threads=num_threads] [--dry-run]
[--write-rate-limit=bitrate]
[--stream [--temp-slot[=true|false|on|off]] [-P | --perm-slot] [-S | --slot=slot_name]]
[--exclude-path=PATHNAME]
[-T OLDDIR=NEWDIR]
[-X | --waldir=wal_dir]
[connection_options] [remote_options]
[logging_options]
```

Creates a copy of a Postgres Pro instance without using the backup catalog.

`-b catchup_mode`
`--backup-mode=catchup_mode`

Specifies the catchup mode to use. Possible values are: `FULL`, `DELTA`, and `PTRACK`.

`--source-pgdata=path_to_pgdata_on_remote_server`

Specifies the path to the data directory of the instance to be copied. The path can be local or remote.

`--destination-pgdata=path_to_local_dir`

Specifies the path to the local data directory to copy to.

`-j num_threads`
`--threads=num_threads`

Sets the number of parallel threads for `catchup` process.

`--stream`

Copies the instance in STREAM WAL delivery mode, including all the necessary WAL files by streaming them from the server via replication protocol. For `catchup`, it is enabled by default.

`--write-rate-limit=bitrate`

Sets the rate of writing data to disk, in MBps or GBps. The default unit is MBps. For example: `--write-rate-limit=1GBps` or `--write-rate-limit=100` (MBps). The default value is 0 — no limitation.

If this option is specified, the following information is displayed at the end of the `catchup` operation:

- `written` — the amount of data written, in MB.
- `total time` — the time that elapsed between the first and last writes, in seconds. Note that this is not the total duration of the `catchup` operation.

- `sleep time` — the amount of forced delay time, in seconds.
- `average rate` — the actual average write rate, in MBps.

For example:

```
INFO: Rate limit: written 14975.445 MB, total time 17.163 s, sleep time 2.370 s,
 average rate 872.560715 MBps
```

`-x=`*`path_prefix`*
`--exclude-path=`*`path_prefix`*

Specifies a prefix for files to exclude from the synchronization of Postgres Pro instances during copying. The prefix must contain a path relative to the data directory of an instance. If the prefix specifies a directory, all files in this directory will not be synchronized.

> **Warning**
>
> This option is dangerous since excluding files from synchronization can result in incomplete synchronization; use with care.

`--temp-slot[=true|false|on|off]`

Creates a *temporary* physical replication slot for streaming WAL from the Postgres Pro instance being copied. `--temp-slot` is enabled by default. It ensures that all the required WAL segments remain available if WAL is rotated while the backup is in progress. This flag can only be used together with the `--stream` flag and cannot be used together with the `--perm-slot` flag. The default slot name is `pg_probackup_slot`. To change it, use the `--slot`/`-S` option and explicitly specify `--temp-slot` or `--temp-slot=true|on`.

`-P`
`--perm-slot`

Creates a *permanent* physical replication slot for streaming WAL from the Postgres Pro instance being copied. This flag can only be used together with the `--stream` flag and cannot be used together with the `--temp-slot` flag. The default slot name is `pg_probackup_perm_slot`, which can be changed using the `--slot`/`-S` option.

`-S` *`slot_name`*
`--slot=`*`slot_name`*

Specifies the replication slot to connect to for WAL streaming. This option can only be used together with the `--stream` flag.

`-T` *`OLDDIR=NEWDIR`*
`--tablespace-mapping=`*`OLDDIR=NEWDIR`*

Relocates the tablespace from the *`OLDDIR`* to the *`NEWDIR`* directory at the time of recovery. Both *`OLDDIR`* and *`NEWDIR`* must be absolute paths. If the path contains the equals sign (=), escape it with a backslash. This option can be specified multiple times for multiple tablespaces.

`-X` *`wal_dir`*
`--waldir=`*`wal_dir`*

Sets the directory to write WAL files to. By default WAL files will be placed in the `pg_wal` subdirectory of the target directory, but this option can be used to place them elsewhere. *`wal_dir`* must be an absolute path, which must not already exist, but if it does, it must be empty to perform `catchup` with `--catchup-mode=FULL`.

For more details of the command settings, see sections Common Options, Connection Options, and Remote Mode Options.

For details on usage, see the section Cloning and Synchronizing Postgres Pro Instance.

maintain

```
pg_probackup maintain --B backup_dir --instance=instance_name
[-i backup_id] --status-sync [--help] [--dry-run]
[--log-level-console=log-level-console] [--log-level-file=log-level-file]
[--log-format-console=log-format-console] [--log-format-file=log-format-file]
[--log-filename=log-filename]
```

Performs a cleanup of the directory with backups of the specified instance after a forced termination of previous pg_probackup commands.

`--status-sync`

Detects expired locks and hanging backups, as well as updates backup statuses.

For more details of the command settings, see sections Common Options and Logging Options.

Options

This section describes command-line options for pg_probackup commands. If the option value can be derived from an environment variable, this variable is specified below the command-line option, in the uppercase. Some values can be taken from the `pg_probackup.conf` configuration file located in the backup catalog.

For details, see the section called “Configuring pg_probackup”.

If an option is specified using more than one method, command-line input has the highest priority, while the `pg_probackup.conf` settings have the lowest priority.

Common Options

The list of general options.

`--dry-run`

Initiates a trial run of the appropriate command, which does not actually do any changes, that is, it does not create, delete or move files on disk. This flag allows you to check that all the command options are correct and the command is ready to run. WAL streaming is skipped with `--dry-run`.

`-B` *directory*
`--backup-path=`*directory*
`BACKUP_PATH`

Specifies the absolute path to the backup catalog. Backup catalog is a directory where all backup files and meta information are stored. Since this option is required for most of the pg_probackup commands, you are recommended to specify it once in the `BACKUP_PATH` environment variable. In this case, you do not need to use this option each time on the command line.

`-D` *directory*
`--pgdata=`*directory*
`PGDATA`

Specifies the absolute path to the data directory of the database cluster. This option is mandatory only for the add-instance command. Other commands can take its value from the `PGDATA` environment variable, or from the `pg_probackup.conf` configuration file.

`-i` *backup_id*
`--backup-id=`*backup_id*

Specifies the unique identifier of the backup.

`--instance` *instance_name*

Specifies the name of the Postgres Pro instance.

`-j` *num_threads*
`--threads=`*num_threads*

Sets the number of parallel threads for `backup`, `restore`, `merge`, `validate`, `checkdb`, and `archive-push` processes.

`--progress`

Shows the progress of operations.

`--help`

Shows detailed information about the options that can be used with this command.

Recovery Target Options

If continuous WAL archiving is configured, you can use one of these options together with restore or validate commands to specify the moment up to which the database cluster must be restored or validated.

`--recovery-target=immediate|latest`

Defines when to stop the recovery:

- The `immediate` value stops the recovery after reaching the consistent state of the specified backup, or the latest available backup if the `-i`/`--backup-id` option is omitted. This is the default behavior for STREAM backups.
- The `latest` value continues the recovery until all WAL segments available in the archive are applied. Setting this value of `--recovery-target` also sets `--recovery-target-timeline` to `latest`.

`--recovery-target-timeline=`*timeline*

Specifies a particular timeline to be used for recovery:

- `current` — the timeline of the specified backup, default.
- `latest` — the timeline of the latest available backup.
- A numeric value.

`--recovery-target-lsn=`*lsn*

Specifies the LSN of the write-ahead log location up to which recovery will proceed.

`--recovery-target-name=`*recovery_target_name*

Specifies a named savepoint up to which to restore the cluster.

`--recovery-target-time=`*time*

Specifies the timestamp up to which recovery will proceed. If the time zone offset is not specified, the local time zone is used.

Example: `--recovery-target-time="2027-04-09 18:21:32+00"`

`--recovery-target-xid=`*xid*

Specifies the transaction ID up to which recovery will proceed.

`--recovery-target-inclusive=`*boolean*

Specifies whether to stop just after the specified recovery target (`true`), or just before the recovery target (`false`). This option can only be used together with `--recovery-target-time`, `--recovery-target-lsn` or `--recovery-target-xid` options. The default depends on the recovery_target_inclusive parameter.

`--recovery-target-action=pause|promote|shutdown`

Specifies recovery_target_action the server should take when the recovery target is reached.

Default: `pause`

Retention Options

You can use these options together with backup and delete commands.

For details on configuring retention policy, see the section Configuring Retention Policy.

`--retention-redundancy=`*`redundancy`*

Specifies the number of full backup copies to keep in the data directory. Must be a non-negative integer. The zero value disables this setting.

Default: `0`

`--retention-window=`*`window`*

Number of days of recoverability. Must be a non-negative integer. The zero value disables this setting.

Default: `0`

`--wal-depth=`*`wal_depth`*

Number of latest valid backups on every timeline that must retain the ability to perform PITR. Must be a non-negative integer. The zero value disables this setting.

Default: `0`

`--delete-wal`

Deletes WAL files that are no longer required to restore the cluster from any of the existing backups.

`--delete-expired`

Deletes backups that do not conform to the retention policy defined in the `pg_probackup.conf` configuration file.

`--merge-expired`

Merges the oldest incremental backup that satisfies the requirements of retention policy with its parent backups that have already expired.

`--dry-run`

Displays the current status of all the available backups, without deleting or merging expired backups, if any.

Pinning Options

You can use these options together with backup and set-backup commands.

For details on backup pinning, see the section Backup Pinning.

`--ttl=`*`ttl`*

Specifies the amount of time the backup should be pinned. Must be a non-negative integer. The zero value unpins the already pinned backup. Supported units: ms, s, min, h, d (s by default).

Example: `--ttl=30d`

`--expire-time=`*`time`*

Specifies the timestamp up to which the backup will stay pinned. Must be an ISO-8601 complaint timestamp. If the time zone offset is not specified, the local time zone is used.

Example: `--expire-time="2027-04-09 18:21:32+00"`

Logging Options

You can use these options with any command.

`--no-color`

Disable coloring for console log messages of `warning` and `error` levels.

`--log-level-console=`*`log_level`*

Controls which message levels are sent to the console log. Valid values are `verbose`, `log`, `info`, `warning`, `error` and `off`. Each level includes all the levels that follow it. The later the level, the fewer messages are sent. The `off` level disables console logging.

Default: `info`

> **Note**
>
> All console log messages are going to stderr, so the output of show and show-config commands does not mingle with log messages.

`--log-level-file=`*`log_level`*

Controls which message levels are sent to a log file. Valid values are `verbose`, `log`, `info`, `warning`, `error`, and `off`. Each level includes all the levels that follow it. The later the level, the fewer messages are sent. The `off` level disables file logging.

Default: `off`

`--log-filename=`*`log_filename`*

Defines the filenames of the created log files. The filenames are treated as a `strftime` pattern, so you can use %-escapes to specify time-varying filenames.

Default: `pg_probackup.log`

For example, if you specify the `pg_probackup-%u.log` pattern, pg_probackup generates a separate log file for each day of the week, with `%u` replaced by the corresponding decimal number: `pg_probackup-1.log` for Monday, `pg_probackup-2.log` for Tuesday, and so on.

This option takes effect if file logging is enabled by the `--log-level-file` option.

`--error-log-filename=`*`error_log_filename`*

Defines the filenames of log files for error messages only. The filenames are treated as a `strftime` pattern, so you can use %-escapes to specify time-varying filenames.

Default: none

For example, if you specify the `error-pg_probackup-%u.log` pattern, pg_probackup generates a separate log file for each day of the week, with `%u` replaced by the corresponding decimal number: `error-pg_probackup-1.log` for Monday, `error-pg_probackup-2.log` for Tuesday, and so on.

This option is useful for troubleshooting and monitoring.

`--log-directory=`*`log_directory`*

Defines the directory in which log files will be created. You must specify the absolute path. This directory is created lazily, when the first log message is written.

Note that the directory for log files is always created locally even if backups are created in the S3 storage. So be sure to pass a local path in *`log_directory`* when needed.

Default: `$BACKUP_PATH/log/`

`--log-format-console=`*`log_format`*

Defines the format of the console log. Only set from the command line. Note that you cannot specify this option in the `pg_probackup.conf` configuration file through the set-config command and that the backup command also treats this option specified in the configuration file as an error. Possible values are:

- `plain` — sets the plain-text format of the console log.
- `json` — sets the JSON format of the console log.

Default: `plain`

`--log-format-file=`*`log_format`*

Defines the format of log files used. Possible values are:

- `plain` — sets the plain-text format of log files.
- `json` — sets the JSON format of log files.

Default: `plain`

`--log-rotation-size=`*`log_rotation_size`*

Maximum size of an individual log file. If this value is reached, the log file is rotated once a pg_probackup command is launched, except `help` and `version` commands. The zero value disables size-based rotation. Supported units: kB, MB, GB, TB (kB by default).

Default: `0`

`--log-rotation-age=`*`log_rotation_age`*

Maximum lifetime of an individual log file. If this value is reached, the log file is rotated once a pg_probackup command is launched, except `help` and `version` commands. The time of the last log file creation is stored in `$BACKUP_PATH/log/log_rotation`. The zero value disables time-based rotation. Supported units: ms, s, min, h, d (min by default).

Default: `0`

Connection Options

You can use these options together with backup, catchup, and checkdb commands.

All libpq environment variables are supported.

`-d` *`dbname`*
`--pgdatabase=`*`dbname`*
`PGDATABASE`

Specifies the name of the database to connect to. The connection is used only for managing backup process, so you can connect to any existing database. If this option is not provided on the command line, `PGDATABASE` environment variable, or the `pg_probackup.conf` configuration file, pg_probackup tries to take this value from the `PGUSER` environment variable, or from the current user name if `PGUSER` variable is not set.

`-h` *`host`*
`--pghost=`*`host`*
`PGHOST`

Specifies the host name of the system on which the server is running. If the value begins with a slash, it is used as a directory for the Unix domain socket.

Default: `localhost`

`-p` *port*
`--pgport=`*port*
`PGPORT`

Specifies the TCP port or the local Unix domain socket file extension on which the server is listening for connections.

Default: `5432`

`-U` *username*
`--pguser=`*username*
`PGUSER`

User name to connect as.

`-w`
`--no-password`

Disables a password prompt. If the server requires password authentication and a password is not available by other means such as a .pgpass file or `PGPASSWORD` environment variable, the connection attempt will fail. This flag can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Forces a password prompt. (Deprecated)

Compression Options

You can use these options together with backup and archive-push commands.

`--compress-algorithm=`*compression_algorithm*

Defines the algorithm to use for compressing data files. Possible values are `zlib`, `lz4`, `zstd`, `pglz`, and `none`. If set to any value, but `none`, this option enables compression that uses the corresponding algorithm. Both data files and WAL files are compressed. By default, compression is disabled. For the archive-push command, the `pglz` compression algorithm is not supported.

> **Note**
>
> pg_probackup supports compression algorithms included in the Postgres Pro version. In particular:
>
> - lz4 is supported for Postgres Pro Enterprise 13 and higher.
> - zstd is supported for Postgres Pro Enterprise 11 and higher.

Default: `none`

`--compress-level=`*compression_level*

Defines the compression level. This option can be used together with the `--compress-algorithm` option. Possible values depend on the compression algorithm specified:

- 0 — 9 for `zlib`
- 1 for `pglz`
- 0 — 12 for `lz4`
- 0 — 22 for `zstd`

The value of 0 sets the default compression level for the specified algorithm:

- 6 for `zlib`

- 1 for `pglz`
- 9 for `lz4`
- 3 for `zstd`

> **Note**
>
> The pure lz4 algorithmn has only one compression level — 1. So, if the specified compression algorithm is `lz4` and `--compress-level` is greater than 1, the lz4hc algorithm is actually used, which is much slower although does better compression.

Default: `1`

`--compress`

Specifies the default compression algorithm and `--compress-level=1`. The default algorithm is selected among those supported by Postgres Pro according to the priorities: `zstd` (highest) -> `lz4` -> `zlib` -> `pglz`. The `--compress` option overrides the `--compression-algorithm` and `--compress-level` settings and cannot be specified together with them.

Archiving Options

These options can be used with the archive-push command in the archive_command setting and the archive-get command in the restore_command setting.

Additionally, remote mode options and logging options can be used.

`--wal-file-path=`*`wal_file_path`*

Provides the path to the WAL file in *`archive_command`* and *`restore_command`*. Use the `%p` variable as the value for this option or explicitly specify the path to a file outside of the data directory. If you skip this option, the path specified in `pg_probackup.conf` will be used.

`--wal-file-name=`*`wal_file_name`*

Provides the name of the WAL file in *`archive_command`* and *`restore_command`*. Use the `%f` variable as the value for this option for correct processing. If the value of `--wal-file-path` is a path outside of the data directory, explicitly specify the filename.

`--overwrite`

Overwrites archived WAL file. Use this flag together with the archive-push command if the specified subdirectory of the backup catalog already contains this WAL file and it needs to be replaced with its newer copy. Otherwise, `archive-push` reports that a WAL segment already exists, and aborts the operation. If the file to replace has not changed, `archive-push` skips this file regardless of the `--overwrite` flag.

`--batch-size=`*`batch_size`*

Used to speed up archiving in case of `archive-push` or to speed up recovery in case of `archive-get`. Sets the maximum number of WAL files that can be copied into the archive by a single `archive-push` process, or from the archive by a single `archive-get` process.

`--archive-timeout=`*`wait_time`*

Sets the timeout for considering existing `.part` files to be stale. By default, pg_probackup waits 300 seconds. This option can be used only with archive-push command.

`--no-ready-rename`

Do not rename status files in the `archive_status` directory. This option should be used only if *`archive_command`* contains multiple commands. This option can be used only with archive-push command.

`--no-sync`

Do not sync copied WAL files to disk. You can use this flag to speed up archiving process. Using this flag can result in WAL archive corruption in case of operating system or hardware crash. This option can be used only with archive-push command.

`--prefetch-dir=`*`path`*

Directory used to store prefetched WAL segments if `--batch-size` option is used. Directory must be located on the same filesystem and on the same mountpoint the `PGDATA/pg_wal` is located. By default files are stored in `PGDATA/pg_wal/pbk_prefetch` directory. This option can be used only with archive-get command.

`--no-validate-wal`

Do not validate prefetched WAL file before using it. Use this option if you want to increase the speed of recovery. This option can be used only with archive-get command.

Remote Mode Options

This section describes the options related to running pg_probackup operations remotely via SSH. These options can be used with add-instance, set-config, backup, catchup, restore, archive-push, and archive-get commands.

For details on configuring and using the remote mode, see the section called “Configuring the Remote Mode” and the section called “Using pg_probackup in the Remote Mode”.

`--remote-proto=`*`proto`*

Specifies the protocol to use for remote operations. Currently only the SSH protocol is supported. Possible values are:

- `ssh` enables the remote mode via SSH. This is the default value.
- `none` explicitly disables the remote mode.

You can omit this option if the `--remote-host` option is specified.

`--remote-host=`*`destination`*

Specifies the remote host IP address or hostname to connect to.

`--remote-port=`*`port`*

Specifies the remote host port to connect to.

Default: `22`

`--remote-user=`*`username`*

Specifies remote host user for SSH connection. If you omit this option, the current user initiating the SSH connection is used.

`--remote-path=`*`path`*

Specifies pg_probackup installation directory on the remote system.

`--ssh-options=`*`ssh_options`*

Provides a string of SSH command-line options. For example, the following options can be used to set *`keep-alive`* for SSH connections opened by pg_probackup: `--ssh-options="-o ServerAliveCountMax=5 -o ServerAliveInterval=60"`. For the full list of possible options, see *ssh_config manual page*.

Remote WAL Archive Options

This section describes the options used to provide the arguments for remote mode options in archive-get used in the restore_command command when restoring ARCHIVE backups or performing PITR.

`--archive-host=`*`destination`*

Provides the argument for the `--remote-host` option in the `archive-get` command.

`--archive-port=`*`port`*

Provides the argument for the `--remote-port` option in the `archive-get` command.

Default: `22`

`--archive-user=`*`username`*

Provides the argument for the `--remote-user` option in the `archive-get` command. If you omit this option, the user that has started the Postgres Pro cluster is used.

Default: Postgres Pro user

Incremental Restore Options

This section describes the options for incremental cluster restore. These options can be used with the restore command.

`-I` *`incremental_mode`*
`--incremental-mode=`*`incremental_mode`*

Specifies the incremental mode to be used. Possible values are:

- `CHECKSUM` — replace only pages with mismatched checksum and LSN.
- `LSN` — replace only pages with LSN greater than point of divergence.
- `NONE` — regular restore.

Partial Restore Options

This section describes the options for partial cluster restore. These options can be used with the restore command.

`--db-exclude=`*`dbname`*

Specifies the name of the database to exclude from restore. All other databases in the cluster will be restored as usual, including `template0` and `template1`. This option can be specified multiple times for multiple databases.

`--db-include=`*`dbname`*

Specifies the name of the database to restore from a backup. All other databases in the cluster will not be restored, with the exception of `template0` and `template1`. This option can be specified multiple times for multiple databases.

S3 Options

This section describes the options needed to store backups in private clouds. These options can be used with any commands that pg_probackup runs using S3 interface.

`--s3=`*`s3_interface_provider`*

Specifies the S3 interface provider. Possible values are:

- `minio` — MinIO object storage, compatible with S3 cloud storage service. With this provider, custom S3 server settings can be specified. The HTTP protocol, port 9000, and region `us-east-1` are used by default.
- `vk` — VK Cloud storage. With this provider, the S3 host address `hb.vkcs.cloud`, port 443, and HTTPS protocol are only used. Custom values of the host, port, and protocol are ignored. The default value of region is `ru-msk`.
- `aws` — Amazon S3 storage, offered by Amazon Web Services (AWS). With this provider, the S3 host address *`bucket_name`*`.s3.`*`region`*`.amazonaws.com`, port 443, and HTTPS protocol are only

used. Custom values of the host, port, and protocol are ignored. The default value of region is `us-east-1`.

With `--s3=minio`, pg_probackup will work fine for a VK Cloud storage if the S3 host address, port and protocol are properly specified (host address is `hb.vkcs.cloud` or the one specified in the appropriate section of the VK Cloud profile, port 443, and HTTPS protocol). Do not specify `--s3=minio` for the Amazon S3 storage.

Once a pg_probackup command runs with the `--s3` option, pg_probackup starts running all commands that support parallel execution on 10 parallel threads (for details, see the section called “Running pg_probackup on Parallel Threads”). You can change the number of threads using the `-j`/`--threads` option.

`--s3-config-file=`*`path_to_config_file`*

Specifies the S3 configuration file. Settings in the configuration file override the environment variables. If this option is not specified, pg_probackup first looks for the S3 configuration file at `/etc/pg_probackup/s3.config` and then at `~postgres/.pg_probackup/s3.config`. The following is an example of the S3 configuration file:

```
access-key = ...
secret-key = ...
s3-host = localhost
s3-port = 9000
s3-bucket = s3demo
s3-region=us-east-1
s3-buffer-size = 32
s3-secure = on | https | http | off
```

Testing and Debugging Options

This section describes options useful only in a test or development environment.

`--cfs-nondatafile-mode`

Instructs backup command to backup CFS in a legacy mode. This allows fine-tuning compatibility with pg_probackup versions earlier than 2.6.0. This option is mainly designed for testing.

`PGPROBACKUP_TESTS_SKIP_HIDDEN`

Instructs pg_probackup to ignore backups marked as hidden. Note that pg_probackup can never mark a backup as hidden. It can only be done by directly editing the `backup.control` file. This option can only be set with environment variables.

`--destroy-all-other-dbs`

By default, pg_probackup exits with an error if an attempt is made to perform a partial incremental restore since this destroys databases not included in the restore set. This flag allows you to suppress the error and proceed with the partial incremental restore (e.g., to keep a development database snapshot up-to-date with a production one). This option can be used with the restore command.

> **Important**
>
> Never use this flag in a production cluster.

`--lock-lifetime`

Specifies the lifetime for locks taken when performing a backup, in seconds. The default value is 300. The minimum value is 60.

`PGPROBACKUP_TESTS_SKIP_EMPTY_COMMIT`

Instructs pg_probackup to skip empty commits after pg_backup_stop.

Versioning

pg_probackup follows *semantic* versioning.

Authors

Postgres Professional, Moscow, Russia.

Credits

pg_probackup utility is based on pg_arman, which was originally written by NTT and then developed and maintained by Michael Paquier.

vacuumlo

vacuumlo — remove orphaned large objects from a Postgres Pro database

Synopsis

`vacuumlo` [*option*...] *dbname*...

Description

vacuumlo is a simple utility program that will remove any “orphaned” large objects from a Postgres Pro database. An orphaned large object (LO) is considered to be any LO whose OID does not appear in any `oid` or `lo` data column of the database.

If you use this, you may also be interested in the `lo_manage` trigger in the lo module. `lo_manage` is useful to try to avoid creating orphaned LOs in the first place.

All databases named on the command line are processed.

Options

vacuumlo accepts the following command-line arguments:

`-l` *limit*
`--limit=`*limit*

Remove no more than *limit* large objects per transaction (default 1000). Since the server acquires a lock per LO removed, removing too many LOs in one transaction risks exceeding max_locks_per_transaction. Set the limit to zero if you want all removals done in a single transaction.

`-n`
`--dry-run`

Don't remove anything, just show what would be done.

`-v`
`--verbose`

Write a lot of progress messages.

`-V`
`--version`

Print the vacuumlo version and exit.

`-?`
`--help`

Show help about vacuumlo command line arguments, and exit.

vacuumlo also accepts the following command-line arguments for connection parameters:

`-h` *host*
`--host=`*host*

Database server's host.

`-p` *port*
`--port=`*port*

Database server's port.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force vacuumlo to prompt for a password before connecting to a database.

This option is never essential, since vacuumlo will automatically prompt for a password if the server demands password authentication. However, vacuumlo will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

Environment

`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters.

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

The environment variable `PG_COLOR` specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

Notes

vacuumlo works by the following method: First, vacuumlo builds a temporary table which contains all of the OIDs of the large objects in the selected database. It then scans through all columns in the database that are of type `oid` or `lo`, and removes matching entries from the temporary table. (Note: Only types with these names are considered; in particular, domains over them are not considered.) The remaining entries in the temporary table identify orphaned LOs. These are removed.

Author

Peter Mount `<peter@retep.org.uk>`

I.2. Third-Party Client Applications

This section covers third-party client applications included in the Postgres Pro Enterprise distribution. They can be run from anywhere, independent of where the database server resides.

pgbadger

pgbadger — rapidly analyze Postgres Pro logs, producing detailed reports and graphs

Synopsis

`pgbadger` [*`connection-option`*...] [*`option`*...] [*`logfile`*...]

Description

pgbadger is a Postgres Pro/PostgreSQL log analyzer, which rapidly provides detailed reports based on your log files. pgbadger is provided with Postgres Pro as a standalone Perl script.

`logfile` can be a single log file, a list of files or a shell command that returns a list of files. To get log content from the standard input, pass "-" as *`logfile`*.

pgbadger can parse huge log files and compressed files. It can autodetect your log file format (syslog, stderr, csvlog or jsonlog) if the file is long enough. Supported compressed formats are gzip, bzip2, lz4, xz, zip and zstd. For the xz format, you must have an xz version higher than 5.05, which supports the `--robot` option. For pgbadger to determine the uncompressed file size for the lz4 format, the file must be compressed with the `--content-size` option.

pgbadger supports any format of log-line prefixes that can be specified through the log_line_prefix configuration setting of your `postgresql.conf` configuration file, provided that at least `%t` and `%p` are specified.

pgbouncer log files can also be parsed.

To speed up log parsing, you can use any of these multiprocessing modes: one core per log file and multiple cores per file. These modes can be combined.

pgbadger can also parse remote log files fetched using a passwordless SSH connection. This mode can be used with compressed files and even supports multiprocessing with multiple cores per file.

Examples of reports can be found at *https://pgbadger.darold.net/#reports*.

Limitations

pgbadger currently has the following limitations:

- Multiprocessing is not supported for compressed log files and CSV files, as well as on Windows.
- CSV format of log files cannot be parsed remotely.
- csvlog logs cannot be passed from the standard input.

Setup and Configuring

pgbadger is provided with Postgres Pro Enterprise as a separate pre-built package `pgbadger` (for the detailed installation instructions, see Chapter 17). Once you have pgbadger installed, complete the setup described in sections below.

[Optional] Set up Parsing Specific Log Formats

If you plan to parse CSV log files, install `Text::CSV_XS` Perl module.

[Optional] Set up Export of Statistics

If you want to export statistics as a JSON file, install `JSON::XS` Perl module:

To install this optional module:

- On a Debian-based system, run:

```
sudo apt-get install libjson-xs-perl
```

- On an RPM system, run:

  ```
  sudo yum install perl-JSON-XS
  ```

[Optional] Set up Parsing Compressed Log Files

By default, pgbadger autodetects the compressed log file format from the file extension and uses decompression utilities accordingly:

- zcat for `gz`
- bzcat for `bz2`
- lz4cat for `lz4`
- zstdcat for `zst`
- unzip or xz for `zip` or `xz`

If the needed utility is outside of your `PATH` directories, use the `--zcat` command-line option to specify the path to the decompression utility. For example:

```
--zcat="/usr/local/bin/gunzip -c" or --zcat="/usr/local/bin/bzip2 -dc"
--zcat="C:\tools\unzip -p"
```

> **Note**
>
> With the default autodetection of the compressed file format, you can mix gz, bz2, lz4, xz, zip and zstd log files. Once you specified a custom value of `--zcat`, mixing compressed files of different formats is longer possible.

Configure Your Postgres Pro Server

Set the values of certain configuration parameters in your `postgresql.conf`:

- Set up logging SQL queries.

  To enable SQL query logging and have the query statistics include actual query strings, set

  ```
  log_min_duration_statement = 0
  ```

  On a busy server you may want to increase this value to only log queries with a longer duration.

  If you just want to report the duration and number of queries and do not want details of queries, set log_min_duration_statement to -1, which disables logging statement durations, and enable log_duration.

  Enabling `log_min_duration_statement` will add reports about slowest queries and queries that took the most time. Note that if you set log_statement to `all`, the setting of `log_min_duration_statement` will have no effect.

  > **Warning**
  >
  > Avoid setting `log_min_duration_statement` to a non-positive value together with enabling `log_duration` and `log_statement` as this will result in wrong counter values and drastically increase the size of your log. Always prefer setting `log_min_duration_statement`.

- Set the log line prefix string in log_line_prefix.

  It must at least include a time escape sequence (`%t`, `%m` or `%n`) and the process-related escape sequence (`%p` or `%c`). For example, for stderr logs, the setting must be at least

```
log_line_prefix = '%t [%p]: '
```

The log line prefix could also specify the user, database name, application name and client IP address. For example,

for stderr logs:

```
log_line_prefix = '%t [%p]: user=%u,db=%d,app=%a,client=%h '
```

or

```
log_line_prefix = '%t [%p]: db=%d,user=%u,app=%a,client=%h '
```

and for syslog logs:

```
log_line_prefix = 'user=%u,db=%d,app=%a,client=%h '
```

or

```
log_line_prefix = 'db=%d,user=%u,app=%a,client=%h '
```

- To get more information from your log files, set certain configuration parameters as follows:

```
log_checkpoints = on
log_connections = on
log_disconnections = on
log_lock_waits = on
log_temp_files = 0
log_autovacuum_min_duration = 0
log_error_verbosity = default
```

To benefit from these settings, do not enable log_statement as pgbadger does not parse the corresponding log format.

- Set the language in which messages are displayed; messages must be in English with or without locale support:

```
lc_messages='C'
```

or

```
lc_messages='en_US.UTF-8'
```

Locales for other languages, such as `ru_RU.utf8`, are not supported.

Usage

The following are simple examples to illustrate miscellaneous pgbadger usage details.

```
pgbadger /var/lib/pgpro/ent-14/data/log/postgresql-2022-01-14_000000.log
pgbadger /var/lib/pgpro/ent-14/data/log/postgres.log.2.gz /var/lib/pgpro/ent-14/data/
log/postgres.log.1.gz /var/lib/pgpro/ent-14/data/log/postgresql-2022-01-14_000000.log
pgbadger /var/lib/pgpro/ent-14/data/log/postgresql/postgresql-2022-01-*
pgbadger --exclude-query="^(COPY|COMMIT)" /var/lib/pgpro/ent-14/data/log/
postgresql-2022-01-14_000000.log
pgbadger -b "2022-01-25 10:56:11" -e "2022-01-25 10:59:11" /var/lib/pgpro/ent-14/data/
log/postgresql-2022-01-25-0000.log
cat /var/lib/pgpro/ent-14/data/log/postgresql-2022-01-14_000000.log | pgbadger -
# Log line prefix with stderr log output
pgbadger --prefix '%t [%p]: user=%u,db=%d,client=%h' /var/lib/pgpro/ent-14/data/log/
postgresql-2022-08-21*
pgbadger --prefix '%m %u@%d %p %r %a : ' /var/lib/pgpro/ent-14/data/log/
postgresql-2022-08-21-0000.log
# Log line prefix with syslog log output
pgbadger --prefix 'user=%u,db=%d,client=%h,appname=%a' /var/lib/pgpro/ent-14/data/log/
postgresql-2022-08-21*
# Use 8 CPUs to parse 10GB file faster
```

```
pgbadger -j 8 /var/lib/pgpro/ent-14/data/log/postgresql-2022-08-21-0000.log
# Use a cron job to report errors weekly
30 23 * * 1 /usr/bin/pgbadger -q -w /var/lib/pgpro/ent-14/data/log/
postgresql-2022-01*.log -o /var/www/pg_reports/pg_errors.html
```

Specifying Remote Log Files

Specify remote log files to parse using a URI. Supported protocols are HTTP[S] and [S]FTP. The `curl` command will be used to download the file, and the file will be parsed during download. The SSH protocol is also supported and will use the `ssh` command to get log files, as when the `--remote-host` option is used.

Use these URI notations for the remote log file:

```
pgbadger http://172.12.110.1//var/lib/pgpro/ent-14/data/log/
postgresql-2022-01-14_000000.log
pgbadger ftp://username@172.12.110.14/postgresql-2022-01-14_000000.log
pgbadger ssh://username@172.12.110.14:2222//var/lib/pgpro/ent-14/data/log/
postgresql-2022-01-14_000000.log*
```

You can parse a local Postgres Pro log and a remote pgbouncer log file together:

```
pgbadger /var/lib/pgpro/ent-14/data/log/postgresql-2022-01-14_000000.log ssh://
username@172.12.110.14/pgbouncer.log
```

Parallel Processing

To enable parallel processing, specify the `-j N` option, where *N* is the number of cores to use.

Parallel processing in pgbadger follows the algorithm below:

```
For each log file
  chunk size = int(file size / N)
  look at start/end offsets of these chunks
  fork N processes and seek to the start offset of each chunk
    each process will terminate when the parser reaches the end offset of its chunk
    each process writes stats into a binary temporary file
  wait for all child processes to terminate
All binary temporary files generated will then be read and loaded into
memory to build the html output.
```

With this method, at start/end of chunks pgbadger may truncate or omit a maximum of *N* queries per log file, which is an insignificant gap if you have millions of queries in your log file. The chance that the query that you were looking for is lost is near zero, so this gap can be considered suitable. Most of the time the query is counted twice, but truncated.

When you have many small log files and many CPUs, it is faster to dedicate one core to one log file at a time. To enable this behavior, specify the `-J N` option instead. Using this method, you can be sure not to lose any queries in the reports. With 200 log files of 10 MB each, the `-J` option starts being really efficient with 8 cores.

Here is a benchmark done on a server with 8 CPUs and a single file of 9.5 GB.

```
 Option |  1 CPU  | 2 CPU | 4 CPU | 8 CPU
--------+---------+-------+-------+------
   -j   | 1h41m18 | 50m25 | 25m39 | 15m58
   -J   | 1h41m18 | 54m28 | 41m16 | 34m45
```

With 200 log files of 10 MB each, which is 2 GB in total, the results are slightly different:

```
 Option | 1 CPU | 2 CPU | 4 CPU | 8 CPU
--------+-------+-------+-------+------
```

```
-j   | 20m15 |  9m56 |  5m20 | 4m20
-J   | 20m15 |  9m49 |  5m00 | 2m40
```

So it is recommended to use the `-j` option unless you have hundreds of small log files and can use at least 8 CPUs.

> **Important**
>
> During parallel parsing, pgbadger generates a lot of temporary files named `tmp_pgbadgerXXXX.bin` in the `/tmp` directory and removes them at the end.

Building Incremental Reports

The following sample cron job builds a report every week with the incremental behavior assuming that your log file and HTML report are also rotated every week:

```
0 4 * * 1 /usr/bin/pgbadger -q `find /var/lib/pgpro/ent-14/data/log/ -mtime -7 -name
 "postgresql.log*"` -o /var/www/pg_reports/pg_errors-`date +\%F`.html -l /var/reports/
pgbadger_incremental_file.dat
```

But better turn on pgbadger's automatic building incremental reports by specifyng the `-I/--incremental` option. In this mode, pgbadger builds one report per day and a cumulative report per week. The output is first built in the binary format and saved to the output directory, specified by the `-O/--outdir` option, and then daily and weekly reports are built in the HTML format with the main index file. The main index file shows a dropdown menu per week with a link to the week's report and links to daily reports for that week. For example, run pgbadger as follows with the file rotated daily:

```
0 4 * * * /usr/bin/pgbadger -I -q /var/lib/pgpro/ent-14/data/log/postgresql/
postgresql.log.1 -O /var/www/pg_reports/
```

You will have all daily and weekly reports. In this mode pgbadger will automatically create an incremental file in the output directory, so you do not have to use the `-l` option unless you want to change the path of that file. This means that you can run pgbadger in this mode every day on a log file rotated every week and it will not count the log entries twice. To save disk space, you may want to use the `-X/--extra-files` command-line option to force pgbadger to write CSS and JavaScript files to the output directory as separate files. The resources will then be loaded using script and link tags.

In the incremental mode, you can also specify the number of weeks to keep in the report by using the `-O/--retention` option:

```
/usr/bin/pgbadger --retention 2 -I -q /var/lib/pgpro/ent-14/data/log/postgresql/
postgresql.log.1 -O /var/www/pg_reports/
```

If pg_dump is scheduled to run at 23:00 and 13:00 every day, you can exclude these periods from the report as follows:

```
pgbadger --exclude-time "2013-09-.* (23|13):.*" postgresql.log
```

This will help avoid having `COPY` statements generated by pg_dump on top of the list of slowest queries. Alternatively, you can use `--exclude-appname "pg_dump"` to solve this problem in a simpler way.

Rebuilding Reports

To update all HTML reports after fixing a pgbadger report or adding a new feature to it, you can rebuild incremental reports. To rebuild all reports in the case a binary file is still available, run:

```
rm /path/to/reports/*.js
rm /path/to/reports/*.css
pgbadger -X -I -O /var/www/pg_reports/ --rebuild
```

This will also update all the resource files (JavaScript and CSS). Use the `-E/--explode` option if the reports were built with this option.

Building Monthly Reports

By default, in the incremental mode pgbadger only computes daily and weekly reports. To have monthly cumulative reports, you will need to use a separate command to specify the report to build. For example, to build a report for August 2021, run:

```
pgbadger -X --month-report 2021-08 /var/www/pg_reports/
```

This will add a link to the month name to the calendar view of incremental reports to look at the monthly report. The report for a current month can be run every day, and it is entirely rebuilt each time. The monthly report is not built by default because it could take too long. Like when rebuilding reports, if reports were built with the per-database option (`-E`/`--explode`), it must be used to build the monthly report:

```
pgbadger -E -X --month-report 2021-08 /var/www/pg_reports/
```

Choosing the Report File Format

The pgbadger report file format is determined by the extension of the file passed to the `-o`/`--outfile` option.

Use the binary format (`-o *.bin`) to create custom incremental and cumulative reports.

For example, to refresh a pgbadger report every hour from a daily log file, you can run the following commands every hour:

```
# Generate incremental data files in the binary format
pgbadger --last-parsed .pgbadger_last_state_file -o sunday/hourX.bin /var/lib/pgpro/
ent-14/data/log/postgresql-Sun.log
# Build a fresh HTML report from the generated binary file
pgbadger sunday/*.bin
```

For another example, assume that you generate one log file per hour. To have reports rebuilt each time the log file is rotated, run:

```
pgbadger -o day1/hour01.bin /var/lib/pgpro/ent-14/data/log/postgresql-2022-01-23_10.log
pgbadger -o day1/hour02.bin /var/lib/pgpro/ent-14/data/log/postgresql-2022-01-23_11.log
pgbadger -o day1/hour03.bin /var/lib/pgpro/ent-14/data/log/postgresql-2022-01-23_12.log
...
```

And to refresh the HTML report, for example, each time after a new binary file is generated, just run:

```
pgbadger -o day1_report.html day1/*.bin
```

Adjust the commands to your particular needs.

Use the JSON format (`-o *.json`) to share data with other languages and to facilitate integration of pgbadger output with other monitoring tools, such as Cacti or Graphite.

Select other output formats to meet your particular needs. For example, this command will generate *Tsung* sessions XML file for `SELECT` queries only:

```
  pgbadger -S -o sessions.tsung --prefix '%t [%p]: user=%u,db=%d ' /var/lib/pgpro/
ent-14/data/log/postgresql-2022-01-14_000000.log
```

Return Codes

pgbadger return codes depend on how it terminated as follows:

- `0`: was a success
- `1`: died on error
- `2`: has been interrupted using `Ctrl+C`, for example
- `3`: the PID file already exists or cannot be created

- `4`: no log file was specified on the command line

Options

This section describes pgbadger command-line options.

`-a` *minutes*
`--average` *minutes*

Specifies the number of minutes for which to build average graphs of queries and connections.

Default: 5.

`-A` *minutes*
`--histo-average` *minutes*

Specifies the number of minutes for which to build histogram graphs of queries.

Default: 60.

`-b` *datetime*
`--begin` *datetime*

Timestamp or time that specifies the start date/time for the data to be parsed in logs.

`-c` *host*
`--dbclient` *host*

Only report on log entries for the specified client host.

`-C`
`--nocomment`

Remove /* ... */ comments from queries.

`-d` *name*
`--dbname` *name*

Only report on log entries for the specified database.

`-D`
`--dns-resolv`

Replace client IP addresses with their DNS names.

> **Warning**
>
> This can considerably slow down pgbadger.

`-e` *datetime*
`--end` *datetime*

Timestamp or time that specifies the end date/time for the data to be parsed in logs.

`-E`
`--explode`

Build one report per each database. Global information not related to any database gets added to the `postgres` database report.

`-f` *logtype*
`--format` *logtype*

Specifies the log type.

Possible values: `syslog`, `syslog2`, `stderr`, `jsonlog`, `csv`, `pgbouncer`, `logplex`, `rds` and `redshift`. Use when pgbadger cannot detect the log format.

`-G`
`--nograph`

Disables graphs in HTML output.

`-h`
`--help`

Show detailed information about pbadger options and exit.

`-H` *path*
`--html-outdir` *path*

Specifies the path to the directory where the HTML report must be written in the incremental mode. Note that binary files remain in the directory specified by `-O`/`--outdir`.

`-i` *name*
`--ident` *name*

Specifies the program name used to identify Postgres Pro messages in syslog logs.

Default: `postgres`.

`-I`
`--incremental`

Use the incremental mode, where reports will be generated by days in a separate directory specified by the `-O`/`--outdir` option.

`-j` *number*
`--jobs` *number*

Specifies the number of jobs to run at the same time. When working with csvlog logs, pgbadger always runs as single job.

Default: 1.

`-J` *number*
`--Jobs` *number*

Specifies the number of log files to parse in parallel.

Default: 1.

`-l` *filename*
`--last-parsed` *filename*

Specifies the file where the last datetime and line parsed are registered to allow incremental log parsing. Useful to watch errors since the last run or to get one report per day with the log rotated weekly.

`-L` *filename*
`--logfile-list` *filename*

Specifies the file containing the list of log files to parse.

`-m` *size*
`--maxlength` *size*

Specifies the maximum length of a query in reports. Longer queries will be truncated.

Default: 100000.

`-M`
`--no-multiline`

Turns off collecting multiline statements to avoid reporting excessive information, especially on errors that generate a huge report.

`-N` *name*
`--appname` *name*

Only report on log entries for the specified application.

`-o` *filename*
`--outfile` *filename*

Specifies the filename for the output and determines the report file format: `out.html`, `out.txt`, `out.bin` or `out.json`. Can be used multiple times to output several formats. For the `json` output, ensure that the Perl module `JSON::XS` is installed. To dump the output to stdout, use the value of "-" as filename.

Default: `out.html`, `out.txt`, `out.bin`, `out.json` or `out.tsung`,

for the respective output format.

`-O` *path*
`--outdir` *path*

Specifies the directory where out files must be saved.

`-p` *string*
`--prefix` *string*

Specifies the value of your custom log_line_prefix string, as defined in your `postgresql.conf`. Only use if your log line prefix is different from the standard `log_line_prefix` strings, for example, if your prefix includes additional variables, such as client IP or application name. The string must contain escape sequences for time (%t, %m or %n) and processes (%p or %c).

`-P`
`--no-prettify`

Disables SQL query code prettifier.

`-q`
`--quiet`

Disables printing anything to stdout, even the progress bar.

`-Q`
`--query-numbering`

Add numbering of queries to the output when used together with `--dump-all-queries` or `--normalized-only`.

`-r` *address*
`--remote-host` *address*

Specifies the host to execute the `cat` command on a remote log file to parse the file locally.

`-R` *number*
`--retention` *number*

Specifies the number of weeks for which to keep reports in the output directory in the incremental mode. The directories for older weeks and days are automatically removed.

Default: 0 (no reports are removed).

`-s` *number*
`--sample` *number*

Specifies the number of query samples to store.

Default: 3.

`-S`
`--select-only`

Only report on SELECT queries.

`-t` *number*
`--top` *number*

Specifies the number of queries to store/display.

Default: 20.

`-T` *string*
`--title` *string*

Specifies the title of the HTML report page.

`-u` *username*
`--dbuser` *username*

Only report on log entries for the specified username.

`-U` *username*
`--exclude-user` *username*

Specifies the username to exclude log entries for from the report. Can be used multiple times.

`-v`
`--verbose`

Enables the verbose or debug mode.

Default: off.

`-V`
`--version`

Show pgbadger version and exit.

`-w`
`--watch-mode`

Only report errors, just like *Logwatch* can do.

`-W`
`--wide-char`

Encode HTML output of queries in UTF8 to avoid Perl messages “Wide character in print”.

`-x` *format*
`--extension` *format*

Specfies the output format. Possible values: `text`, `html`, `bin` or `json`.

Default: `html`.

`-X`
`--extra-files`

In the incremental mode, write CSS and JavaScript resources to the output directory as separate files.

`-z` *command*
`--zcat` *command*

Specifies the full command to run the zcat program. Use if zcat, bzcat or unzip is outside of your `PATH` directories.

`-Z` *+/-XX*
`--timezone` *+/-XX*

Specifies the number of hours from GMT for the timezone. Use to adjust date/time in JavaScript graphs. The value can be an integer (e.g., 2), or a float, (e.g., 2.5).

`--pie-limit` *number*

Specifies the number such that instead of lower pie data the sum will be shown.

`--exclude-query` *regexp*

Specifies the regular expression such that matching queries will be excluded from the report. For example: "^(VACUUM|COMMIT)". Can be used multiple times.

`--exclude-file` *filename*

Specifies the path to the file that contains each regular expression to use to exclude matching queries from the report, one expression per line.

`--include-query` *regexp*

Specifies the regular expression such that only matching queries will be included in the report. Can be used multiple times. For example: "(tbl1|tbl2)".

`--include-file` *filename*

Specifies the path to the file that contains each regular expression to use to include matching queries in the report, one expression per line.

`--disable-error`

Turns off generation of an error report.

`--disable-hourly`

Turns off generation of an hourly report.

`--disable-type`

Turns off generation of a report on queries by type, database and user.

`--disable-query`

Turns off generation of query reports, such as slowest or most frequent queries, queries by users, by database and so on.

`--disable-session`

Turns off generation of a session report.

`--disable-connection`

Turns off generation of a connection report.

`--disable-lock`

Turns off generation of a lock report.

`--disable-temporary`

Turns off generation of a report on temporary files.

`--disable-checkpoint`

Turns off generation of checkpoint/restartpoint reports.

`--disable-autovacuum`

Turns off generation of an autovacuum report.

`--charset` *name*

Specifies the HTML charset to be used.

Default: utf-8.

`--csv-separator` *char*

Specifies the CSV field separator.

Default: “,”.

`--exclude-time` *regexp*

Specifies the regular expression such that log entries for any matching timestamp will be excluded from the report. For example: “2013-04-12 .*”. Can be used multiple times.

`--include-time` *regexp*

Specifies the regular expression such that log entries for any matching timestamp will be included in the report. For example: “2013-04-12 .*”. Can be used multiple times.

`--exclude-db` *name*

Specifies the name of the database to exclude related log entries from the report. For example: “outdated_db”. Can be used multiple times.

`--exclude-appname` *name*

Specifies the name of the application to exclude related log entries from the report. For example: “pg_dump”. Can be used multiple time.

`--exclude-line` *regexp*

Specifies the regular expression such that any matching log entry will be excluded from the report. Can be used multiple times.

`--exclude-client` *name*

Specifies the client IP/name to exclude related log entries from the report. Can be used multiple times.

`--anonymize`

Obscure all literals in queries. Useful to hide confidential data.

`--noreport`

Prevents generation of reports in the incremental mode.

`--log-duration`

Associate log entries generated by `log_duration = on` and `log_statement = all`.

`--enable-checksum`

Add the MD5 sum under each query report.

`--journalctl` *command*

Specifies the command to produce the information similar to what the Postgres Pro log file contains. Usually, like this: `journalctl -u postgrespro-ent-14`.

`--pid-dir` *path*

Specifies the path to store the PID file.

Default: `/tmp`.

`--pid-file` *filename*

Specifies the name of the PID file to manage concurrent execution of pgbadger.

Default: `pgbadger.pid`.

`--rebuild`

Rebuild all HTML reports in incremental output directories that contain binary data files.

`--pgbouncer-only`

Only show pgbouncer-related menus in the header.

`--start-monday`

In the incremental mode, start calendar weeks on Monday. By default, they start on Sunday.

`--iso-week-number`

In the incremental mode, start calendar weeks on Monday (by default, they start on Sunday) with ISO 8601 week numbering: 01 to 53, where week 1 is the first week of a year that has at least 4 days.

`--normalized-only`

Only dump all normalized queries to `out.txt`.

`--log-timezone` *+/-XX*

Specifies the number of hours from GMT for the timezone to adjust date/time read from the log file before parsing. The use of this option makes log search with date/time more complicated. The value can be an integer (e.g., 2), or a float, (e.g., 2.5).

`--prettify-json`

Prettify JSON output.

`--month-report` *YYYY-MM*

Specifies the month (YYYY-MM) to create a cumulative HTML report for. Requires incremental output directories to be set and all the necessary binary data files available.

`--day-report` *YYYY-MM-DD*

Specifies the day (YYYY-MM-DD) to create an HTML report for. Requires incremental output directories to be set and all the necessary binary data files available.

`--noexplain`

Avoid processing log lines generated by auto_explain.

`--command` *cmd*

Specifies the command to run to retrieve log entries on stdin. pgbadger will open a pipe to this command and parse log entries that it generates.

`--no-week`

Avoid building weekly reports in the incremental mode. Use if building weekly reports takes too long.

`--explain-url` *URL*

Specifes the URL to override the URL of the graphical explain tool.

Default: *http://explain.depesz.com/*

`--tempdir` *path*

Specifies the directory for temporary files.

Default: `File::Spec->tmpdir() || '/tmp'`.

`--no-process-info`

Disables changing the pgbadger process title to help identify this process. Useful for systems where changing process titles is not supported.

`--dump-all-queries`

Dump all queries found in the log file to a text file, replacing bind parameters in the queries at their respective placeholder positions.

`--keep-comments`

Retains comments in normalized queries. Useful to distinguish between same normalized queries.

`--no-progressbar`

Disables displaying the progress bar.

`--dump-raw-csv`

Parse the log and dump the information into CSV format. No further processing is done, no report.

`--include-pid` *PID*

Only report events related to the session PID (%p). Can be used multiple times.

`--include-session` *ID*

Only report events related to the session ID (%c). Can be used multiple times.

`--histogram-query` *VAL*

Use custom inbound for query time histogram. Default inbound in milliseconds: 0,1,5,10,25,50,100,500,1000,10000.

`--histogram-session` *VAL*

Use custom inbound for session time histogram. Default inbound in milliseconds: 0,500,1000,30000,60000,600000,1800000,3600000,28800000.

Remote Log Connection Options

pgbadger can parse a remote log file fetched using passwordless SSH connection. Use the `-r`/`--remote-host` option to set the IP address or name of the target host. More options to define SSH connection parameters are as follows:

`--ssh-program` *ssh*

Specifies the path to the SSH program to use.

Default: ssh.

`--ssh-port` *port*

Specifies the SSH port for the connection.

Default: 22.

`--ssh-user` *username*

Specifies the username for the connection.

Default: user running pgbadger.

`--ssh-identity` *filename*

Specifies the path to the identity file.

`--ssh-timeout` *seconds*

Specifies the timeout in seconds in case of the SSH connection failure.

Default: 10.

`--ssh-option` *options*

Specifies the list of options to define SSH connection parameters. The following options are always used:

```
-o ConnectTimeout=$ssh_timeout -o PreferredAuthentications=hostbased,publickey
```

```
-o PreferredAuthentications=hostbased,publickey
```

Author

Gilles Darold <gilles@darold.net>

pg_repack

pg_repack — utility and Postgres Pro Enterprise extension to reorganize tables

Synopsis

`pg_repack` [*option*...] [*dbname*]

Description

pg_repack is a Postgres Pro Enterprise extension which lets you remove bloat from tables and indexes, and optionally restore the physical order of clustered indexes. Unlike CLUSTER and `VACUUM FULL` it works online, without holding an exclusive lock on the processed tables during processing. pg_repack is efficient to boot, with performance comparable to using `CLUSTER` directly.

pg_repack is a fork of the previous *https://github.com/reorg/pg_reorg* project.

You can choose one of the following methods to reorganize data:

- Online `CLUSTER` (ordered by cluster index)
- Ordering by specified columns
- Online `VACUUM FULL` (packing rows only)
- Rebuild or relocate only the indexes of a table

> **Note**
>
> Only superusers can use the utility.

> **Note**
>
> Target table must have a PRIMARY KEY, or at least a UNIQUE total index on a NOT NULL column.

Installation

On Linux systems, pg_repack is provided together with Postgres Pro Enterprise as a separate pre-built package `pg-repack-ent-14` and requires the `postgrespro-ent-14-server` package to be installed with all the dependencies. For the list of available packages and detailed installation instructions, see Chapter 17. On Windows systems, pg_repack is automatically installed as part of Postgres Pro.

Once you have pg_repack installed, load the `pg_repack` extension in the database you want to process, as follows:

```
$ psql -c "CREATE EXTENSION pg_repack" -d your_database
```

You can later remove `pg_repack` from a Postgres Pro installation using `DROP EXTENSION pg_repack`.

If you are upgrading from a previous version of pg_repack, just drop the old version from the database as explained above and install the new version.

Options

Reorganization Options

`-a`
`--all`

Attempt to repack all the databases of the cluster. Databases where the `pg_repack` extension is not installed will be skipped.

`-t` *table*
`--table=`*table*

Reorganize the specified table(s) only. Multiple tables may be reorganized by writing multiple `-t` switches. By default, all eligible tables in the target databases are reorganized.

`-I` *table*
`--parent-table=`*table*

Reorganize both the specified table(s) and its inheritors. Multiple table hierarchies may be reorganized by writing multiple `-I` switches.

`-c` *schema*
`--schema=`*schema*

Repack the tables in the specified schema(s) only. Multiple schemas may be repacked by writing multiple `-c` switches. Can be used in conjunction with `--tablespace` to move tables to a different tablespace.

`-o` *column*`[, ...]`
`--order-by=`*column*`[, ...]`

Perform an online `CLUSTER` ordered by the specified columns.

`-n`
`--no-order`

Perform an online `VACUUM FULL`. Since version 1.2 this is the default for non-clustered tables.

`-N`
`--dry-run`

Show what would be repacked and exit.

`-j` *num_jobs*
`--jobs=`*num_jobs*

Create the specified number of extra connections to Postgres Pro, and use these extra connections to parallelize the rebuild of indexes on each table. Parallel index builds are only supported for full-table repacks, not with `--index` or `--only-indexes` options. If your server has extra cores and disk I/O available, this can be a useful way to speed up pg_repack.

`-s` *tablespace*
`--tablespace=`*tablespace*

Move the repacked tables to the specified tablespace: essentially an online version of `ALTER TABLE ... SET TABLESPACE`. The tables' indexes are left in the original tablespace unless `--moveidx` is specified too.

`-S`
`--moveidx`

Also move the indexes of the repacked tables to the tablespace specified by the `--tablespace` option.

`-i` *index*
`--index=`*index*

Repack the specified index(es) only. Multiple indexes may be repacked by writing multiple `-i` switches. May be used in conjunction with `--tablespace` to move the index(es) to a different tablespace.

`-x`
`--only-indexes`

Repack only the indexes of the specified table(s), which must be specified with the `--table` option.

`-T` *secs*
`--wait-timeout=`*secs*

pg_repack needs to take an exclusive lock at the end of the reorganization. This setting controls how many seconds pg_repack will wait to acquire this lock. If the lock cannot be taken after this duration and `--no-kill-backend` option is not specified, pg_repack will forcibly cancel the conflicting queries. If you are using Postgres Pro or PostgreSQL version 8.4 or newer, pg_repack will fall back to using `pg_terminate_backend()` to disconnect any remaining backends after this timeout has passed twice. The default is 60 seconds.

`-D`
`--no-kill-backend`

Skip repacking a table if the lock cannot be taken for duration specified in `--wait-timeout`, instead of cancelling conflicting queries. The default is `false`.

`-Z`
`--no-analyze`

Disable `ANALYZE` after a full-table reorganization. If not specified, `ANALYZE` is executed after the reorganization.

`-k`
`--no-superuser-check`

Skip the superuser checks in the client. This setting is useful for using pg_repack on platforms that support running it as non-superusers.

`-C`
`--exclude-extension`

Skip tables that belong to the specified extension(s). Some extensions may heavily depend on such tables at planning time etc.

`--switch-threshold`

Switch tables when that many tuples are left in the log table. This setting can be used to avoid the inability to catch up with write-heavy tables.

Connection Options

Options to connect to servers. You cannot use `--all` and `--dbname` or `--table` or `--parent-table` together.

`-a`
`--all`

Reorganize all databases.

`[-d]` *dbname*
`[--dbname=]`*dbname*

Specifies the name of the database to be reorganized. If this is not specified and `-a` (or `--all`) is not used, the database name is read from the environment variable `PGDATABASE`. If that is not set, the user name specified for the connection is used.

`-h` *host*
`--host=`*host*

Specifies the host name of the machine on which the server is running. If the value begins with a slash, it is used as the directory for the Unix domain socket.

`-p` *port*
`--port=`*port*

Specifies the TCP port or local Unix domain socket file extension on which the server is listening for connections.

`-U` *username*
`--username=`*username*

User name to connect as.

`-w`
`--no-password`

Never issue a password prompt. If the server requires password authentication and a password is not available by other means such as a `.pgpass` file, the connection attempt will fail. This option can be useful in batch jobs and scripts where no user is present to enter a password.

`-W`
`--password`

Force pg_repack to prompt for a password before connecting to a database.

This option is never essential, since pg_repack will automatically prompt for a password if the server demands password authentication. However, pg_repack will waste a connection attempt finding out that the server wants a password. In some cases it is worth typing `-W` to avoid the extra connection attempt.

Generic Options

`-e`
`--echo`

Echo the commands that pg_repack generates and sends to the server.

`-E` *level*
`--elevel=`*level*

Choose the output message level from `DEBUG`, `INFO`, `NOTICE`, `WARNING`, `ERROR`, `LOG`, `FATAL`, and `PANIC`. The default is `INFO`.

`--help`

Show help about pg_repack command line arguments, and exit.

`-V`
`--version`

Print the pg_repack version and exit.

Environment

`PGDATABASE`
`PGHOST`
`PGPORT`
`PGUSER`

Default connection parameters

This utility, like most other Postgres Pro utilities, also uses the environment variables supported by libpq (see Section 36.15).

Examples

Perform an online `CLUSTER` of all the clustered tables in the database `test`, and perform an online `VACUUM FULL` of all the non-clustered tables:

```
$ pg_repack test
```

Perform an online `VACUUM FULL` on the tables `foo` and `bar` in the database `test` (an eventual cluster index is ignored):

```
$ pg_repack --no-order --table foo --table bar test
```

Move all indexes of table `foo` to tablespace `tbs`:

```
$ pg_repack -d test --table foo --only-indexes --tablespace tbs
```

Move the specified index to tablespace `tbs`:

```
$ pg_repack -d test --index idx --tablespace tbs
```

Diagnostics

Error messages are reported when pg_repack fails. The following list shows the cause of errors.

You need to cleanup by hand after fatal errors. To cleanup, just remove `pg_repack` from the database and install it again.

For Postgres Pro or PostgreSQL 9.1 and newer execute:

```
DROP EXTENSION pg_repack CASCADE
```

in the database where the error occurred, followed by

```
CREATE EXTENSION pg_repack
```

For previous versions load the script `$SHAREDIR/contrib/uninstall_pg_repack.sql` into the database where the error occurred and then load `$SHAREDIR/contrib/pg_repack.sql` again.

```
INFO: database "db" skipped:
pg_repack VER is not installed in the database:
pg_repack is not installed in the database when the --all option is specified.
```

Create the `pg_repack` extension in the database.

```
ERROR: pg_repack VER is not installed in the database:
pg_repack is not installed in the database specified by --dbname
```

Create the `pg_repack` extension in the database.

```
ERROR: program 'pg_repack V1' does not match database library 'pg_repack V2':
There is a mismatch between the pg_repack binary and the database library
(.so or .dll).
```

The mismatch could be due to the wrong binary in the `PATH` or the wrong database being addressed. Check the program directory and the database; if they are what expected you may need to repeat `pg_repack` installation.

```
ERROR: extension 'pg_repack V1' required, found 'pg_repack V2':
The SQL extension found in the database does not match the version required by the
 pg_repack program.
```

You should drop the extension from the database and reload it as described in the section called “Installation”.

```
ERROR: relation "table" must have a primary key or not-null unique keys:
```

```
The target table doesn't have a PRIMARY KEY or any UNIQUE constraints defined.
```

Define a PRIMARY KEY or a UNIQUE constraint on the table.

```
ERROR: query failed: ERROR: column "col" does not exist:
The target table doesn't have columns specified by --order-by option.
```

Specify existing columns.

```
WARNING: the table "tbl" already has a trigger called z_repack_trigger:
The trigger was probably installed during a previous attempt
to run pg_repack on the table which was interrupted
and for some reason failed to clean up the temporary objects.
```

You can remove all the temporary objects by dropping and re-creating the extension: see the section called “Installation” for the details.

```
WARNING: trigger "trg" conflicting on table "tbl":
The target table has a trigger whose name follows z_repack_trigger
in alphabetical order.
```

The `z_repack_trigger` should be the last BEFORE trigger to fire. Please rename your trigger so that it sorts alphabetically before `pg_repack` one; you can use:

```
ALTER TRIGGER zzz_my_trigger
 ON sometable RENAME TO yyy_my_trigger;
```

```
ERROR: Another pg_repack command may be running on the table. Please try again later.
```

There is a chance of deadlock when two concurrent `pg_repack` commands are run on the same table. So, try to run the command after some time.

```
WARNING: Cannot create index "schema"."index_xxxxx", already exists
DETAIL: An invalid index may have been left behind by a previous
pg_repack on the table which was interrupted. Please use DROP INDEX
"schema"."index_xxxxx" to remove this index and try again.
```

A temporary index apparently created by pg_repack has been left behind, and we do not want to risk dropping this index ourselves. If the index was in fact created by an old pg_repack job which didn't get cleaned up, you should just use `DROP INDEX` and try the `repack` command again.

Restrictions

pg_repack comes with the following restrictions.

Temporary tables

pg_repack cannot reorganize temporary tables.

GiST indexes

pg_repack cannot cluster tables by `GiST` indexes.

DDL commands

You will not be able to perform DDL commands of the target table(s) *except* `VACUUM` or `ANALYZE` while pg_repack is working. pg_repack will hold an `ACCESS SHARE` lock on the target table during a full-table repack, to enforce this restriction.

If you are using version 1.1.8 or earlier, you must not attempt to perform any DDL commands on the target table(s) while pg_repack is running. In many cases pg_repack would fail and rollback correctly, but there were some cases in these earlier versions which could result in data corruption.

See also

clusterdb, vacuumdb

I.3. Additional Postgres Pro Server Applications

This section covers Postgres Pro Enterprise server-related applications. They are typically run on the host where the database server resides. See also Postgres Pro Server Applications for information about server applications that are part of the core Postgres Pro Enterprise distribution.

mamonsu

mamonsu — a monitoring agent for collecting Postgres Pro and system metrics

Synopsis

`mamonsu agent` [*agent_action*]

`mamonsu bootstrap -M` *mamonsu_user* [`-c` | `--config`] [`-x` | `--create-extensions`] [*connection_options*]

`mamonsu export` {`template` | `config`} *filename* [*export_options*]

`mamonsu report` [*report_options*] [*connection_options*]

`mamonsu tune` [*tuning_options*] [*connection_options*]

`mamonsu upload` [*upload_options*]

`mamonsu zabbix dashboard upload` *template_name*

`mamonsu zabbix` {`template` | `host` | `hostgroup`} *server_action*

`mamonsu zabbix item` {`error` | `lastvalue` | `lastclock`} *host_id*

`mamonsu zabbix version`

`mamonsu` [`-c` | `--config`] [`-d` | `--daemonize`]

`mamonsu --version`

`mamonsu --help`

Description

mamonsu is a monitoring agent for collecting Postgres Pro and system metrics that can be visualized on the Zabbix server. Unlike the native Zabbix Agent configured to collect Postgres Pro metrics, mamonsu uses a single database connection, which allows to minimize performance impact on the monitored system.

The mamonsu agent includes the following components:

- A supervisor process that monitors database and system activity.
- Plugins that specify which Postgres Pro and system metrics to collect.
- Customizable configuration and template files that define which plugins to use and how to visualize the collected data.

mamonsu is an active agent, which means that it sends the data to the Zabbix server once it is collected. Pre-configured to monitor multiple Postgres Pro and system metrics out of the box, mamonsu can be extended with your own custom plugins to track other metrics critical for your system.

mamonsu also provides the command-line interface for updating some Zabbix server settings, as well as getting an overview of the monitored system configuration and tuning Postgres Pro and system settings on the fly. You can find the list of all mamonsu commands in the section called “Command-Line Reference”.

Installation and Setup

> **Important**
>
> Before you start installation, attentively read Compatibility Considerations.

To use mamonsu, you must create a Zabbix account and set up a Zabbix server as explained in *Zabbix documentation*. Naturally, you must also have a Postgres Pro instance up and running if you are going to monitor Postgres Pro metrics. If you are configuring your Postgres Pro cluster from scratch, see Chapter 17 and Section 18.2 for Postgres Pro installation and setup instructions, respectively.

> **Note**
>
> While mamonsu can collect Postgres Pro metrics from a remote cluster, system metrics are only collected locally. If you choose to collect Postgres Pro metrics remotely, make sure to disable collection of system metrics to avoid confusion, as they will be displayed under the same host in Zabbix.

mamonsu is provided with Postgres Pro Enterprise as a separate pre-built package `mamonsu` (for the detailed installation instructions, see Chapter 17). Once you have installed mamonsu, complete the following steps to set up metrics collection:

1. **Optionally, bootstrap mamonsu**

   If you omit this step, metrics can only be collected on behalf of a superuser, which is not recommended.

   In this step, the `bootstrap` command sets the mamonsu user, creates `mamonsu` schema in the specified or implied database, as well as extensions and objects needed for monitoring.

   `bootstrap` has no mandatory options. When run without options, it takes the values needed from the configuration file (`/etc/mamonsu/agent.conf` by default). Below is a simple example of bootstrap:

   1. In the `[postgres]` section of `agent.conf`, specify connection parameters for the Postgres Pro cluster you are going to monitor. For more details, see Connection Parameters.
   2. Run the following command to bootstrap mamonsu:

      ```
      mamonsu bootstrap
      ```

      This command will create the user `mamonsu` with the password `mamonsu`, create monitoring functions in the database specified in `agent.conf` and grant the right to execute them to the `mamonsu` user.

   In the following example, `bootstrap` options are passed explicitly.

   1. Create a non-privileged database user for mamonsu. For example:

      ```
      CREATE USER mamonsu_user WITH PASSWORD 'mamonsu_password';
      GRANT pg_monitor TO mamonsu_user;
      ```

   2. Create a database that will be used for connection to Postgres Pro. For example:

      ```
      CREATE DATABASE mamonsu_database OWNER mamonsu_user;
      ```

   3. Run the following command to bootstrap mamonsu:

      ```
      mamonsu bootstrap -M mamonsu_user -x -c /etc/mamonsu/agent.conf -d
       mamonsu_database -U postgres --host myhost --port 5432
      ```

      For details of the options `-M`, `-x` and `-c`, see `bootstrap`. For details of other options, see Connection Options. This command will create monitoring functions in the *`mamonsu_database`* and grant the right to execute them to *`mamonsu_user`*. The pg_buffercache extension will also be created to ensure collection of metrics on the shared buffer cache, and the path to the configuration file will be changed.

   As a result, a superuser connection is no longer required. Note that mamonsu also creates several tables in the `mamonsu` schema in the specified database. Do not delete these tables as they are required for mamonsu to work.

2. **Configure mamonsu**

   Edit the `agent.conf` configuration file, which is located in the `/etc/mamonsu/` directory by default.

   - Configure Zabbix-related settings. The `address` field must point to the running Zabbix server, while the `client` field must provide the name of the Zabbix host. You can find the list of hosts available for your account in the Zabbix web interface under **Configuration > Hosts**.

     ```
     [zabbix]
     ; enabled by default
     enabled = True
     client = zabbix_host_name
     address = zabbix_server
     ```

   - By default, mamonsu will collect both Postgres Pro and system metrics. If required, you can disable metrics collection of either type by setting the `enabled` parameter to `False` in the `[postgres]` or `[system]` section of the `agent.conf` file, respectively.

     ```
     [system]
     ; enabled by default
     enabled = True
     ```

     > **Note**
     >
     > While mamonsu can collect Postgres Pro metrics from a remote cluster, system metrics are only collected locally. If you choose to collect Postgres Pro metrics remotely, make sure to disable collection of system metrics to avoid confusion, as they will be displayed under the same host in Zabbix.

   - If you are going to collect Postgres Pro metrics, specify connection parameters for the Postgres Pro cluster you are going to monitor. In the `user`, `password`, and `database` fields, you must specify the *`mamonsu_user`*, *`mamonsu_password`*, and the *`mamonsu_database`* used for bootstrap, respectively. If you skipped the bootstrap, specify superuser credentials and the database to connect to.

     ```
     [postgres]
     ; enabled by default
     enabled = True
     user = mamonsu_user
     database = mamonsu_database
     password = mamonsu_password
     port = 5432
     ```

   These are the main mamonsu settings to get started. You can also fine-tune other mamonsu settings as explained in the section called “Configuration Parameters”.

3. **Configure how to display metrics on the Zabbix server**

   1. Generate a template that defines how to visualize the collected metrics on the Zabbix server:

      ```
      mamonsu export template template.xml
      ```

      mamonsu generates the `template.xml` file in your current directory. By default, the name of the template that will be displayed in the Zabbix account is `PostgresPro-`*`OS`*, where *`OS`* is the name of your operating system. To get a template with a different display name, you can run the above command with the `--template-name` option.

   2. Optionally, specify your Zabbix account settings in the following environment variables on your monitoring system:

- Set the `ZABBIX_USER` and `ZABBIX_PASSWD` variables to the login and password of your Zabbix account, respectively.
- Set the `ZABBIX_URL` to `http://zabbix/`

If you skip this step, you will have to add the following options to all `mamonsu zabbix` commands that you run:

```
--url=http://zabbix/ --user=zabbix_login --password=zabbix_password
```

3. Upload `template.xml` to the Zabbix server.

```
mamonsu zabbix template export template.xml
```

Alternatively, you can upload the template through the Zabbix web interface: log in to your Zabbix account and select **Templates > Import**.

4. Link the generated template to the host to be monitored.

In the Zabbix web interface, select your host, go to **Templates > Add**, select your template, and click **Update**.

> **Tip**
>
> If you would like to link a template with a new Zabbix host, you can do it from the command line using `mamonsu zabbix` commands. See the section called “Managing Zabbix Server Settings from the Command Line” for details.

When the setup is complete, start mamonsu. For example, on Linux systems, you can start mamonsu as a service with the following command:

```
service mamonsu start
```

mamonsu picks up all the parameters from the mamonsu configuration file and starts monitoring your system.

Command-Line Reference

agent

Syntax:

```
mamonsu agent { metric-list | metric-get metric_name | version }
```

Provide information on the collected metrics from the command line. You can specify one of the following parameters:

`metric-list`

Show the list of metrics that mamonsu is collecting. The output of this command provides the item key of each metric, its latest value, and the time when this value was received.

`metric-get` *`metric_name`*

Check the latest value for the specified metric. You can get the list of available metrics using the `metric-list` option.

`version`

Display mamonsu version.

bootstrap

Syntax:

```
mamonsu bootstrap -M mamonsu_user
        [-c[ config_file] | --config[=config_file]]
        [-x | --create-extensions] [connection_options]
```

Bootstrap mamonsu. This command can take the following options:

`-M`

Specify a non-privileged user that will own all mamonsu processes.

`-c config_file`
`--config=config_file`

Specify the `agent.conf` file where the `[postgres]` section contains the database name to be used if `--dbname` is not specified through *connection_options*.

Default: `/etc/mamonsu/agent.conf`

`-x`
`--create-extensions`

Create auxiliary extensions. The pg_buffercache extension will be created, which is no longer created by default. For Postgres Pro 12 or higher, the `bootstrap -x` command will also create functions to work with the pgpro_stats extension and grant the right to execute them to the `mamonsu` user.

connection_options

Provide optional *command-line connection parameters*.

export

Syntax:

```
mamonsu export config filename.conf  [--add-plugins=plugin_directory]
mamonsu export template filename.xml [--add-plugins=plugin_directory]
                                     [--template-name=template_name]
                                     [--application=application_name]
                                     [--old-zabbix]
```

Generate a template or configuration file for metrics collection. The optional parameters to customize metrics collection are as follows:

`--add-plugins=plugin_directory`

Collect metrics that are defined in custom plugins located in the specified *plugin_directory*. If you are going to use custom plugins, you must provide this option when generating both the configuration file and the template.

`--template-name=template_name`

Specify the name of the template that will be displayed on the Zabbix server.

Default: `PostgresPro-OS`, where *OS* is the name of your operating system

`--application=application_name`

Specify an identifier under which the collected metrics will be displayed on the Zabbix server.

Default: `App-PostgresPro-OS`, where *OS* is the name of your operating system

`--old-zabbix`

Export a template for Zabbix server version 4.2 or lower. By default, the template is generated in a format compatible with Zabbix 4.4 or higher.

export zabbix-parameters

Syntax:

```
mamonsu export zabbix-parameters filename.conf [--add-plugins=plugin_directory]
                                       [--plugin-type={pg | sys | all}]
                                       [--pg-version=version]
                                       [--config=config_file]
```

Export metrics configuration for use with the native *Zabbix agent*. The optional parameters to customize metrics collection are as follows:

`--add-plugins=`*`plugin_directory`*

Collect metrics that are defined in custom plugins located in the specified *`plugin_directory`*. If you are going to use custom plugins, you must provide this option when generating both the configuration file and the template.

`--plugin-type={pg | sys | all}`

Specify the type of metrics to collect:

- `pg` for Postgres Pro metrics.
- `sys` for system metrics.
- `all` for both Postgres Pro and system metrics.

Default: `all`

`--pg-version=`*`version`*

Specify the major version of the server for which to configure metrics collection. `mamonsu` can collect metrics for all supported Postgres Pro versions, as well as PostgreSQL versions starting from 9.5.

Default: `10`

`--config=`*`config_file`*

Specify the `agent.conf` file to be used as the source for metrics definitions.

Default: `/etc/mamonsu/agent.conf`

export zabbix-template

Syntax:

```
mamonsu export zabbix-template filename.conf [--add-plugins=plugin_directory]
                                       [--plugin-type={pg | sys | all}]
                                       [--template-name=template_name]
                                       [--application=application_name]
                                       [--config=config_file]
                                       [--old-zabbix]
```

Export a template for use with the native Zabbix agent. The optional parameters to customize metrics collection are as follows:

`--add-plugins=`*`plugin_directory`*

Collect metrics that are defined in custom plugins located in the specified *`plugin_directory`*. If you are going to use custom plugins, you must provide this option when generating both the configuration file and the template.

`--plugin-type={pg | sys | all}`

Specify the type of metrics to collect:

- `pg` configures Postgres Pro metrics.
- `sys` configures system metrics.
- `all` configures both Postgres Pro and system metrics.

Default: `all`

`--template-name=`*`template_name`*

Specify the name of the template that will be displayed on the Zabbix server.

Default: `PostgresPro-`*`OS`*, where *`OS`* is the name of your operating system

`--application=`*`application_name`*

Specify an identifier under which the collected metrics will be displayed on the Zabbix server.

Default: `App-PostgresPro-`*`OS`*, where *`OS`* is the name of your operating system

`--config=`*`config_file`*

Specify the `agent.conf` file to be used as the source for metrics definitions.

Default: `/etc/mamonsu/agent.conf`

`--old-zabbix`

Export a template for Zabbix server version 4.2 or lower. By default, the template is generated in a format compatible with Zabbix 4.4 or higher.

report

Syntax:

```
mamonsu report [--run-system=Boolean] [--run-postgres=Boolean]
               [--print-report=Boolean] [--report-path=report_file]
               [--disable-sudo] [connection_options]
```

Generate a detailed report on the hardware, operating system, memory usage and other parameters of the monitored system, as well as Postgres Pro configuration.

The following optional parameters customize the report:

`--run-system=`*`Boolean`*

Include system information into the generated report.

Default: `True`

`--run-postgres=`*`Boolean`*

Include information on Postgres Pro into the generated report.

Default: `True`

`--print-report=`*`Boolean`*

Print the report to stdout.

Default: `True`

`--report-path=`*`report_file`*

Save the report into the specified file.

Default: `/tmp/report.txt`

`--disable-sudo`

Do not report data that can only be received with superuser rights. This option is only available for Linux systems.

`connection_options`

Provide optional *command-line connection parameters*.

tune

Syntax:

```
mamonsu tune [--dry-run] [--disable-sudo] [--log-level {INFO|DEBUG|WARN}]
             [--dont-tune-pgbadger] [--dont-reload-postgresql]
             [connection_options]
```

Optimize Postgres Pro and system configuration based on the collected statistics. You can use the following options:

`--dry-run`

Display the settings to be tuned without changing the actual system and Postgres Pro configuration.

`--disable-sudo`

Do not tune the settings that can only be changed by a superuser. This option is only available for Linux systems.

`--dont-tune-pgbadger`

Do not tune pgbadger parameters.

`--log-level { INFO | DEBUG | WARN}`

Change the logging level.

Default: `INFO`

`--dont-reload-postgresql`

Forbid mamonsu to run the `pg_reload_conf()` function. If you specify this option, the modified settings that require reloading Postgres Pro configuration do not take effect immediately.

`connection_options`

Provide optional *command-line connection parameters*.

upload

Syntax:

```
mamonsu upload [--zabbix-file=metrics_file]
               [--zabbix-address=zabbix_address] [--zabbix-port=port_number]
               [--zabbix-client=zabbix_host_name] [--zabbix-log-level={INFO|DEBUG|
WARN}]
```

Upload metrics data previously saved into a file onto a Zabbix server for visualization. For details on how to save metrics into a file, see the section called “Logging Parameters”.

This command can take the following options:

`--zabbix-address=`*`zabbix_address`*

The address of the Zabbix server.

Default: `localhost`

`--zabbix-port=`*`port_number`*

The port of the Zabbix server.

Default: 10051

`--zabbix-file=`*`metrics_file`*

A text file that stores the collected metrics data to be visualized, such as `localhost.log`.

`--zabbix-client=`*`zabbix_host_name`*

The name of the Zabbix host.

Default: `localhost`

`--zabbix-log-level={INFO|DEBUG|WARN}`

Change the logging level.

Default: `INFO`

zabbix dashboard upload

Syntax:

```
mamonsu dashboard upload template_name
```

Upload a Zabbix dashboard with the mamonsu metrics to a template on the Zabbix server version 6.0 or higher.

zabbix item

Syntax:

```
mamonsu zabbix item {error | lastvalue | lastclock } host_name
```

View the specified property of the latest metrics data received by Zabbix for the specified host.

zabbix version

Syntax:

```
mamonsu zabbix version
```

Get the version of the Zabbix server that mamonsu is connected to.

zabbix host

Syntax:

```
mamonsu zabbix host list
mamonsu zabbix host show host_name
mamonsu zabbix host id host_name
mamonsu zabbix host delete host_id
mamonsu zabbix host create host_name hostgroup_id template_id mamonsu_address
mamonsu zabbix host info {templates | hostgroups | graphs | items} host_id
```

Manage Zabbix hosts using one of the actions described in the section called “Zabbix Server Actions”.

zabbix hostgroup

Syntax:

```
mamonsu zabbix hostgroup list
mamonsu zabbix hostgroup show hostgroup_name
mamonsu zabbix hostgroup id hostgroup_name
```

```
mamonsu zabbix hostgroup delete hostgroup_id
mamonsu zabbix hostgroup create hostgroup_name
```

Manage Zabbix host groups using one of the actions described in the section called "Zabbix Server Actions".

zabbix template

Syntax:

```
mamonsu zabbix template list
mamonsu zabbix template show template_name
mamonsu zabbix template id template_name
mamonsu zabbix template delete template_id
mamonsu zabbix template export file
```

Manage Zabbix templates using one of the actions described in the section called "Zabbix Server Actions".

[--config] [--daemonize]

Syntax:

```
mamonsu [-c config_file | --config=config_file]
        [-d | --daemonize]
```

Start working as a monitoring agent in the foreground or in the background using configuration parameters loaded from the configuration file. If the specified or default configuration file does not exist, exit with an error. Useful for debugging. You can specify the following options:

`-c config_file`
`--config=config_file`

Specify the `agent.conf` file where to load the configuration parameters from.

Default: `/etc/mamonsu/agent.conf`

`-d`
`--daemonize`

Run in the background. Without it, mamonsu will run in the foreground.

--version

Syntax:

```
mamonsu --version
```

Display `mamonsu` version.

--help

Syntax:

```
mamonsu --help
```

Display `mamonsu` command-line help.

Connection Options

connection_options provide command-line connection parameters for the target Postgres Pro cluster. *connection_options* can be `--host`, `--port`, `--dbname` (`-d`), `--username` (`-U`), and `--password` (`-W`). The `--dbname` option should specify the *mamonsu_database* created for monitoring purposes. Note that the `--username` (`-U`) option must specify a superuser that can access the cluster.

If you omit *connection_options*, mamonsu checks the configuration file for the needed settings.

Zabbix Server Actions

Using mamonsu, you can control some of the Zabbix server functionality from the command line. Specifically, you can create or delete Zabbix hosts and host groups, as well as generate, import, and delete Zabbix templates using one of the following commands. The *object_name* to use must correspond to the type of the Zabbix object specified in the command: `template`, `host`, or `hostgroup`.

`list`

Display the list of available templates, hosts, or host groups.

`show` *object_name*

Display the details about the specified template, host, or host group.

`id` *object_name*

Show the ID of the specified object, which is assigned automatically by the Zabbix server.

`delete` *object_id*

Delete the object with the specified ID.

`create` *hostgroup_name*
`create` *host_name hostgroup_id template_id mamonsu_address*

Create a new host or a host group.

`export` *template_name*

Generate a Zabbix template.

`info {templates | hostgroups | graphs | items}` *host_id*

Display detailed information about the templates, host groups, graphs, and metrics available on the host with the specified ID.

Configuration Parameters

The `agent.conf` configuration file is located in the `/etc/mamonsu` directory by default. It provides several groups of parameters that control which metrics to collect and how to log the collected data:

- connection parameters
- logging parameters
- plugin parameters

All parameters must be specified in the *parameter = value* format.

Connection Parameters

[postgres]

The `[postgres]` section controls Postgres Pro metrics collection and can contain the following parameters:

`enabled`

Enables/disables Postgres Pro metrics collection if set to `True` or `False`, respectively.

Default: `True`

`user`

The user on behalf of which the cluster will be monitored. It must be the mamonsu user set in bootstrap, or a superuser if `bootstrap` was not run.

Default: `postgres`

`password`

The password for the specified user.

`database`

The database to connect to for metrics collection.

Default: `postgres`

`host`

The server address to connect to.

Default: `localhost`

`port`

The port to connect to.

Default: 5432

`application_name`

Application name that identifies mamonsu connected to the Postgres Pro cluster.

Default: `mamonsu`

`query_timeout`

statement_timeout for the mamonsu session, in seconds. If a Postgres Pro metric query does not complete within this time interval, it gets terminated.

Default: 10

Alternatively you can specify environment variables rather than the configuration parameters. The following environment variables can be used: `PGUSER`, `PGPASSWORD`, `PGHOST`, `PGDATABASE`, `PGPORT`, and `PGAPPNAME`. See Section 36.15 for their meaning.

[system]

The `[system]` section controls system metrics collection and can contain the following parameters:

`enabled`

Enables/disables system metrics collection if set to `True` or `False`, respectively.

Default: `True`

[zabbix]

The `[zabbix]` section provides connection settings for the Zabbix server and can contain the following parameters:

`enabled`

Enables/disables sending the collected metrics data to the Zabbix server if set to `True` or `False`, respectively.

Default: `True`

`client`

The name of the Zabbix host.

`address`

The address of the Zabbix server.

Default: 127.0.0.1

`port`

The port of the Zabbix server.

Default: 10051

`timeout`

Maximum time to wait while connecting to the Zabbix server, in seconds.

Default: 15

[agent]

The `[agent]` section specifies the location of mamonsu and whether it is allowed to access metrics from the command line:

`enabled`

Enables/disables metrics collection from the command line using the `agent` command.

Default: `True`

`host`

The address of the system on which mamonsu is running.

Default: 127.0.0.1

`port`

The port on which mamonsu is running.

Default: 10052

[sender]

The `[sender]` section controls the queue size of the data to be sent to the Zabbix server:

`queue`

The maximum number of collected metric values that can be accumulated locally before mamonsu sends them to the Zabbix server. Once the accumulated data is sent, the queue is cleared.

Default: 2048

Logging Parameters

[metric_log]

The `[metric_log]` section enables storing the collected metrics data in text files locally. This section can contain the following parameters:

`enabled`

Enables/disables storing the collected metrics data in a text file. If this option is set to `True`, mamonsu creates the `localhost.log` file for storing metric values.

Default: `False`

`directory`

Specifies the directory where log files with metrics data will be stored.

Default: `/var/log/mamonsu`

`max_size_mb`

The maximum size of a log file, in MB. When the specified size is reached, it is renamed to `localhost.log.archive`, and an empty `localhost.log` file is created.

Default: 1024

[log]

The `[log]` section specifies logging settings for mamonsu and can contain the following parameters:

`file`

Specifies the log filename, which can be preceded by the full path.

`level`

Specifies the debug level. This option can take `DEBUG`, `ERROR`, or `INFO` values.

Default: `INFO`

`format`

The format of the logged data.

Default: `[%(levelname)s] %(asctime)s - %(name)s - %(message)s`

where `levelname` is the debug level, `asctime` returns the current time, `name` specifies the plugin that emitted this log entry or `root` otherwise, and `message` provides the actual log message.

Plugin Parameters

[plugins]

The `[plugins]` section specifies custom plugins to be added for metrics collection and can contain the following parameters:

`enabled`

Enables/disables using custom plugins for metrics collection if set to `True` or `False`, respectively.

Default: `False`

`directory`

Specifies the directory that contains custom plugins for metrics collection. Setting this parameter to `None` forbids using custom plugins.

Default: `/etc/mamonsu/plugins`

If you need to configure any of the plugins you add to mamonsu after installation, you have to add this plugin section to the `agent.conf` file.

The syntax of this section should follow the syntax used with the examples shown below in the section called “Individual Plugin Sections”.

Individual Plugin Sections

All built-in plugins are installed along with mamonsu. To configure a built-in plugin you should find a corresponding section below the `Individual Plugin Sections` heading and edit its parameter values:

`enabled`

Enables/disables using built-in plugins if set to `True` or `False`, respectively. These values are case-sensitive.

Default: `False`

`interval`

Specifies the plugin operation interval, in seconds. The parameter is set with an integer specifying the plugin operation interval in seconds. You can set different intervals for different plugins. For plugins that collect PostgreSQL/ Postgres Pro metrics, for example, autovacuum, checkpoint, etc., this is the interval within which mamonsu accesses the Postgres Pro instance for metrics collection. For system plugins, for example, diskstats, memory, etc., this is the interval within which the operating system is accessed. For service plugins, for example, agentapi, logsender, zbxsender, this is the interval within which their functions are called. Note that the `interval` parameter of the zbxsender plugin is associated with the `timeout` parameter of the `[zabbix]` section. The maximum Zabbix server response timeout greater than the plugin operation interval may cause misbehavior of the zbxsender plugin: the plugin restarts with an error message if the connection or data transfer require longer time than the value specified in the `interval` parameter.

Default: 60

The example below shows individual plugin sections corresponding to the `preparedtransaction` and the `pgprobackup` built-in plugins:

```
[preparedtransaction]
max_prepared_transaction_time = 60
interval = 60

[pgprobackup]
enabled = false
interval = 300
backup_dirs = /backup_dir1,/backup_dir2
pg_probackup_path = /usr/bin/pg_probackup-11
```

[preparedtransaction]

This plugin gets age in seconds of the oldest prepared transaction and number of all transactions prepared for a two-phase commit. For additional information refer to PREPARE TRANSACTION and Section 54.81.

The `max_prepared_transaction_time` parameter specifies the threshold in seconds for the age of the prepared transaction.

The plugin collects two metrics: `pgsql.prepared.count` (number of prepared transactions) and `pgsql.prepared.oldest` (oldest prepared transaction age in seconds).

If `pgsql.prepared.oldest` value exceeds the threshold specified by the `max_prepared_transaction_time` parameter, a trigger with the following message is fired: "PostgreSQL prepared transaction is too old on {host}".

[pgprobackup]

This plugin uses pg_probackup to track its backups' state and gets size of backup directories which store all backup files.

Please note that this plugin counts the total size of all files in the target directory. Make sure that extraneous files are not stored in this directory.

The `backup_dirs` parameter specifies a comma-separated list of paths to directories for which metrics should be collected.

The `pg_probackup_path` parameter specifies the path to pg_probackup.

By default this plugin is disabled. To enable it set the `enabled` parameter to `True`.

This plugin collects two metrics: `pg_probackup.dir.size[#backup_directory]` (the size of the target directory) and `pg_probackup.dir.error[#backup_directory]` (backup errors) for each specified *`backup_directory`*.

If any generated backup has bad status, like `ERROR`, `CORRUPT`, `ORPHAN`, a trigger is fired.

Usage

Collecting and Viewing Metrics Data

Once started, mamonsu begins collecting system and Postgres Pro metrics. The `agent` command enables you to get an overview of the collected metrics from the command line in real time.

To view the list of available metrics, use the `agent metric-list` command:

```
mamonsu agent metric-list
```

The output of this command provides the item key of each metric, its latest value, and the time when this value was received. For example:

```
system.memory[active]       7921004544    1564570818
system.memory[swap_cache]       868352    1564570818
pgsql.connections[idle]            6.0    1564570818
pgsql.archive_command[failed_trying_to_archive]    0    1564570818
```

To view the current value for a specific metric, you can use the `agent metric-get` command:

```
mamonsu agent metric-get metric_name
```

where *`metric_name`* is the item key of the metric to monitor, as returned by the `metric-list` command. For example, `pgsql.connections[idle]`.

You can view graphs for the collected metrics in the Zabbix web interface under the **Graphs** menu. For details on working with Zabbix, see its official documentation at *https://www.zabbix.com/documentation/current/manual*.

If you have chosen to save all the collected metrics data into a file, as explained in the section called “Logging Parameters”, you can later upload these metrics onto a Zabbix server for visualization using the upload command.

Adding Custom Plugins

You can extend mamonsu with your own custom plugins, as follows:

1. Save all custom plugins in a single directory, such as `/etc/mamonsu/plugins`.
2. Make sure this directory is specified in your configuration file under the `[plugins]` section:

   ```
   [plugins]
   directory = /etc/mamonsu/plugins
   ```
3. Generate a new Zabbix template to include custom plugins:

   ```
   mamonsu export template template.xml --add-plugins=/etc/mamonsu/plugins
   ```
4. Upload the generated `template.xml` to the Zabbix server as explained in the section called “Installation and Setup”.

Tuning Postgres Pro and System Configuration

Based on the collected metrics data, mamonsu can tune your Postgres Pro and system configuration for optimal performance.

You can get detailed information about the hardware, operating system, memory usage and other parameters of the monitored system, as well as Postgres Pro configuration, as follows:

```
mamonsu report
```

To view the suggested optimizations without applying them, run the `tune` command with the `--dry-run` option:

```
mamonsu tune --dry-run
```

To apply all the suggested changes, run the `tune` command without any parameters:

```
mamonsu tune
```

You can exclude some settings from the report or disable some of the optimizations by passing optional parameters. See the section called “Command-Line Reference” for the full list of parameters available for `report` and `tune` commands.

Managing Zabbix Server Settings from the Command Line

mamonsu enables you to work with the Zabbix server from the command line. You can upload template files to Zabbix, create and delete Zabbix hosts and host groups, link templates with hosts and check the latest metric values.

To set up your Zabbix host from scratch, you can follow these steps:

1. Optionally, specify your Zabbix account settings in the following environment variables on your monitoring system:

   - Set the `ZABBIX_USER` and `ZABBIX_PASSWD` variables to the login and password of your Zabbix account, respectively.
   - Set the `ZABBIX_URL` to `http://zabbix/`

   If you skip this step, you will have to add the following options to all `mamonsu zabbix` commands that you run:

   ```
   --url=http://zabbix/ --user=zabbix_login --password=zabbix_password
   ```

2. Generate a new template file and upload it to the Zabbix server:

   ```
   mamonsu export template template.xml
   mamonsu zabbix template export template.xml
   ```

3. Create a new host group:

   ```
   mamonsu zabbix hostgroup create hostgroup_name
   ```

4. Check the IDs for this host group and the uploaded template, which are assigned automatically by the Zabbix server:

   ```
   mamonsu zabbix hostgroup id hostgroup_name
   mamonsu zabbix template id template_name
   ```

5. Create a host associated with this group and link it with the uploaded template using a single command:

   ```
   mamonsu zabbix host create host_name hostgroup_id template_id mamonsu_address
   ```

   where *`host_name`* is the name of the host, *`hostgroup_id`* and *`template_id`* are the unique IDs returned in the previous step, and *`mamonsu_address`* is the IP address of the system on which mamonsu runs.

Once your Zabbix host is configured, complete the setup of your monitoring system as explained in the section called “Installation and Setup”.

Exporting Metrics for Native Zabbix Agent

Using mamonsu, you can convert system and Postgres Pro metrics definitions to the format supported by the native *Zabbix agent*.

This feature currently has the following limitations:

- You cannot export metrics if you run `mamonsu` on Windows systems.
- Metrics definitions for `pg_wait_sampling` and CFS features available in Postgres Pro Enterprise are not converted.

> **Important**
>
> To work with Zabbix proxy, you must export settings to the format supported by the native Zabbix agent.

To collect metrics provided by mamonsu using the native Zabbix agent, do the following:

1. Generate a configuration file that is compatible with the native Zabbix agent and place it under `/etc/zabbix/zabbix_agent.d/`. You can prepend the filename with the required path:

   ```
   mamonsu export zabbix-parameters /etc/zabbix/zabbix_agent.d/zabbix_agent.conf
   ```

   For all possible options of the `export zabbix-parameters` command, see the section called “Command-Line Reference”.

2. Generate a template for the native Zabbix agent:

   ```
   mamonsu export zabbix-template template.xml
   ```

   For all possible options of the `export zabbix-template` command, see the section called “Command-Line Reference”.

3. Upload the generated template to the Zabbix server, as explained in the section called “Installation and Setup”.

4. If you are going to collect Postgres Pro metrics, change the following macros in the template after the upload:

   - For `{$PG_CONNINFO}`, provide connection parameters for the Postgres Pro server to be monitored.
   - For `{$PG_PATH}`, specify psql installation directory.

Compatibility Considerations

If you want to upgrade mamonsu to a version that is not compatible with the previous one, what you must do to continue using the application depends on whether you need to retain the metrics data collected.

- If you need to retain the collected data, do the following:

  1. Install the new version of mamonsu.
  2. Generate a new template for the Zabbix server.
  3. If you performed a bootstrap using the previous version of mamonsu, run the `bootstrap` command again.
  4. Upload the new template to the Zabbix server.
  5. Rename the host for which you want to retain the collected data and leave the old template linked to that host.
  6. Create a new host for the same system and link the new template to it.
  7. Restart mamonsu. It will collect data for the new host. The old host will no longer be used, but the data collected will be available.

- If you do not need to retain the collected data, do the following:

  1. Install the new version of mamonsu.
  2. Generate a new template for the Zabbix server.

3. If you performed a bootstrap using the previous version of mamonsu, run the `bootstrap` command again.
4. Upload the new template to the Zabbix server.
5. In the settings of the Zabbix host, link the new template to the host instead of the old one.
6. Restart mamonsu. It will start collecting data. All the data collected earlier will be lost.

pgpro_controldata

pgpro_controldata — display control information of a PostgreSQL/Postgres Pro database cluster and compatibility information for a cluster and/or server

Synopsis

`pgpro_controldata` [*option*...]

Description

`pgpro_controldata` prints control information, such as the catalog version, initialized by `initdb` command of any PostgreSQL/Postgres Pro server. It also shows information about write-ahead logging and checkpoint processing. This information is cluster-wide and not specific to any database.

`pgpro_controldata` also helps to check compatibility between PostgreSQL/Postgres Pro database servers and clusters. It can print server or cluster parameters that can affect the compatibility and check whether a cluster and server are compatible by comparing those parameters.

pgpro_controldata is provided with Postgres Pro Enterprise as a separate pre-built package `pgpro-controldata` (for the detailed installation instructions, see Chapter 17).

Options

`pgpro_controldata` accepts the following command-line arguments. If no arguments are specified, `pgpro_controldata` just prints the control information like pg_controldata does. Note that compatibility-related command-line arguments `-P` and `-S` specified together work the same way as `-C`.

General-Purpose

`-B`
`--bindir`

Specifies the PostgreSQL/Postgres Pro executable directory, needed to get server compatibility parameters.

`-D` *datadir*
`--pgdata=`*datadir*

Specifies the file system location of the database configuration files. If this option is omitted, the environment variable `PGDATA` is used.

`-V`
`--version`

Print the pgpro_controldata version, then exit.

`-?`
`--help`

Show help about pgpro_controldata command-line arguments, then exit.

Compatibility-Related

`-C`
`--compatibility-check`

Display all parameters that can affect compatibility between the specified server and cluster and check whether they are compatible.

Use the `-D` option or the environment variable `PGDATA` to provide the path to the data directory, where read access is required.

If the `-B` option is omitted, the current server is assumed.

The cluster data and the server must have the same byte order and architecture type for this option to work correctly.

`-P`
`--cluster-compatibility-params`

Display all parameters of the specified cluster that can affect the compatibility.

Use the `-D` option or the environment variable `PGDATA` to provide the path to the data directory, where read access is required.

The cluster data and the server must have the same byte order and architecture type for this option to work correctly.

`-S`
`--server-compatibility-params`

Display all parameters of the specified or current server that can affect the compatibility.

If the `-B` option is omitted, the current server is assumed.

Environment

`PGDATA`

Default data directory location

`PG_COLOR`

Specifies whether to use color in diagnostic messages. Possible values are `always`, `auto` and `never`.

See Also

pg_controldata

pg_integrity_check

pg_integrity_check — calculate and validate checksums for controlled files (certified edition only)

Synopsis

`pg_integrity_check` [*connection-option*...] [-s | --system] [-u | --user] [-c | --catalog] [-o | --output] [-l *filename* | --log=*filename*] [--syslog] [-D *datadir*] [-C *filename*] [-v | --verbose] [-? | --help]

Description

`pg_integrity_check` is a utility provided with Postgres Pro Enterprise that can calculate and validate checksums for the objects you would like to control. When running `pg_integrity_check`, you must specify at least one of the options that define the type of the controlled objects: `-s`, `-u`, or `-c` for read-only files, additional files, or system catalog tables, respectively.

If you use the `-o` option, `pg_integrity_check` calculates checksums and writes them into configuration files under the `share/security/` directory. You must have write access to the corresponding files to perform this command. You cannot use the `-o` option together with the `-s` option, since a checksum for read-only files cannot be overwritten.

If you omit the `-o` option, `pg_integrity_check` compares the calculated checksums with the corresponding checksums in the configuration files. If the checksums differ for any of the controlled objects, `pg_integrity_check` displays a message indicating the difference.

For details on using `pg_integrity_check`, see Section 32.2.

Options

connection-options

Standard options for connecting to a database: `-d`, `-h`, `-p`, `-U`. You must specify `-d` and `-U` options when validating checksums for catalog tables with the `-c` option. For detailed description of connection options, see psql.

`-s`
`--system`

Validate checksums for read-only files. Checksums for read-only files control both file contents and file attributes.

`-u`
`--user`

Validate checksums for additional files. Checksums for additional files control both file contents and file attributes.

`-c`
`--catalog`

Validate checksums for system catalog tables. For the `-c` option to work correctly, you must also specify connection parameters for the database. The database server must be started and accept connections.

`-o`
`--output`

Recalculate checksums and write it into a file.

`-l` *filename*
`--log=`*filename*

Write checksum validation results into a log file.

`--syslog`

Write checksum validation results into the syslog.

`-D` *`datadir`*

Data directory of the database cluster. This option is required to define the filenames for the generated configuration files when using `-u` option.

`-C` *`filename`*

The absolute path to the configuration file used for integrity checks of system catalog tables of the selected database. If used with the `-o` option, `pg_integrity_check` writes into the specified file. If no other option is used, `pg_integrity_check` checks data against the specified file.

`-v`
`--verbose`

Print debugging information, including checksum values.

`-?`
`--help`

Print command-line help.

Return Values

0 — checksums are calculated or validated successfully.

1 — an error occurred during the initial checksum calculation for read-only files.

2 — checksum validation revealed changes in one or more of the controlled objects.

3 — an unexpected error occurred during checksum validation.

Examples

Compute checksums for additional files and write them into the `share/security/_var_lib_pgpro_ent-14_data.user.conf` configuration file:

```
pg_integrity_check -u -o -D /var/lib/pgpro/ent-14/data
```

Check integrity of all controlled objects in the `postgres` database on behalf of the `postgres` user:

```
pg_integrity_check -s -u -c -D /var/lib/pgpro/ent-14/data -d postgres -h localhost -p
 5432 -U postgres
```

I.4. Third-Party Server Applications

This section covers third-party server-related applications. They are typically run on the host where the database server resides.

pgbouncer

pgbouncer — a Postgres Pro connection pooler

Synopsis

On Linux systems:

`pgbouncer` [-d] [-R] [-v] [-u *`user`*] pgbouncer.ini

`pgbouncer` -V | -h

On Windows:

`pgbouncer` [-v] [-u *`user`*] pgbouncer.ini

`pgbouncer` -V | -h

To use pgbouncer as a Windows service:

`pgbouncer.exe` --regservice pgbouncer.ini

`pgbouncer.exe` --unregservice pgbouncer.ini

Description

pgbouncer is a Postgres Pro connection pooler. Any target application can be connected to pgbouncer as if it were a Postgres Pro server, and pgbouncer will create a connection to the actual server, or it will reuse one of its existing connections.

The aim of pgbouncer is to lower the performance impact of opening new connections to Postgres Pro.

In order not to compromise transaction semantics for connection pooling, pgbouncer supports several types of pooling when rotating connections:

Session pooling

Most polite method. When a client connects, a server connection will be assigned to it for the whole duration the client stays connected. When the client disconnects, the server connection will be put back into the pool. This is the default method.

Transaction pooling

A server connection is assigned to a client only during a transaction. When pgbouncer notices that transaction is over, the server connection will be put back into the pool.

Statement pooling

Most aggressive method. The server connection will be put back into the pool immediately after a query completes. Multi-statement transactions are disallowed in this mode as they would break.

The administration interface of pgbouncer consists of some new `SHOW` commands available when connected to a special “virtual” database `pgbouncer`.

Quick Start

pgbouncer is provided with Postgres Pro Enterprise as a separate pre-built package `pgbouncer` (for the detailed installation instructions, see Chapter 17). Basic setup and usage is as follows.

1. Create a `pgbouncer.ini` file. Details in the `pgbouncer(5)` man page. Simple example:

```
[databases]
template1 = host=localhost dbname=template1 auth_user=someuser
```

```
[pgbouncer]
listen_port = 6432
listen_addr = localhost
auth_type = md5
auth_file = userlist.txt
logfile = pgbouncer.log
pidfile = pgbouncer.pid
admin_users = someuser
```

2. Create a `userlist.txt` file that contains the users allowed in:

```
"someuser" "same_password_as_in_server"
```

3. Launch pgbouncer:

```
$ pgbouncer -d pgbouncer.ini
```

> **Note**
>
> The above command does not work on Windows systems. Instead, pgbouncer must be launched as a service that first needs to be registered, as follows:
>
> ```
> pgbouncer --regservice
> ```

4. Have your application (or the `psql` client) connect to pgbouncer instead of directly to the Postgres Pro server:

```
$ psql -p 6432 -U someuser template1
```

5. Manage pgbouncer by connecting to the special administration database pgbouncer and issuing `SHOW HELP;` to begin:

```
$ psql -p 6432 -U someuser pgbouncer
pgbouncer=# SHOW HELP;
NOTICE:  Console usage
DETAIL:
  SHOW [HELP|CONFIG|DATABASES|FDS|POOLS|CLIENTS|SERVERS|SOCKETS|LISTS|VERSION|...]
  SET key = arg
  RELOAD
  PAUSE
  SUSPEND
  RESUME
  SHUTDOWN
  [...]
```

6. If you made changes to the `pgbouncer.ini` file, you can reload it with:

```
pgbouncer=# RELOAD;
```

Options

`-d, --daemon`

Run in the background. Without it, the process will run in the foreground. In daemon mode, setting `pidfile` as well as `logfile` or `syslog` is required. No log messages will be written to stderr after going into the background.

> **Note**
>
> Does not work on Windows, pgbouncer needs to run as service there.

`-R, --reboot`

> **Note**
>
> This option is deprecated. Instead of this option use a rolling restart with multiple pgbouncer processes listening on the same port using `so_reuseport` instead.

Do an online restart. That means connecting to the running process, loading the open sockets from it, and then using them. If there is no active process, boot normally.

> **Note**
>
> Works only if OS supports Unix sockets and the `unix_socket_dir` is not disabled in configuration. Does not work on Windows. Does not work with TLS connections, they are dropped.

`-u` *user*`, --user` *user*

Switch to the given user on startup.

`-v, --verbose`

Increase verbosity. Can be used multiple times.

`-q, --quiet`

Be quiet: do not log to stderr. This does not affect logging verbosity, only that stderr is not to be used. For use in `init.d` scripts.

`-V, --version`

Show version.

`-h, --help`

Show short help.

`--regservice`

Win32: Register to run as Windows service. The `service_name` configuration parameter value is used as the name to register under.

`--unregservice`

Win32: Unregister Windows service.

Admin Console

The console is available by connecting as normal to the database pgbouncer:

```
$ psql -p 6432 pgbouncer
```

Only users listed in the configuration parameters `admin_users` or `stats_users` are allowed to log in to the console. (Except when `auth_mode=any`, then any user is allowed in as a `stats_user`.)

Additionally, the user name `pgbouncer` is allowed to log in without password, if the login comes via the Unix socket and the client has same Unix user uid as the running process.

The admin console currently only supports the simple query protocol. Some drivers use the extended query protocol for all commands; these drivers will not work for this.

Show Commands

The `SHOW` commands output information. Each command is described below.

SHOW STATS

Shows statistics. In this and related commands, the total figures are since process start, the averages are updated every `stats_period`.

`database`

Statistics are presented per database.

`total_xact_count`

Total number of SQL transactions pooled by pgbouncer.

`total_query_count`

Total number of SQL queries pooled by pgbouncer.

`total_received`

Total volume in bytes of network traffic received by pgbouncer.

`total_sent`

Total volume in bytes of network traffic sent by pgbouncer.

`total_xact_time`

Total number of microseconds spent by pgbouncer when connected to Postgres Pro in a transaction, either idle in transaction or executing queries.

`total_query_time`

Total number of microseconds spent by pgbouncer when actively connected to Postgres Pro, executing queries.

`total_wait_time`

Time spent by clients waiting for a server, in microseconds. Updated when a client connection is assigned a backend connection.

`avg_xact_count`

Average transactions per second in last stat period.

`avg_query_count`

Average queries per second in last stat period.

`avg_recv`

Average received (from clients) bytes per second.

`avg_sent`

Average sent (to clients) bytes per second.

`avg_xact_time`

Average transaction duration, in microseconds.

`avg_query_time`

Average query duration, in microseconds.

`avg_wait_time`

Average time spent by clients waiting for a server that were assigned a backend connection within the current `stats_period`, in microseconds (average per second within that period).

SHOW STATS_TOTALS

Subset of `SHOW STATS` showing the total values (`total_`).

SHOW STATS_AVERAGES

Subset of `SHOW STATS` showing the average values (`avg_`).

SHOW TOTALS

Like `SHOW STATS` but aggregated across all databases.

SHOW SERVERS

`type`

S, for server.

`user`

User name pgbouncer uses to connect to server.

`database`

Database name.

`state`

State of the pgbouncer server connection, one of `active`, `idle`, `used`, `tested`, `new`, `active_cancel`, or `being_canceled`.

`addr`

IP address of Postgres Pro server.

`port`

Port of Postgres Pro server.

`local_addr`

Connection start address on local machine.

`local_port`

Connection start port on local machine.

`connect_time`

When the connection was made.

`request_time`

When last request was issued.

`wait`

Not used for server connections.

`wait_us`

Not used for server connections.

`close_needed`

1 if the connection will be closed as soon as possible, because a configuration file reload or DNS update changed the connection information or `RECONNECT` was issued.

`ptr`

Address of internal object for this connection. Used as unique ID.

`link`

Address of client connection the server is paired with.

`remote_pid`

PID of backend server process. In case connection is made over Unix socket and OS supports getting process ID info, its OS PID. Otherwise it's extracted from cancel packet the server sent, which should be the PID in case the server is Postgres Pro, but it's a random number in case the server is another pgbouncer.

`tls`

A string with TLS connection information, or empty if not using TLS.

`application_name`

A string containing the `application_name` set on the linked client connection, or empty if this is not set, or if there is no linked connection.

SHOW CLIENTS

`type`

C, for client.

`user`

Client connected user.

`database`

Database name.

`state`

State of the client connection, one of `active`, `waiting`, `active_cancel_req`, or `waiting_cancel_req`.

`addr`

IP address of the client.

`port`

Source port of the client.

`local_addr`

Connection end address on local machine.

`local_port`

Connection end port on local machine.

`connect_time`

Timestamp of connect time.

`request_time`

Timestamp of latest client request.

`wait`

Current waiting time in seconds.

`wait_us`

Microsecond part of the current waiting time.

`close_needed`

Not used for clients.

`ptr`

Address of internal object for this connection. Used as unique ID.

`link`

Address of server connection the client is paired with.

`remote_pid`

Process ID, in case client connects over Unix socket and OS supports getting it.

`tls`

A string with TLS connection information, or empty if not using TLS.

`application_name`

A string containing the `application_name` set by the client for this connection, or empty if this is not set.

SHOW POOLS

A new pool entry is made for each couple of (database, user).

`database`

Database name.

`user`

User name.

`cl_active`

Client connections that are either linked to server connections or are idle with no queries waiting to be processed.

`cl_waiting`

Client connections that have sent queries but have not yet got a server connection.

`cl_active_cancel_req`

Client connections that have forwarded query cancellations to the server and are waiting for the server response.

`cl_waiting_cancel_req`

Client connections that have not forwarded query cancellations to the server yet.

`sv_active`

Server connections that are linked to a client.

`sv_active_cancel`

Server connections that are currently forwarding a cancel request.

`sv_being_canceled`

Servers that normally could become idle but are waiting to do so until all in-flight cancel requests have completed that were sent to cancel a query on this server.

`sv_idle`

Server connections that are unused and immediately usable for client queries.

`sv_used`

Server connections that have been idle for more than `server_check_delay`, so they need `server_check_query` to run on them before they can be used again.

`sv_tested`

Server connections that are currently running either `server_reset_query` or `server_check_query`.

`sv_login`

Server connections currently in the process of logging in.

`maxwait`

How long the first (oldest) client in the queue has waited, in seconds. If this starts increasing, then the current pool of servers does not handle requests quickly enough. The reason may be either an overloaded server or just too small of a `pool_size` setting.

`maxwait_us`

Microsecond part of the maximum waiting time.

`pool_mode`

The pooling mode in use.

SHOW PEER_POOLS

A new `peer_pool` entry is made for each configured peer.

`database`

ID of the configured peer entry.

`cl_active_cancel_req`

Client connections that have forwarded query cancellations to the server and are waiting for the server response.

`cl_waiting_cancel_req`

Client connections that have not forwarded query cancellations to the server yet.

`sv_active_cancel`

Server connections that are currently forwarding a cancel request.

`sv_login`

Server connections currently in the process of logging in.

SHOW LISTS

Show following internal information, in columns (not rows):

`databases`

Count of databases.

`users`

Count of users.

`pools`

Count of pools.

`free_clients`

Count of free clients.

`used_clients`

Count of used clients.

`login_clients`

Count of clients in `login` state.

`free_servers`

Count of free servers.

`used_servers`

Count of used servers.

`dns_names`

Count of DNS names in the cache.

`dns_zones`

Count of DNS zones in the cache.

`dns_queries`

Count of in-flight DNS queries.

`dns_pending`

Not used.

SHOW USERS

`name`

The user name.

`pool_mode`

The user's override `pool_mode`, or `NULL` if the default will be used instead.

SHOW DATABASES

`name`

Name of configured database entry.

`host`

Host pgbouncer connects to.

`port`

Port pgbouncer connects to.

`database`

Actual database name pgbouncer connects to.

`force_user`

When the user is part of the connection string, the connection between pgbouncer and Postgres Pro is forced to the given user, whatever the client user.

`pool_size`

Maximum number of server connections.

`min_pool_size`

Minimum number of server connections.

`reserve_pool`

Maximum number of additional connections for this database.

`pool_mode`

The database's override pool_mode, or `NULL` if the default will be used instead.

`max_connections`

Maximum number of allowed connections for this database, as set by `max_db_connections`, either globally or per database.

`current_connections`

Current number of connections for this database.

`paused`

1 if this database is currently paused, else 0.

`disabled`

1 if this database is currently disabled, else 0.

SHOW PEERS

`peer_id`

ID of the configured peer entry.

`host`

Host pgbouncer connects to.

`port`

Port pgbouncer connects to.

`pool_size`

Maximum number of server connections that can be made to this peer.

SHOW FDS

Internal command — shows list of file descriptors (FDs) in use with internal state attached to them.

When the connected user has the user name `pgbouncer`, connects through the Unix socket and has the same UID as the running process, the actual FDs are passed over the connection. This mechanism is used to do an online restart.

> **Note**
>
> This does not work on Windows.

This command also blocks the internal event loop, so it should not be used while pgbouncer is in use.

`fd`

File descriptor numeric value.

`task`

One of `pooler`, `client` or `server`.

`user`

User of the connection using the FD.

`database`

Database of the connection using the FD.

`addr`

IP address of the connection using the FD, `unix` if a Unix socket is used.

`port`

Port used by the connection using the FD.

`cancel`

Cancel key for this connection.

`link`

File descriptor for corresponding server/client. `NULL` if idle.

SHOW SOCKETS, SHOW ACTIVE_SOCKETS

Shows low-level information about sockets or only active sockets. This includes the information shown under `SHOW CLIENTS` and `SHOW SERVERS` as well as other more low-level information.

SHOW CONFIG

Show the current configuration settings, one per row, with the following columns:

`key`

Configuration variable name.

`value`

Configuration value.

`default`

Configuration default value.

`changeable`

Either `yes` or `no`, shows if the variable can be changed while running. If `no`, the variable can be changed only at boot-time. Use `SET` to change a variable at run time.

SHOW MEM

Shows low-level information about the current sizes of various internal memory allocations. The information presented is subject to change.

SHOW DNS_HOSTS

Show host names in DNS cache.

`hostname`

Host name.

`ttl`

How many seconds until next lookup.

`addrs`

Comma separated list of addresses.

SHOW DNS_ZONES

Show DNS zones in cache.

`zonename`

Zone name.

`serial`

Current serial.

`count`

Host names belonging to this zone.

SHOW VERSION

Show the pgbouncer version string.

SHOW STATE

Show the pgbouncer state settings. Current states are active, paused and suspended.

Process Controlling Commands

PAUSE [*db*]

pgbouncer tries to disconnect from all servers. Disconnecting each server connection waits for that server connection to be released according to the server pool's pooling mode (in transaction pooling mode, the transaction must complete, in statement mode, the statement must complete, and in session pooling mode the client must disconnect). The command will not return before all server connections have been disconnected. To be used at the time of database restart.

If database name is given, only that database will be paused.

New client connections to a paused database will wait until `RESUME` is called.

DISABLE *db*

Reject all new client connections on the given database.

ENABLE *db*

Allow new client connections after a previous `DISABLE` command.

RECONNECT *db*

Close each open server connection for the given database, or all databases, after it is released (according to the pooling mode), even if its lifetime is not up yet. New server connections can be made immediately and will connect as necessary according to the pool size settings.

This command is useful when the server connection setup has changed, for example to perform a gradual switchover to a new server. It is not necessary to run this command when the connection string in `pgbouncer.ini` has been changed and reloaded (see `RELOAD`) or when DNS resolution has changed,

because then the equivalent of this command will be run automatically. This command is only necessary if something downstream of pgbouncer routes the connections.

After this command is run, there could be an extended period where some server connections go to an old destination and some server connections go to a new destination. This is likely only sensible when switching read-only traffic between read-only replicas, or when switching between nodes of a multimaster replication setup. If all connections need to be switched at the same time, `PAUSE` is recommended instead. To close server connections without waiting (for example, in emergency failover rather than gradual switchover scenarios), also consider `KILL`.

KILL *db*

Immediately drop all client and server connections on given database.

New client connections to a killed database will wait until `RESUME` is called.

SUSPEND

All socket buffers are flushed and pgbouncer stops listening for data on them. The command will not return before all buffers are empty. To be used at the time of pgbouncer online reboot.

New client connections to a suspended database will wait until `RESUME` is called.

RESUME [*db*]

Resume work from previous `KILL`, `PAUSE`, or `SUSPEND` command.

SHUTDOWN

The pgbouncer process will exit.

RELOAD

The pgbouncer process will reload its configuration files and update changeable settings. This includes the main configuration file as well as the files specified by the settings `auth_file` and `auth_hba_file`.

pgbouncer notices when a configuration file reload changes the connection parameters of a database definition. An existing server connection to the old destination will be closed when the server connection is next released (according to the pooling mode), and new server connections will immediately use the updated connection parameters.

WAIT_CLOSE [*db*]

Wait until all server connections, either of the specified database or of all databases, have cleared the `close_needed` state (see the section called “SHOW SERVERS”). This can be called after a `RECONNECT` or `RELOAD` to wait until the respective configuration change has been fully activated, for example in switchover scripts.

Other Commands

SET *key* = *arg*

Changes a configuration setting (see also the section called “SHOW CONFIG”). For example:

```
SET log_connections = 1;
SET server_check_query = 'select 2';
```

(Note that this command is run on the pgbouncer admin console and sets pgbouncer settings. A `SET` command run on another database will be passed to the Postgres Pro backend like any other SQL command.)

Signals

`SIGHUP`

Reload config. Same as issuing the command `RELOAD` on the console.

`SIGINT`

Safe shutdown. Same as issuing `PAUSE` and `SHUTDOWN` on the console.

`SIGTERM`

Immediate shutdown. Same as issuing `SHUTDOWN` on the console.

`SIGUSR1`

Same as issuing `PAUSE` on the console.

`SIGUSR2`

Same as issuing `RESUME` on the console.

Libevent Settings

From the libevent documentation:

> It is possible to disable support for `epoll`, `kqueue`, `devpoll`, `poll`, or `select` by setting the environment variable `EVENT_NOEPOLL`, `EVENT_NOKQUEUE`, `EVENT_NODEVPOLL`, `EVENT_NOPOLL` or `EVENT_NOSELECT`, respectively.
>
> By setting the environment variable `EVENT_SHOW_METHOD`, `libevent` displays the kernel notification method that it uses.

`pgbouncer.ini` Configuration File

The configuration file is in the `.ini` format. Section names are between `[` and `]`. Lines starting with `;` or `#` are taken as comments and ignored. The characters `;` and `#` are not recognized as special when they appear later in the line.

Generic Settings

`logfile`

Specifies the log file. For daemonization (`-d`), either this or `syslog` has to be set. The log file is kept open, so after rotation, `kill -HUP` or on console `RELOAD;` should be done. On Windows, the service must be stopped and started.

Note that setting `logfile` does not by itself turn off logging to stderr. Use the command-line option `-q` or `-d` for that.

Default: not set

`pidfile`

Specifies the PID file. Without `pidfile` set, daemonization (`-d`) is not allowed.

Default: not set

`listen_addr`

Specifies a list (comma-separated) of addresses where to listen for TCP connections. You may also use `*` meaning "listen on all addresses". When not set, only Unix socket connections are accepted.

Addresses can be specified numerically (IPv4/IPv6) or by name.

Default: not set

`listen_port`

Which port to listen on. Applies to both TCP and Unix sockets.

Default: 6432

`unix_socket_dir`

Specifies the location for Unix sockets. Applies to both the listening socket and server connections. If set to an empty string, Unix sockets are disabled. A value that starts with `@` specifies that a Unix socket in the abstract namespace should be created (currently supported on Linux and Windows).

For online reboot (`-R`) to work, a Unix socket needs to be configured, and it needs to be in the file-system namespace.

Default: `/tmp` (empty on Windows)

`unix_socket_mode`

File system mode for Unix socket. Ignored for sockets in the abstract namespace. Not supported on Windows.

Default: 0777

`unix_socket_group`

Group name to use for Unix socket. Ignored for sockets in the abstract namespace. Not supported on Windows.

Default: not set

`user`

If set, specifies the Unix user to change to after startup. Works only if pgbouncer is started as root or if it's already running as the given user.

Not supported on Windows.

Default: not set

`pool_mode`

Specifies when a server connection can be reused by other clients.

`session`

Server is released back to pool after client disconnects. Default.

`transaction`

Server is released back to pool after transaction finishes.

`statement`

Server is released back to pool after query finishes. Transactions spanning multiple statements are disallowed in this mode.

`max_client_conn`

Maximum number of client connections allowed.

When this setting is increased, then the file descriptor limits in the operating system might also have to be increased. Note that the number of file descriptors potentially used is more than `max_client_conn`. If each user connects under its own username to the server, the theoretical maximum used is:

```
max_client_conn + (max pool_size * total databases * total users)
```

If a database user is specified in the connection string (all users connect under the same user name), the theoretical maximum is:

```
max_client_conn + (max pool_size * total databases)
```

The theoretical maximum should never be reached, unless somebody deliberately crafts a special load for it. Still, it means you should set the number of file descriptors to a safely high number.

Search for `ulimit` in your favorite shell man page. Note: `ulimit` does not apply in a Windows environment.

Default: 100

`default_pool_size`

How many server connections to allow per user/database pair. Can be overridden in the per-database configuration.

Default: 20

`min_pool_size`

Add more server connections to pool if below this number. Improves the behavior when the normal load suddenly comes back after a period of total inactivity. The value is effectively capped at the pool size.

Default: 0 (disabled)

`reserve_pool_size`

How many additional connections to allow to a pool (see `reserve_pool_timeout`). The 0 value disables this parameter.

Default: 0 (disabled)

`reserve_pool_timeout`

If a client has not been serviced in this time, pgbouncer enables use of additional connections from the reserve pool. The 0 value disables this parameter. [seconds]

Default: 5.0

`max_db_connections`

Do not allow more than this many server connections per database (regardless of user). This considers the pgbouncer database that the client has connected to, not the Postgres Pro database of the outgoing connection. This can also be set per database in the `[databases]` section.

Note that when you hit the limit, closing a client connection to one pool will not immediately allow a server connection to be established for another pool, because the server connection for the first pool is still open. Once the server connection closes (due to idle timeout), a new server connection will immediately be opened for the waiting pool.

Default: 0 (unlimited)

`max_user_connections`

Do not allow more than this many server connections per user (regardless of database). This considers the pgbouncer user that is associated with a pool, which is either the user specified for the server connection or in absence of that the user the client has connected as. This can also be set per user in the `[users]` section.

Note that when you hit the limit, closing a client connection to one pool will not immediately allow a server connection to be established for another pool, because the server connection for the first pool is still open. Once the server connection closes (due to idle timeout), a new server connection will immediately be opened for the waiting pool.

Default: 0 (unlimited)

`server_round_robin`

By default, pgbouncer reuses server connections in LIFO (last-in, first-out) manner, so that few connections get the most load. This gives best performance if you have a single server serving a database. But if there is a round-robin system behind a database address (TCP, DNS, or host list), then it is better if pgbouncer also uses connections in that manner, thus achieving uniform load.

Default: 0

`track_extra_parameters`

By default, pgbouncer tracks `client_encoding`, `datestyle`, `timezone`, `standard_conforming_strings` and `application_name` parameters per client. To allow other parameters to be tracked, they can be specified here, so that pgbouncer knows that they should be maintained in the client variable cache and restored in the server whenever the client becomes active.

If you need to specify multiple values, use a comma-separated list (e.g. `default_transaction_read-only, IntervalStyle`)

> **Note**
>
> Most parameters cannot be tracked this way. The only parameters that can be tracked are ones that Postgres Pro reports to the client. Postgres Pro has an official list of parameters that it reports to the client. Postgres Pro extensions can change this list though, they can add parameters themselves that they also report, and they can start reporting already existing paremeters that Postgres Pro does not report. Notably Citus 12.0+ causes PostgreSQL to also report `search_path`.

The `postgres` protocol allows specifying parameter settings, both directly as a parameter in the startup packet, or inside the `options` startup packet. Parameters specified using both of these methods are supported by `track_extra_parameters`. However, it's not possible to include `options` itself in `track_extra_parameters`, only the parameters contained in `options`.

Default: `IntervalStyle`

`ignore_startup_parameters`

By default, pgbouncer allows only parameters it can keep track of in startup packets: `client_encoding`, `datestyle`, `timezone` and `standard_conforming_strings`.

All other parameters will raise an error. To allow other parameters, they can be specified here, so that pgbouncer knows that they are handled by the admin and it can ignore them.

If you need to specify multiple values, use a comma-separated list (e.g. `options,extra_float_digits`).

The `postgres` protocol allows specifying parameter settings, both directly as a parameter in the startup packet, or inside the `options` startup packet. Parameters specified using both of these methods are supported by `ignore_startup_parameters`. It's even possible to include `options` itself in `ignore_startup_parameters`, which results in any unknown parameters contained inside `options` to be ignored.

Default: empty

`peer_id`

The peer ID used to identify this pgbouncer process in a group of pgbouncer processes that are peered together. The `peer_id` value should be unique within a group of peered pgbouncer processes. When set to 0, pgbouncer peering is disabled. See also [peers] Section for more information. The maximum value that can be used for the `peer_id` is 16383.

Default: 0

`disable_pqexec`

Disable the Simple Query protocol (PQexec). Unlike the Extended Query protocol, Simple Query allows multiple queries in one packet, which allows some classes of SQL-injection attacks. Disabling it can improve security. Obviously, this means only clients that exclusively use the Extended Query protocol will stay working.

Default: 0

`application_name_add_host`

Add the client host address and port to the application name setting set on connection start. This helps in identifying the source of bad queries, etc. This logic applies only at the start of a connection. If `application_name` is later changed with `SET`, pgbouncer does not change it again.

Default: 0

`conffile`

Show location of current configuration file. Changing it will make pgbouncer use another configuration file for next `RELOAD` / `SIGHUP`.

Default: file from command line

`service_name`

Used on win32 service registration.

Default: `pgbouncer`

`job_name`

Alias for `service_name`.

`stats_period`

Sets how often the averages shown in various `SHOW` commands are updated and how often aggregated statistics are written to the log (but see `log_stats`). [seconds]

Default: 60

Authentication Settings

pgbouncer handles its own client authentication and has its own database of users. These settings control this.

`auth_type`

How to authenticate users.

`cert`

The client must connect over TLS connection with a valid client certificate. The user name is then taken from the `CommonName` field from the certificate.

`md5`

Use MD5-based password check. This is the default authentication method. `auth_file` may contain both MD5-encrypted and plain-text passwords. If `md5` is configured and a user has a SCRAM secret, then SCRAM authentication is used automatically instead.

`scram-sha-256`

Use password check with SCRAM-SHA-256. `auth_file` has to contain SCRAM secrets or plain-text passwords. Note that SCRAM secrets can only be used for verifying the password of a client

but not for logging into a server. To be able to use SCRAM on server connections, use plain-text passwords.

`plain`

The clear-text password is sent over the wire. Deprecated.

`trust`

No authentication is done. The user name must still exist in `auth_file`.

`any`

Like the `trust` method, but the user name given is ignored. Requires that all databases are configured to log in as a specific user. Additionally, the console database allows any user to log in as admin.

`hba`

The actual authentication type is loaded from `auth_hba_file`. This allows different authentication methods for different access paths, for example: connections over Unix socket use `peer` authentication method, connections over TCP must use TLS.

`pam`

Pluggable Authentication Modules (PAM) method is used to authenticate users, `auth_file` is ignored. This method is not compatible with databases using the `auth_user` option. The service name reported to PAM is `pgbouncer`. `pam` is not supported in the HBA configuration file.

`auth_hba_file`

HBA configuration file to use when `auth_type` is `hba`.

Default: not set

`auth_file`

The name of the file to load user names and passwords from. See the section called “Authentication File Format” for details.

Most authentication types (see `auth_type`) require that either `auth_file` or `auth_user` be set; otherwise there would be no users defined.

Default: not set

`auth_user`

If `auth_user` is set, then any user not specified in `auth_file` will be queried through the `auth_query` query from `pg_shadow` in the database, using `auth_user`. The password of `auth_user` will be taken from `auth_file`. (If `auth_user` does not require a password, then it does not need to be defined in `auth_file`.)

Direct access to `pg_shadow` requires admin rights. It's preferable to use a non-superuser that calls a `SECURITY DEFINER` function instead.

Default: not set

`auth_query`

Query to load user's password from database.

Direct access to `pg_shadow` requires admin rights. It's preferable to use a non-superuser that calls a `SECURITY DEFINER` function instead.

Note that the query is run inside the target database. So if a function is used, it needs to be installed into each database.

Default: `SELECT usename, passwd FROM pg_shadow WHERE usename=$1`

`auth_dbname`

Database name in the [databases] section to be used for authentication purposes. This option can be either global or overriden in the connection string if this parameter is specified.

Log Settings

`syslog`

Toggles syslog on/off. On Windows, the event log is used instead.

Default: 0

`syslog_ident`

Under what name to send logs to syslog.

Default: `pgbouncer` (program name)

`syslog_facility`

Under what facility to send logs to syslog. Possibilities: `auth`, `authpriv`, `daemon`, `user`, `local0-7`.

Default: `daemon`

`log_connections`

Log successful logins.

Default: 1

`log_disconnections`

Log disconnections with reasons.

Default: 1

`log_pooler_errors`

Log error messages the pooler sends to clients.

Default: 1

`log_stats`

Write aggregated statistics into the log, every `stats_period`. This can be disabled if external monitoring tools are used to grab the same data from `SHOW` commands.

Default: 1

`verbose`

Increase verbosity. Mirrors the `-v` switch on the command line. For example, using `-v -v` on the command line is the same as `verbose=2`.

Default: 0

Console Access Control

`admin_users`

Comma-separated list of database users that are allowed to connect and run all commands on the console. Ignored when `auth_type` is `any`, in which case any user name is allowed in as admin.

Default: empty

`stats_users`

Comma-separated list of database users that are allowed to connect and run read-only queries on the console. That means all `SHOW` commands except `SHOW FDS`.

Default: empty

Connection Sanity Checks, Timeouts

`server_reset_query`

Query sent to server on connection release, before making it available to other clients. At that moment no transaction is in progress, so the value should not include `ABORT` or `ROLLBACK`.

The query is supposed to clean any changes made to the database session so that the next client gets the connection in a well-defined state. The default is `DISCARD ALL`, which cleans everything, but that leaves the next client no pre-cached state. It can be made lighter, e.g. `DEALLOCATE ALL` to just drop prepared statements, if the application does not break when some state is kept around.

When transaction pooling is used, the `server_reset_query` is not used, because in that mode, clients must not use any session-based features, since each transaction ends up in a different connection and thus gets a different session state.

Default: `DISCARD ALL`

`server_reset_query_always`

Whether `server_reset_query` should be run in all pooling modes. When this setting is off (default), the `server_reset_query` will be run only in pools that are in sessions-pooling mode. Connections in transaction-pooling mode should not have any need for a reset query.

This setting is for working around broken setups that run applications that use session features over a transaction-pooled pgbouncer. It changes non-deterministic breakage to deterministic breakage: clients always lose their state after each transaction.

Default: 0

`server_check_delay`

How long to keep released connections available for immediate re-use, without running `server_check_query` on it. If 0 then the query is always run.

Default: 30.0

`server_check_query`

Simple do-nothing query to check if the server connection is alive.

If an empty string, then sanity checking is disabled.

Default: `select 1`

`server_fast_close`

Disconnect a server in session pooling mode immediately or after the end of the current transaction if it is in `close_needed` mode (set by `RECONNECT`, `RELOAD` that changes connection settings, or DNS change), rather than waiting for the session end. In statement or transaction pooling mode, this has no effect since that is the default behavior there.

If because of this setting a server connection is closed before the end of the client session, the client connection is also closed. This ensures that the client notices that the session has been interrupted.

This setting makes connection configuration changes take effect sooner if session pooling and long-running sessions are used. The downside is that client sessions are liable to be interrupted by a

configuration change, so client applications will need logic to reconnect and reestablish session state. But note that no transactions will be lost, because running transactions are not interrupted, only idle sessions.

Default: 0

`server_lifetime`

The pooler will close an unused (not currently linked to any client connection) server connection that has been connected longer than this. Setting it to 0 means the connection is to be used only once, then closed. [seconds]

Default: 3600.0

`server_idle_timeout`

If a server connection has been idle more than this many seconds it will be closed. If 0 then timeout is disabled. [seconds]

Default: 600.0

`server_connect_timeout`

If connection and login don't finish in this amount of time, the connection will be closed. [seconds]

Default: 15.0

`server_login_retry`

If login to the server failed, because of failure to connect or from authentication, the pooler waits this much before retrying to connect. During the waiting interval, new clients trying to connect to the failing server will get an error immediately without another connection attempt. [seconds]

The purpose of this behavior is that clients don't unnecessarily queue up waiting for a server connection to become available if the server is not working. However, it also means that if a server is momentarily failing, for example during a restart or if the configuration was erroneous, then it will take at least this long until the pooler will consider connecting to it again. Planned events such as restarts should normally be managed using the `PAUSE` command to avoid this.

Default: 15.0

`client_login_timeout`

If a client connects but does not manage to log in in this amount of time, it will be disconnected. Mainly needed to avoid dead connections stalling `SUSPEND` and thus online restart. [seconds]

Default: 60.0

`autodb_idle_timeout`

If the automatically created (via "*") database pools have been unused this many seconds, they are freed. The negative aspect of that is that their statistics are also forgotten. [seconds]

Default: 3600.0

`dns_max_ttl`

How long DNS lookups can be cached. The actual DNS TTL is ignored. [seconds]

Default: 15.0

`dns_nxdomain_ttl`

How long DNS errors and `NXDOMAIN` DNS lookups can be cached. [seconds]

Default: 15.0

`dns_zone_check_period`

Period to check if a zone serial has changed.

pgbouncer can collect DNS zones from host names (everything after first dot) and then periodically check if the zone serial changes. If it notices changes, all host names under that zone are looked up again. If any host IP changes, its connections are invalidated.

Default: 0.0 (disabled)

`resolv_conf`

The location of a custom `resolv.conf` file. This is to allow specifying custom DNS servers and perhaps other name resolution options, independent of the global operating system configuration.

The parsing of the file is done by the DNS backend library, not pgbouncer, so see the library's documentation for details on allowed syntax and directives.

Default: empty (use operating system defaults)

TLS Settings

`client_tls_sslmode`

TLS mode to use for connections from clients. TLS connections are disabled by default. When enabled, `client_tls_key_file` and `client_tls_cert_file` must be also configured to set up the key and certificate pgbouncer uses to accept client connections.

`disable`

Plain TCP. If client requests TLS, it's ignored. Default.

`allow`

If client requests TLS, it is used. If not, plain TCP is used. If the client presents a client certificate, it is not validated.

`prefer`

Same as `allow`.

`require`

The client must use TLS. If not, the client connection is rejected. If the client presents a client certificate, it is not validated.

`verify-ca`

Client must use TLS with valid client certificate.

`verify-full`

Same as `verify-ca`.

`client_tls_key_file`

Private key for pgbouncer to accept client connections.

Default: not set

`client_tls_cert_file`

Certificate for private key. Clients can validate it.

Default: not set

`client_tls_ca_file`

Root certificate file to validate client certificates.

Default: not set

`client_tls_protocols`

Which TLS protocol versions are allowed. Allowed values: `tlsv1.0`, `tlsv1.1`, `tlsv1.2`, `tlsv1.3`. Shortcuts: `all` (tlsv1.0,tlsv1.1,tlsv1.2,tlsv1.3), `secure` (tlsv1.2,tlsv1.3), `legacy` (all).

Default: `secure`

`client_tls_ciphers`

Allowed TLS ciphers, in OpenSSL syntax. Shortcuts: `default`/`secure`, `compat`/`legacy`, `insecure`/`all`, `normal`, `fast`.

Only connections using TLS version 1.2 and lower are affected. There is currently no setting that controls the cipher choices used by TLS version 1.3 connections.

Default: `fast`

`client_tls_ecdhcurve`

Elliptic Curve name to use for ECDH key exchanges.

Allowed values: `none` (DH is disabled), `auto` (256-bit ECDH), curve name.

Default: `auto`

`client_tls_dheparams`

DHE key exchange type.

Allowed values: `none` (DH is disabled), `auto` (2048-bit DH), `legacy` (1024-bit DH).

Default: `auto`

`server_tls_sslmode`

TLS mode to use for connections to Postgres Pro servers. The default mode is `prefer`.

`disable`

Plain TCP. TLS is not even requested from the server.

`prefer`

TLS connection is always requested first from Postgres Pro. If refused, the connection will be established over plain TCP. Server certificate is not validated. Default.

`require`

Connection must go over TLS. If server rejects it, plain TCP is not attempted. Server certificate is not validated.

`verify-ca`

Connection must go over TLS and server certificate must be valid according to `server_tls_ca_file`. Server host name is not checked against certificate.

`verify-full`

Connection must go over TLS and server certificate must be valid according to `server_tls_ca_file`. Server host name must match certificate information.

`server_tls_ca_file`

Root certificate file to validate Postgres Pro server certificates.

Default: not set

`server_tls_key_file`

Private key for pgbouncer to authenticate against Postgres Pro server.

Default: not set

`server_tls_cert_file`

Certificate for private key. Postgres Pro server can validate it.

Default: not set

`server_tls_protocols`

Which TLS protocol versions are allowed. Allowed values: `tlsv1.0`, `tlsv1.1`, `tlsv1.2`, `tlsv1.3`. Shortcuts: `all` (tlsv1.0,tlsv1.1,tlsv1.2,tlsv1.3), `secure` (tlsv1.2,tlsv1.3), `legacy` (all).

Default: `secure`

`server_tls_ciphers`

Allowed TLS ciphers, in OpenSSL syntax. Shortcuts: `default`/`secure`, `compat`/`legacy`, `insecure`/`all`, `normal`, `fast`.

Only connections using TLS version 1.2 and lower are affected. There is currently no setting that controls the cipher choices used by TLS version 1.3 connections.

Default: `fast`

Dangerous Timeouts

Setting the following timeouts can cause unexpected errors.

`query_timeout`

Queries running longer than that are canceled. This should be used only with a slightly smaller server-side `statement_timeout`, to apply only for network problems. [seconds]

Default: 0.0 (disabled)

`query_wait_timeout`

Maximum time queries are allowed to spend waiting for execution. If the query is not assigned to a server during that time, the client is disconnected. The 0 value disables this parameter. If this is disabled, clients will be queued indefinitely. [seconds]

This setting is used to prevent unresponsive servers from grabbing up connections. It also helps when the server is down or rejects connections for any reason.

Default: 120.0

`cancel_wait_timeout`

Maximum time cancellation requests are allowed to spend waiting for execution. If the cancel request is not assigned to a server during that time, the client is disconnected. 0 disables. If this is disabled, cancel requests will be queued indefinitely. [seconds]

This setting is used to prevent a client locking up when a cancel cannot be forwarded due to the server being down.

Default: 10.0

`client_idle_timeout`

Client connections idling longer than this many seconds are closed. This should be larger than the client-side connection lifetime settings, and only used for network problems. [seconds]

Default: 0.0 (disabled)

`idle_transaction_timeout`

If a client has been in the “idle in transaction” state longer, it will be disconnected. [seconds]

Default: 0.0 (disabled)

`suspend_timeout`

How long to wait for buffer flush during `SUSPEND` or reboot (`-R`). A connection is dropped if the flush does not succeed. [seconds]

Default: 10

Low-Level Network Settings

`pkt_buf`

Internal buffer size for packets. Affects size of TCP packets sent and general memory usage. Actual libpq packets can be larger than this, so no need to set it large.

Default: 4096

`max_packet_size`

Maximum size for Postgres Pro packets that pgbouncer allows through. One packet is either one query or one result set row. The full result set can be larger.

Default: 2147483647

`listen_backlog`

The value of the `backlog` argument for `listen()`. Determines how many new unanswered connection attempts are kept in the queue. When the queue is full, further new connections are dropped.

Default: 128

`sbuf_loopcnt`

How many times to process data on one connection, before proceeding. Without this limit, one connection with a big result set can stall pgbouncer for a long time. One loop processes one `pkt_buf` amount of data. 0 means no limit.

Default: 5

`so_reuseport`

Specifies whether to set the socket option `SO_REUSEPORT` on TCP listening sockets. On some operating systems, this allows running multiple pgbouncer instances on the same host listening on the same port and having the kernel distribute the connections automatically. This option is a way to get pgbouncer to use more CPU cores. (pgbouncer is single-threaded and uses one CPU core per instance.)

This setting has the desired effect on Linux. On systems that don't support the socket option at all, turning this setting on will result in an error.

Each pgbouncer instance on the same host needs different settings for at least `unix_socket_dir` and `pidfile`, as well as `logfile` if that is used. Also note that if you make use of this option, you can no longer connect to a specific pgbouncer instance via TCP/IP, which might have implications for monitoring and metrics collection.

To make sure query cancellations keep working, you should set up pgbouncer peering between the different pgbouncer processes. For details see the `peer_id` configuration option and the `[peers]` configuration section. There's also an example that uses peering and `so_reuseport` in the Examples section.

Default: 0

`tcp_defer_accept`

Sets the `TCP_DEFER_ACCEPT` socket option; see `man 7 tcp` for details. (This is a Boolean option: 1 means enabled. The actual value set if enabled is currently hardcoded to 45 seconds.)

This is currently only supported on Linux.

Default: 1 on Linux, otherwise 0

`tcp_socket_buffer`

Default: not set

`tcp_keepalive`

Turns on basic keepalive with OS defaults.

On Linux, the system defaults are **tcp_keepidle=7200**, **tcp_keepintvl=75**, **tcp_keepcnt=9**. They are probably similar on other operating systems.

Default: 1

`tcp_keepcnt`

Default: not set

`tcp_keepidle`

Default: not set

`tcp_keepintvl`

Default: not set

`tcp_user_timeout`

Sets the `TCP_USER_TIMEOUT` socket option. This specifies the maximum amount of time in milliseconds that transmitted data may remain unacknowledged before the TCP connection is forcibly closed. If set to 0, then operating system's default is used.

This is currently only supported on Linux.

Default: 0

Section [databases]

The section `[databases]` defines the names of the databases that clients of pgbouncer can connect to and specifies where those connections will be routed. The section contains key=value lines like

```
dbname = connection string
```

where the key will be taken as a database name and the value as a connection string, consisting of key=value pairs of connection parameters, described below (similar to libpq, but the actual libpq is not used and the set of available features is different).

Example:

```
foodb = host=host1.example.com port=5432
```

```
bardb = host=localhost dbname=bazdb
```

The database name can contain characters `_0-9A-Za-z` without quoting. Names that contain other chars need to be quoted with standard SQL ident quoting: double quotes where "" is taken as single quote.

The database name `pgbouncer` is reserved for the admin console and cannot be used as a key here.

`*` acts as fallback database: if the exact name does not exist, its value is taken as connection string for the requested database. For example, if there is the following entry (and no other overriding entries):

```
* = host=foo
```

In this case, a connection to pgbouncer specifying a database `bar` will effectively behave as if the following entry exists (taking advantage of the default for `dbname` being the client-side database name):

```
bar = host=foo dbname=bar
```

Such automatically created database entries are cleaned up if they stay idle longer than the time specified by the `autodb_idle_timeout` parameter.

`dbname`

Destination database name.

Default: same as client-side database name

`host`

Host name or IP address to connect to. Host names are resolved at connection time, the result is cached per `dns_max_ttl` parameter. When a host name's resolution changes, existing server connections are automatically closed when they are released (according to the pooling mode), and new server connections immediately use the new resolution. If DNS returns several results, they are used in a round-robin manner.

If the value begins with `/`, then a Unix socket in the file-system namespace is used. If the value begins with `@`, then a Unix socket in the abstract namespace is used.

A comma-separated list of host names or addresses can be specified. In that case, connections are made in a round-robin manner. (If a host list contains host names that in turn resolve via DNS to multiple addresses, the round-robin systems operate independently. This is an implementation dependency that is subject to change.) Note that in a list, all hosts must be available at all times: there are no mechanisms to skip unreachable hosts or to select only available hosts from a list or similar. (This is different from what a host list in libpq means.) Also note that this only affects how the destinations of new connections are chosen. See also the setting `server_round_robin` for how clients are assigned to already established server connections.

Examples:

```
host=localhost
host=127.0.0.1
host=2001:0db8:85a3:0000:0000:8a2e:0370:7334
host=/var/run/postgresql
host=192.168.0.1,192.168.0.2,192.168.0.3
```

Default: not set, meaning to use a Unix socket

`port`

Default: 5432

`user`

If `user=` is set, all connections to the destination database will be done with the specified user, meaning that there will be only one pool for this database.

Otherwise pgbouncer logs into the destination database with the client user name, meaning that there will be one pool per user.

`password`

If no password is specified here, the password from the `auth_file` or `auth_query` will be used.

`auth_user`

Override of the global `auth_user` setting, if specified.

`pool_size`

Set the maximum size of pools for this database. If not set, the `default_pool_size` is used.

`min_pool_size`

Set the minimum pool size for this database. If not set, the global `min_pool_size` is used.

`reserve_pool`

Set additional connections for this database. If not set, `reserve_pool_size` is used.

`connect_query`

Query to be executed after a connection is established, but before allowing the connection to be used by any clients. If the query raises errors, they are logged but ignored otherwise.

`pool_mode`

Set the pool mode specific to this database. If not set, the default `pool_mode` is used.

`max_db_connections`

Configure a database-wide maximum (i.e. all pools within the database will not have more than this many server connections).

`client_encoding`

Ask specific `client_encoding` from server.

`datestyle`

Ask specific `datestyle` from server.

`timezone`

Ask specific `timezone` from server.

Section [users]

This section contains key=value lines like

```
user1 = settings
```

where the key will be taken as a user name and the value as a list of configuration settings specific for this user.

Example:

```
user1 = pool_mode=session
```

Only a few settings are available here.

`pool_mode`

Set the pool mode to be used for all connections from this user. If not set, the database or default `pool_mode` is used.

`max_user_connections`

Configure a maximum for the user (i.e. all pools with the user will not have more than this many server connections).

Section [peers]

This section defines the peers that pgbouncer can forward cancellation requests to and where those cancellation requests will be routed.

pgbouncer processes can be peered together in a group by defining a `peer_id` value and a `[peers]` section in the configs of all the pgbouncer processes. These pgbouncer processes can then forward cancellation requests to the process that it originated from. This is needed to make cancellations work when multiple pgbouncer processes (possibly on different servers) are behind the same TCP load balancer. Cancellation requests are sent over different TCP connections than the query they are cancelling, so a TCP load balancer might send the cancellation request connection to a different process than the one that it was meant for. By peering them these cancellation requests eventually end up at the right process.

The section contains key=value lines like

```
peer_id = connection string
```

where the key will be taken as a `peer_id` and the value as a connection string, consisting of key=value pairs of connection parameters, described below (similar to libpq, but the actual libpq is not used and the set of available features is different).

Example:

```
1 = host=host1.example.com
2 = host=/tmp/pgbouncer-2  port=5555
```

> **Note**
>
> For peering to work, the `peer_id` of each pgbouncer process in the group must be unique within the peered group. And the `[peers]` section should contain entries for each of those peer IDs. An example can be found in the Examples section. It is allowed, but not necessary, for the `[peers]` section to contain the `peer_id` of the pgbouncer that the config is for. Such an entry will be ignored, but it is allowed to make config management easier. Because it allows using the exact same `[peers]` section for multiple configs.

`host`

Host name or IP address to connect to. Host names are resolved at connection time, the result is cached per `dns_max_ttl` parameter. If DNS returns several results, they are used in a round-robin manner. But in general it's not recommended to use a hostname that resolves to multiple IPs, because then the cancel request might still be forwarded to the wrong node and it would need to be forwarded again (which is only allowed up to three times).

If the value begins with `/`, then a Unix socket in the file-system namespace is used. If the value begins with `@`, then a Unix socket in the abstract namespace is used.

Examples:

```
host=localhost
host=127.0.0.1
host=2001:0db8:85a3:0000:0000:8a2e:0370:7334
host=/var/run/pgbouncer-1
```

`port`

Default: 6432

`pool_size`

If not set, the `default_pool_size` is used.

Include Directive

The pgbouncer configuration file can contain include directives, which specify another configuration file to read and process. This allows splitting the configuration file into physically separate parts. The include directives look like this:

```
%include filename
```

If the filename is not an absolute path, it is taken as relative to the current working directory.

Authentication File Format

This section describes the format of the file specified by the `auth_file` setting. It is a text file in the following format:

```
"username1" "password" ...
"username2" "md5abcdef012342345" ...
"username2" "SCRAM-SHA-256$iterations:salt$storedkey:serverkey"
```

There should be at least two fields, surrounded by double quotes. The first field is the user name and the second is either a plain-text, a MD5-hashed password, or a SCRAM secret. pgbouncer ignores the rest of the line. Double quotes in a field value can be escaped by writing two double quotes.

Postgres Pro MD5-hashed password format:

```
"md5" + md5(password + username)
```

So user `admin` with password `1234` will have MD5-hashed password `md545f2603610af569b6155c45067268c6b`.

Postgres Pro SCRAM secret format:

```
SCRAM-SHA-256$iterations:salt$storedkey:serverkey
```

The passwords or secrets stored in the authentication file serve two purposes. First, they are used to verify the passwords of incoming client connections, if a password-based authentication method is configured. Second, they are used as the passwords for outgoing connections to the backend server, if the backend server requires password-based authentication (unless the password is specified directly in the database's connection string). The latter works if the password is stored in plain text or MD5-hashed. SCRAM secrets can only be used for logging into a server if the client authentication also uses SCRAM, the pgbouncer database definition does not specify a user name, and the SCRAM secrets are identical in pgbouncer and the Postgres Pro server (same salt and iterations, not merely the same password). This is due to an inherent security property of SCRAM: the stored SCRAM secret cannot by itself be used for deriving login credentials.

The authentication file can be written by hand, but it's also useful to generate it from some other list of users and passwords. See `./etc/mkauth.py` for a sample script to generate the authentication file from the `pg_shadow` system table.

Alternatively, use `auth_query` instead of `auth_file` to avoid having to maintain a separate authentication file.

HBA File Format

The location of the HBA file is specified by the setting `auth_hba_file`. It is only used if `auth_type` is set to `hba`.

The file follows the format of the Postgres Pro `pg_hba.conf` file described in Section 20.1.

- Supported record types: `local`, `host`, `hostssl`, `hostnossl`.

- Database field: Supports `all`, `sameuser`, @*`file`*, multiple names. Not supported: `replication`, `samerole`, `samegroup`.
- User name field: Supports `all`, @*`file`*, multiple names. Not supported: `+groupname`.
- Address field: Supports `IPv4`, `IPv6`. Not supported: DNS names, domain prefixes.
- Auth-method field: Only methods supported by pgbouncer's `auth_type` are supported, plus `peer` and `reject`, but except `any` and `pam`, which only work globally. User name map (`map=`) parameter is not supported.

Examples

Small example configuration:

```
[databases]
template1 = host=localhost dbname=template1 auth_user=someuser

[pgbouncer]
pool_mode = session
listen_port = 6432
listen_addr = localhost
auth_type = md5
auth_file = users.txt
logfile = pgbouncer.log
pidfile = pgbouncer.pid
admin_users = someuser
stats_users = stat_collector
```

Database examples:

```
[databases]

; foodb over Unix socket
foodb =

; redirect bardb to bazdb on localhost
bardb = host=localhost dbname=bazdb

; access to destination database will go with single user
forcedb = host=localhost port=300 user=baz password=foo client_encoding=UNICODE
 datestyle=ISO
```

Example of a secure function for `auth_query`:

```
CREATE OR REPLACE FUNCTION pgbouncer.user_lookup(in i_username text, out uname text,
 out phash text)
RETURNS record AS $$
BEGIN
    SELECT usename, passwd FROM pg_catalog.pg_shadow
    WHERE usename = i_username INTO uname, phash;
    RETURN;
END;$$ LANGUAGE plpgsql SECURITY DEFINER;
REVOKE ALL ON FUNCTION pgbouncer.user_lookup(text) FROM public, pgbouncer;
GRANT EXECUTE ON FUNCTION pgbouncer.user_lookup(text) TO pgbouncer;
```

Example configs for 2 peered pgbouncer processes to create a multi-core pgbouncer setup using `so_reuseport`.

The config for the first process:

```
[databases]
postgres = host=localhost dbname=postgres
```

```
[peers]
1 = host=/tmp/pgbouncer1
2 = host=/tmp/pgbouncer2

[pgbouncer]
listen_addr=127.0.0.1
auth_file=auth_file.conf
so_reuseport=1
unix_socket_dir=/tmp/pgbouncer1
peer_id=1
```

The config for the second process:

```
[databases]
postgres = host=localhost dbname=postgres

[peers]
1 = host=/tmp/pgbouncer1
2 = host=/tmp/pgbouncer2

[pgbouncer]
listen_addr=127.0.0.1
auth_file=auth_file.conf
so_reuseport=1
; only unix_socket_dir and peer_id are different
unix_socket_dir=/tmp/pgbouncer2
peer_id=2
```

pg_filedump

pg_filedump — display formatted contents of a Postgres Pro heap, index, or control file

Synopsis

`pg_filedump` [*option*...] [*file*]

Description

pg_filedump is a utility to format Postgres Pro heap/index/control files into a human-readable form. You can format/dump the files several ways, as listed in the Options section, as well as dump a straight binary. The type of file (heap/index) can usually be determined automatically by the content of the blocks within the file. However, to format a `pg_control` file you must use the `-c` option. The default is to format the entire file using the block size listed in block 0 and display block relative addresses. These defaults can be modified using run-time options. Some options may seem strange but they are there for a reason. For example, block size. It is there because if the header of block 0 is corrupt, you need a method of forcing a block size.

Installation

pg_filedump is provided with Postgres Pro Enterprise as a separate pre-built package `pg-filedump-ent-14` (for the detailed installation instructions, see Chapter 17).

Options

Defaults are: relative addressing, range of the entire file, block size as listed on block 0 in the file.

The following options are valid for heap and index files:

`-a`

Display absolute addresses when formatting. Block header information is always block-relative.

`-b`

Display binary block images within a range. The option will turn off all formatting options.

`-d`

Display formatted block content dump. The option will turn off all other formatting options.

`-D` *attrlist*

Decode tuples using given comma-separated list of types. The list of supported types:

`bigint`
`bigserial`
`bool`
`char`
`charN` — char(n)
`date`
`float`
`float4`
`float8`
`int`
`json`
`macaddr`
`name`
`numeric`
`oid`
`real`

`serial`
`smallint`
`smallserial`
`text`
`time`
`timestamp`
`timetz`
`uuid`
`varchar`
`varcharN` — varchar(n)
`xid`
`xml`
`~` — ignore all attributes left in a tuple

`-f`

Display formatted block content dump along with interpretation.

`-h`

Display help.

`-i`

Display interpreted item details.

`-k`

Verify block checksums.

`-o`

Do not dump old values.

`-R` *`startblock`* `[`*`endblock`*`]`

Display specific block ranges within the file. Blocks are indexed from 0. *`startblock`*: block to start at. *`endblock`*: block to end at. A *`startblock`* without an *`endblock`* will format a single block.

`-s` *`segsize`*

Force segment size to *`segsize`*.

`-t`

Dump TOAST files.

`-v`

Output additional information about TOAST relations.

`-n` *`segnumber`*

Force segment number to *`segnumber`*.

`-S` *`blocksize`*

Force block size to *`blocksize`*.

`-x`

Force interpreted formatting of block items as index items.

`-y`

Force interpreted formatting of block items as heap items.

The following options are valid for control files:

`-c`

Interpret the file listed as a control file.

`-f`

Display formatted content dump along with interpretation.

`-S` *`blocksize`*

Force block size to *`blocksize`*.

Additional parameters:

`-m`

Interpret file as `pg_filenode.map` file and print contents. All other options will be ignored.

In most cases, it is recommended to use the `-i` and `-f` options to get the most useful dump output.

Author

Patrick Macdonald `<patrickm@redhat.com>`

Appendix J. External Projects

Postgres Pro is a complex software project, and managing the project is difficult. We have found that many enhancements to Postgres Pro can be more efficiently developed separately from the core project.

J.1. Client Interfaces

There are only two client interfaces included in the base Postgres Pro Enterprise distribution:

- libpq is included because it is the primary C language interface, and because many other client interfaces are built on top of it.
- ECPG is included because it depends on the server-side SQL grammar, and is therefore sensitive to changes in Postgres Pro itself.

All other language interfaces are external projects and are distributed separately. A *list of language interfaces* is maintained on the PostgreSQL wiki. Note that some of these packages are not released under the same license as Postgres Pro. For more information on each language interface, including licensing terms, refer to its website and documentation.

https://wiki.postgresql.org/wiki/List_of_drivers

J.2. Administration Tools

There are several administration tools available for Postgres Pro. One of them is PPEM, an integrated administration panel for Postgres Pro Enterprise management. It provides centralized privilege-based access to a unified management and monitoring interface with embedded command line. There are other solutions, e.g. an open-source platform *pgAdmin*.

J.3. Procedural Languages

Postgres Pro includes several procedural languages with the base distribution: PL/pgSQL, PL/Tcl, PL/Perl, and PL/Python.

In addition, there are a number of procedural languages that are developed and maintained outside the core Postgres Pro distribution. A list of *procedural languages* is maintained on the PostgreSQL wiki. Note that some of these projects are not released under the same license as Postgres Pro. For more information on each procedural language, including licensing information, refer to its website and documentation.

https://wiki.postgresql.org/wiki/PL_Matrix

J.4. Extensions

Postgres Pro is designed to be easily extensible. For this reason, extensions loaded into the database can function just like features that are built in. The extensions shipped with Postgres Pro are described in Appendix F. Other extensions are developed independently, like *PostGIS*. Even Postgres Pro replication solutions can be developed externally. For example, *Slony-I* is a popular primary/standby replication solution that is developed independently from the core project.

Appendix K. Configuring Postgres Pro for 1C Solutions

You can install and use Postgres Pro with 1C solutions in a client/server model.

Make sure that the Russian locale (such as `ru_RU.UTF-8` on Linux systems) is installed and that it is the active locale of the user who creates the database cluster. For example, for Debian systems do the following:

```
sudo dpkg-reconfigure locales # Choose locale ru_RU.UTF-8 to generate
export LANG="ru_RU.UTF-8"
/opt/pgpro/ent-14/bin/pg-setup initdb
```

For more details, see related sections of the documentation for your operating system and for 1C.

Also, for optimal performance and stability, modify the following settings in the `postgresql.conf` configuration file of Postgres Pro server:

1. Increase the maximum number of allowed concurrent connections to the database server, up to 1000 connections. 1C solutions can open a large number of connections, even if not all of them are used, so it is recommended to allow not less than 500 connections.

   ```
   max_connections = 1000
   ```

2. To ensure that temporary tables are handled correctly, modify the following parameters:

   - Increase the buffer size for temporary tables:

     ```
     temp_buffers = 32MB
     ```

   - Increase the number of allowed locks of tables or indexes per transaction to 256:

     ```
     max_locks_per_transaction = 256
     ```

     Typically, 1C solutions use a lot of temporary tables. Every backend process usually contains multiple temporary tables. When closing a connection, Postgres Pro tries to drop all temporary tables in a single transaction, so this transaction may use a lot of locks. If the number of locks exceeds the `max_locks_per_transaction` value, the transaction will fail, leaving multiple orphaned temporary tables.

3. Enable backslash escapes in all strings, and switch off the warning about using the backslash escape symbol:

   ```
   standard_conforming_strings = off
   escape_string_warning = off
   ```

4. Set the `effective_cache_size` parameter to at least half of RAM available on the system. Postgres Pro query optimizer performance depends on the amount of allocated RAM.

5. Optimize query planning using `plantuner` extension, as follows:

   - Add `plantuner` to the `shared_preload_libraries` variable:

     ```
     shared_preload_libraries = 'plantuner'
     ```

   - Tune Postgres Pro optimizer to improve planning for recently created empty tables:

     ```
     plantuner.fix_empty_table = 'on'
     ```

Appendix L. Postgres Pro Limits

Table L.1 describes various hard limits of Postgres Pro. However, practical limits, such as performance limitations or available disk space may apply before absolute hard limits are reached.

Table L.1. Postgres Pro Limitations

Item	Upper Limit	Comment
database size	unlimited	
number of databases	4,294,950,911	
relations per database	1,431,650,303	
relation size	32 TB	with the default `BLCKSZ` of 8192 bytes
rows per table	limited by the number of tuples that can fit onto 4,294,967,295 pages	
columns per table	1,600	further limited by tuple size fitting on a single page; see note below
columns in a result set	1,664	
field size	1 GB	
indexes per table	unlimited	constrained by maximum relations per database
columns per index	32	can be increased by recompiling Postgres Pro
partition keys	32	can be increased by recompiling Postgres Pro
identifier length	63 bytes	can be increased by recompiling Postgres Pro
function arguments	100	can be increased by recompiling Postgres Pro
query parameters	65,535	

The maximum number of columns for a table is further reduced as the tuple being stored must fit in a single 8192-byte heap page. For example, excluding the tuple header, a tuple made up of 1,600 `int` columns would consume 6400 bytes and could be stored in a heap page, but a tuple of 1,600 `bigint` columns would consume 12800 bytes and would therefore not fit inside a heap page. Variable-length fields of types such as `text`, `varchar`, and `char` can have their values stored out of line in the table's TOAST table when the values are large enough to require it. Only an 18-byte pointer must remain inside the tuple in the table's heap. For shorter length variable-length fields, either a 4-byte or 1-byte field header is used and the value is stored inside the heap tuple.

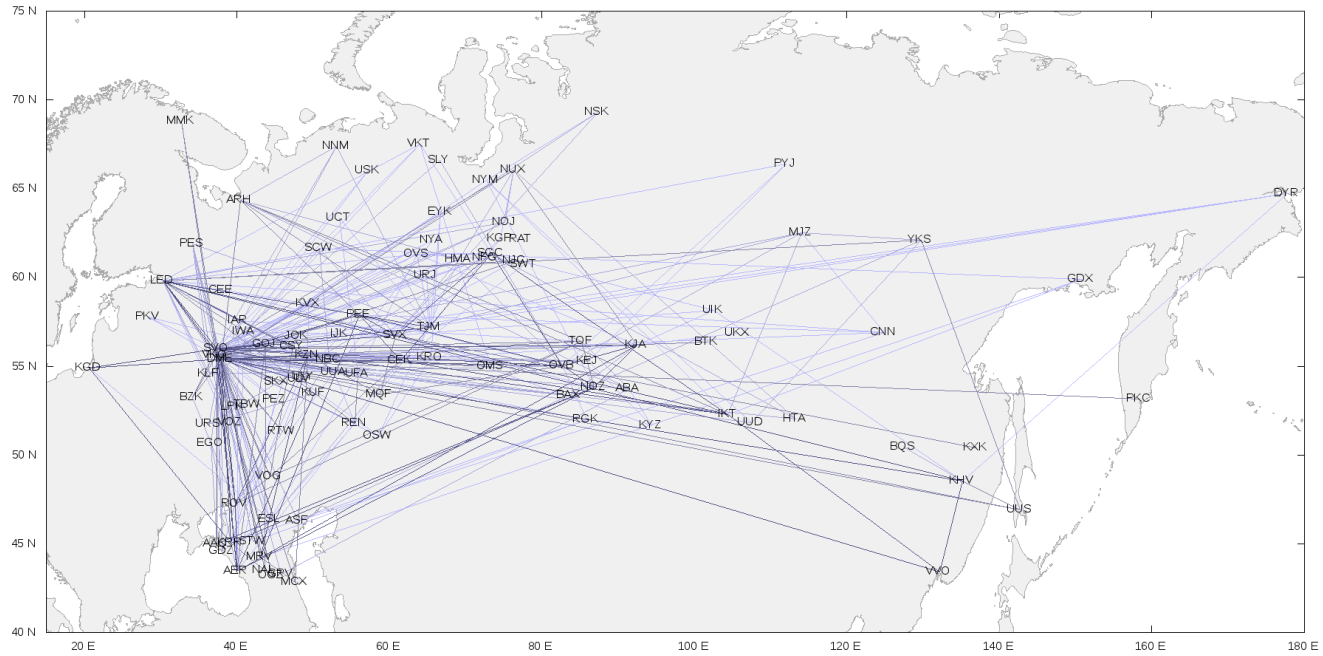
Columns that have been dropped from the table also contribute to the maximum column limit. Moreover, although the dropped column values for newly created tuples are internally marked as null in the tuple's null bitmap, the null bitmap also occupies space.

Each table can store a theoretical maximum of 2^32 out-of-line values; see Section 70.2 for a detailed discussion of out-of-line storage. This limit arises from the use of a 32-bit OID to identify each such value. The practical limit is significantly less than the theoretical limit, because as the OID space fills up, finding an OID that is still free can become expensive, in turn slowing down INSERT/UPDATE statements. Typically, this is only an issue for tables containing many terabytes of data; partitioning is a possible workaround.

Appendix M. Demo Database “Airlines”

This is an overview of a demo database for Postgres Pro. This appendix describes the database schema, which consists of eight tables and several views. The subject field of this database is airline flights in Russia. You can download the database from *our website*. See Section M.1 for details.

Figure M.1. Airlines in Russia



You can use this database for various purposes, such as:

- learning SQL language on your own
- preparing books, manuals, and courses on SQL
- showing Postgres Pro features in stories and articles

When developing this demo database, we pursued several goals:

- Database schema must be simple enough to be understood without extra explanations.
- At the same time, database schema must be complex enough to allow writing meaningful queries.
- The database must contain true-to-life data that will be interesting to work with.

This demo database is distributed under the *PostgreSQL license*.

You can send us your feedback to *edu@postgrespro.ru*.

M.1. Installation

The demo database is available at *edu.postgrespro.com* in three flavors, which differ only in the data size:

- *demo-small-en.zip* (21 MB) — flight data for one month (DB size is about 300 MB)
- *demo-medium-en.zip* (62 MB) — flight data for three months (DB size is about 700 MB)
- *demo-big-en.zip* (232 MB) — flight data for one year (DB size is about 2.5 GB)

The small database is good for writing queries, and it will not take up much disk space. The large database can help you understand the query behavior on large data volumes and consider query optimization.

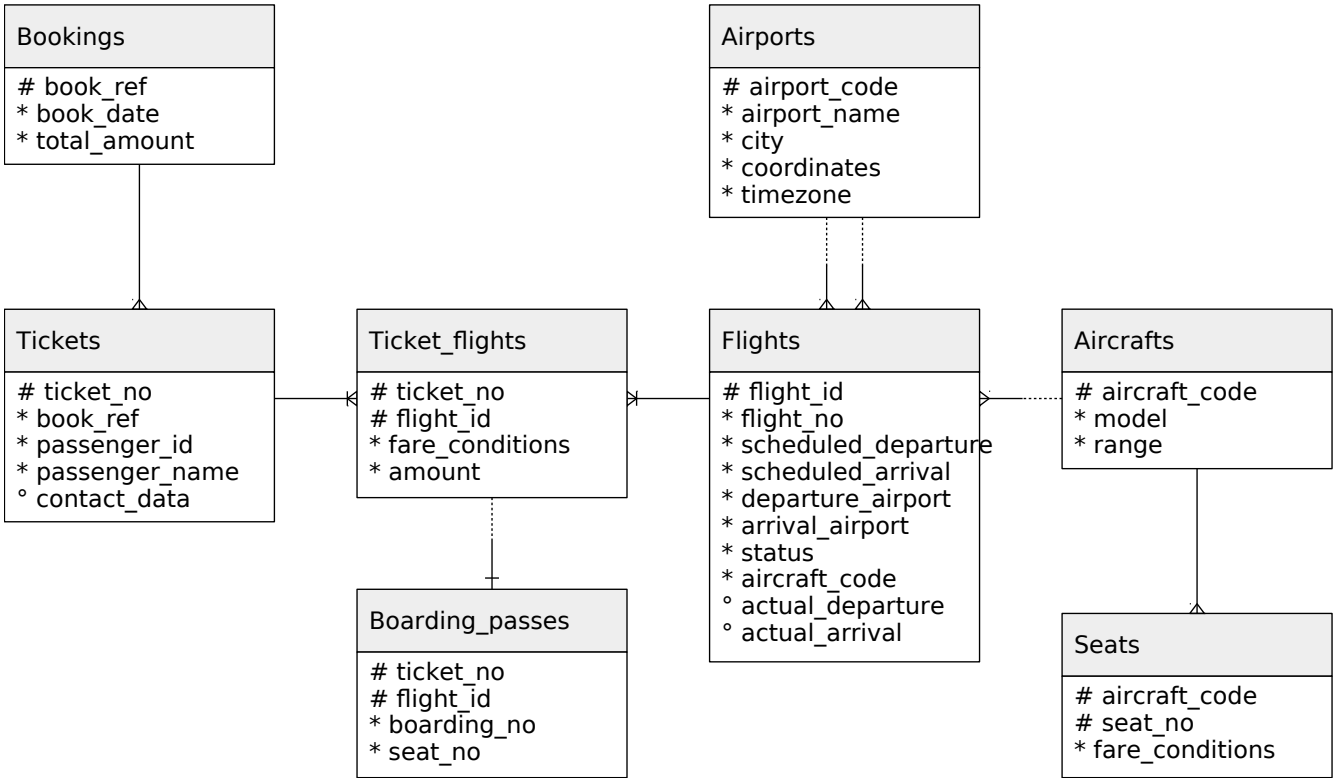
The files include an SQL script that creates the `demo` database and fills it with data (virtually, it is a backup copy created with the pg_dump utility). The owner of the `demo` database will be the DBMS user who runs the script. For example, to create the small database, run the script as the user `postgres` by means of psql:

```
psql -f demo_small_YYYYMMDD.sql -U postgres
```

Note that if the `demo` database already exists, it will be deleted and recreated!

M.2. Schema Diagram

Figure M.2. Bookings Schema Diagram



M.3. Schema Description

The main entity is a booking (`bookings`).

One booking can include several passengers, with a separate ticket (`tickets`) issued to each passenger. A ticket has a unique number and includes information about the passenger. As such, the passenger is not a separate entity. Both the passenger's name and identity document number can change over time, so it is impossible to uniquely identify all the tickets of a particular person; for simplicity, we can assume that all passengers are unique.

The ticket includes one or more flight segments (`ticket_flights`). Several flight segments can be included into a single ticket if there are no non-stop flights between the points of departure and destination (connecting flights), or if it is a round-trip ticket. Although there is no constraint in the schema, it is assumed that all tickets in the booking have the same flight segments.

Each flight (`flights`) goes from one airport (`airports`) to another. Flights with the same flight number have the same points of departure and destination, but differ in departure date.

At flight check-in, the passenger is issued a boarding pass (`boarding_passes`), where the seat number is specified. The passenger can check in for the flight only if this flight is included into the ticket. The flight-seat combination must be unique to avoid issuing two boarding passes for the same seat.

The number of seats (`seats`) in the aircraft and their distribution between different travel classes depends on the model of the aircraft (`aircrafts`) performing the flight. It is assumed that every aircraft model has only one cabin configuration. Database schema does not check that seat numbers in boarding passes have the corresponding seats in the aircraft (such verification can be done using table triggers, or at the application level).

M.4. Schema Objects

M.4.1. List of Relations

```
       Name       |     Type      |  Small  | Medium |   Big   |       Description
------------------+---------------+---------+--------+---------+-------------------------
 aircrafts        | view          |         |        |         | Aircraft
 aircrafts_data   | table         |  16 kB  |  16 kB |  16 kB  | Aircraft (translations)
 airports         | view          |         |        |         | Airports
 airports_data    | table         |  56 kB  |  56 kB |  56 kB  | Airports (translations)
 boarding_passes  | table         |  31 MB  | 102 MB | 427 MB  | Boarding passes
 bookings         | table         |  13 MB  |  30 MB | 105 MB  | Bookings
 flights          | table         |   3 MB  |   6 MB |  19 MB  | Flights
 flights_v        | view          |         |        |         | Flights
 routes           | view          |         |        |         | Routes
 seats            | table         |  88 kB  |  88 kB |  88 kB  | Seats
 ticket_flights   | table         |  64 MB  | 145 MB | 516 MB  | Flight segments
 tickets          | table         |  47 MB  | 107 MB | 381 MB  | Tickets
```

M.4.2. View `bookings.aircrafts`

Each aircraft model is identified by its three-digit code (`aircraft_code`). The view also includes the name of the aircraft model (`model`) and the maximal flying distance, in kilometers (`range`).

The value of the `model` field is selected according to the chosen language. See Section M.4.15 for details.

```
    Column     |  Type   | Modifiers |             Description
---------------+---------+-----------+-------------------------------------
 aircraft_code | char(3) | not null  | Aircraft code, IATA
 model         | text    | not null  | Aircraft model
 range         | integer | not null  | Maximal flying distance, km
View definition:
 SELECT ml.aircraft_code,
    ml.model ->> lang() AS model,
    ml.range
   FROM aircrafts_data ml;
```

M.4.3. Table `bookings.aircrafts_data`

This is the base table for the `aircrafts` view. The `model` field of this table contains translations of aircraft models to different languages, in the JSONB format. In most cases, this table is not supposed to be used directly.

```
    Column     |  Type   | Modifiers |             Description
---------------+---------+-----------+-------------------------------------
 aircraft_code | char(3) | not null  | Aircraft code, IATA
```

```
 model         | jsonb   | not null     | Aircraft model
 range         | integer | not null     | Maximal flying distance, km
Indexes:
    PRIMARY KEY, btree (aircraft_code)
Check constraints:
    CHECK (range > 0)
Referenced by:
    TABLE "flights" FOREIGN KEY (aircraft_code)
        REFERENCES aircrafts_data(aircraft_code)
    TABLE "seats" FOREIGN KEY (aircraft_code)
        REFERENCES aircrafts_data(aircraft_code) ON DELETE CASCADE
```

M.4.4. View `bookings.airports`

An airport is identified by a three-letter code (`airport_code`) and has a name (`airport_name`).

There is no separate entity for the city, but there is a city name (`city`) to identify the airports of the same city. The view also includes coordinates (`coordinates`) and the time zone (`timezone`).

The values of the `airport_name` and `city` fields are selected according to the chosen language. See Section M.4.15 for details.

```
   Column     |  Type   | Modifiers    |                 Description
--------------+---------+--------------+---------------------------------------------
 airport_code | char(3) | not null     | Airport code
 airport_name | text    | not null     | Airport name
 city         | text    | not null     | City
 coordinates  | point   | not null     | Airport coordinates (longitude and latitude)
 timezone     | text    | not null     | Airport time zone
View definition:
 SELECT ml.airport_code,
    ml.airport_name ->> lang() AS airport_name,
    ml.city ->> lang() AS city,
    ml.coordinates,
    ml.timezone
   FROM airports_data ml;
```

M.4.5. Table `bookings.airports_data`

This is the base table for the `airports` view. This table contains translations of `airport_name` and `city` values to different languages, in the JSONB format. In most cases, this table is not supposed to be used directly.

```
   Column     |  Type   | Modifiers    |                 Description
--------------+---------+--------------+---------------------------------------------
 airport_code | char(3) | not null     | Airport code
 airport_name | jsonb   | not null     | Airport name
 city         | jsonb   | not null     | City
 coordinates  | point   | not null     | Airport coordinates (longitude and latitude)
 timezone     | text    | not null     | Airport time zone
Indexes:
    PRIMARY KEY, btree (airport_code)
Referenced by:
    TABLE "flights" FOREIGN KEY (arrival_airport)
        REFERENCES airports_data(airport_code)
    TABLE "flights" FOREIGN KEY (departure_airport)
        REFERENCES airports_data(airport_code)
```

M.4.6. Table bookings.boarding_passes

At the time of check-in, which opens twenty-four hours before the scheduled departure, the passenger is issued a boarding pass. Like the flight segment, the boarding pass is identified by the ticket number and the flight number.

Boarding passes are assigned sequential numbers (boarding_no), in the order of check-ins for the flight (this number is unique only within the context of a particular flight). The boarding pass specifies the seat number (seat_no).

```
   Column    |    Type    | Modifiers    |         Description
-------------+------------+--------------+-------------------------
 ticket_no   | char(13)   | not null     | Ticket number
 flight_id   | integer    | not null     | Flight ID
 boarding_no | integer    | not null     | Boarding pass number
 seat_no     | varchar(4) | not null     | Seat number
Indexes:
    PRIMARY KEY, btree (ticket_no, flight_id)
    UNIQUE CONSTRAINT, btree (flight_id, boarding_no)
    UNIQUE CONSTRAINT, btree (flight_id, seat_no)
Foreign-key constraints:
    FOREIGN KEY (ticket_no, flight_id)
        REFERENCES ticket_flights(ticket_no, flight_id)
```

M.4.7. Table bookings.bookings

Passengers book tickets for themselves, and, possibly, for several other passengers, in advance (book_date, not earlier than one month before the flight). The booking is identified by its number (book_ref, a six-position combination of letters and digits).

The total_amount field stores the total cost of all tickets included into the booking, for all passengers.

```
   Column     |      Type     | Modifiers    |         Description
--------------+---------------+--------------+-------------------------
 book_ref     | char(6)       | not null     | Booking number
 book_date    | timestamptz   | not null     | Booking date
 total_amount | numeric(10,2) | not null     | Total booking cost
Indexes:
    PRIMARY KEY, btree (book_ref)
Referenced by:
    TABLE "tickets" FOREIGN KEY (book_ref) REFERENCES bookings(book_ref)
```

M.4.8. Table bookings.flights

The natural key of the bookings.flights table consists of two fields — flight_no and scheduled_departure. To make foreign keys for this table more compact, a surrogate key is used as the primary key (flight_id).

A flight always connects two points — the airport of departure (departure_airport) and arrival (arrival_airport). There is no such entity as a “connecting flight”: if there are no non-stop flights from one airport to another, the ticket simply includes several required flight segments.

Each flight has a scheduled date and time of departure (scheduled_departure) and arrival (scheduled_arrival). The actual departure time (actual_departure) and arrival time (actual_arrival) can differ: the difference is usually not very big, but sometimes can be up to several hours if the flight is delayed.

Flight status (`status`) can take one of the following values:

`Scheduled`

The flight is available for booking. It happens one month before the planned departure date; before that time, there is no entry for this flight in the database.

`On Time`

The flight is open for check-in (in twenty-four hours before the scheduled departure) and is not delayed.

`Delayed`

The flight is open for check-in (in twenty-four hours before the scheduled departure) but is delayed.

`Departed`

The aircraft has already departed and is airborne.

`Arrived`

The aircraft has reached the point of destination.

`Cancelled`

The flight is canceled.

```
        Column       |     Type    | Modifiers    |         Description
---------------------+-------------+--------------+-----------------------------
 flight_id           | serial      | not null     | Flight ID
 flight_no           | char(6)     | not null     | Flight number
 scheduled_departure | timestamptz | not null     | Scheduled departure time
 scheduled_arrival   | timestamptz | not null     | Scheduled arrival time
 departure_airport   | char(3)     | not null     | Airport of departure
 arrival_airport     | char(3)     | not null     | Airport of arrival
 status              | varchar(20) | not null     | Flight status
 aircraft_code       | char(3)     | not null     | Aircraft code, IATA
 actual_departure    | timestamptz |              | Actual departure time
 actual_arrival      | timestamptz |              | Actual arrival time
Indexes:
    PRIMARY KEY, btree (flight_id)
    UNIQUE CONSTRAINT, btree (flight_no, scheduled_departure)
Check constraints:
    CHECK (scheduled_arrival > scheduled_departure)
    CHECK ((actual_arrival IS NULL)
       OR  ((actual_departure IS NOT NULL AND actual_arrival IS NOT NULL)
            AND (actual_arrival > actual_departure)))
    CHECK (status IN ('On Time', 'Delayed', 'Departed',
                      'Arrived', 'Scheduled', 'Cancelled'))
Foreign-key constraints:
    FOREIGN KEY (aircraft_code)
        REFERENCES aircrafts(aircraft_code)
    FOREIGN KEY (arrival_airport)
        REFERENCES airports(airport_code)
    FOREIGN KEY (departure_airport)
        REFERENCES airports(airport_code)
Referenced by:
    TABLE "ticket_flights" FOREIGN KEY (flight_id)
        REFERENCES flights(flight_id)
```

M.4.9. Table `bookings.seats`

Seats define the cabin configuration of each aircraft model. Each seat is defined by its number (`seat_no`) and has an assigned travel class (`fare_conditions`): `Economy`, `Comfort` or `Business`.

```
      Column     |     Type    | Modifiers    |      Description
-----------------+-------------+--------------+--------------------
 aircraft_code   | char(3)     | not null     | Aircraft code, IATA
 seat_no         | varchar(4)  | not null     | Seat number
 fare_conditions | varchar(10) | not null     | Travel class
Indexes:
    PRIMARY KEY, btree (aircraft_code, seat_no)
Check constraints:
    CHECK (fare_conditions IN ('Economy', 'Comfort', 'Business'))
Foreign-key constraints:
    FOREIGN KEY (aircraft_code)
        REFERENCES aircrafts(aircraft_code) ON DELETE CASCADE
```

M.4.10. Table `bookings.ticket_flights`

A flight segment connects a ticket with a flight and is identified by their numbers.

Each flight has its cost (`amount`) and travel class (`fare_conditions`).

```
     Column      |     Type      | Modifiers    |    Description
-----------------+---------------+--------------+--------------------
 ticket_no       | char(13)      | not null     | Ticket number
 flight_id       | integer       | not null     | Flight ID
 fare_conditions | varchar(10)   | not null     | Travel class
 amount          | numeric(10,2) | not null     | Travel cost
Indexes:
    PRIMARY KEY, btree (ticket_no, flight_id)
Check constraints:
    CHECK (amount >= 0)
    CHECK (fare_conditions IN ('Economy', 'Comfort', 'Business'))
Foreign-key constraints:
    FOREIGN KEY (flight_id) REFERENCES flights(flight_id)
    FOREIGN KEY (ticket_no) REFERENCES tickets(ticket_no)
Referenced by:
    TABLE "boarding_passes" FOREIGN KEY (ticket_no, flight_id)
        REFERENCES ticket_flights(ticket_no, flight_id)
```

M.4.11. Table `bookings.tickets`

A ticket has a unique number (`ticket_no`) that consists of 13 digits.

The ticket includes a passenger ID (`passenger_id`) — the identity document number, — their first and last names (`passenger_name`), and contact information (`contact_data`).

Neither the passenger ID, nor the name is permanent (for example, one can change the last name or passport), so it is impossible to uniquely identify all tickets of a particular passenger.

```
     Column     |     Type    | Modifiers    |          Description
----------------+-------------+--------------+---------------------------
 ticket_no      | char(13)    | not null     | Ticket number
 book_ref       | char(6)     | not null     | Booking number
 passenger_id   | varchar(20) | not null     | Passenger ID
 passenger_name | text        | not null     | Passenger name
```

```
 contact_data   | jsonb       |             | Passenger contact information
Indexes:
    PRIMARY KEY, btree (ticket_no)
Foreign-key constraints:
    FOREIGN KEY (book_ref) REFERENCES bookings(book_ref)
Referenced by:
    TABLE "ticket_flights" FOREIGN KEY (ticket_no) REFERENCES tickets(ticket_no)
```

M.4.12. View `bookings.flights_v`

There is a `flights_v` view over the `flights` table that provides additional information:

- Details about the airport of departure — `departure_airport`, `departure_airport_name`, `departure_city`
- Details about the airport of arrival — `arrival_airport`, `arrival_airport_name`, `arrival_city`
- Local departure time — `scheduled_departure_local`, `actual_departure_local`
- Local arrival time — `scheduled_arrival_local`, `actual_arrival_local`
- Flight duration — `scheduled_duration`, `actual_duration`.

```
          Column           |    Type     |              Description
---------------------------+-------------+---------------------------------------
 flight_id                 | integer     | Flight ID
 flight_no                 | char(6)     | Flight number
 scheduled_departure       | timestamptz | Scheduled departure time
 scheduled_departure_local | timestamp   | Scheduled departure time,
                           |             | local time at the point of departure
 scheduled_arrival         | timestamptz | Scheduled arrival time
 scheduled_arrival_local   | timestamp   | Scheduled arrival time,
                           |             | local time at the point of destination
 scheduled_duration        | interval    | Scheduled flight duration
 departure_airport         | char(3)     | Departure airport code
 departure_airport_name    | text        | Departure airport name
 departure_city            | text        | City of departure
 arrival_airport           | char(3)     | Arrival airport code
 arrival_airport_name      | text        | Arrival airport name
 arrival_city              | text        | City of arrival
 status                    | varchar(20) | Flight status
 aircraft_code             | char(3)     | Aircraft code, IATA
 actual_departure          | timestamptz | Actual departure time
 actual_departure_local    | timestamp   | Actual departure time,
                           |             | local time at the point of departure
 actual_arrival            | timestamptz | Actual arrival time
 actual_arrival_local      | timestamp   | Actual arrival time,
                           |             | local time at the point of destination
 actual_duration           | interval    | Actual flight duration
```

M.4.13. View `bookings.routes`

The `bookings.flights` table contains some redundancies, which you can use to single out route information (flight number, airports of departure and destination) that does not depend on the exact flight dates.

Such information is shown in the `routes` view.

```
        Column          |   Type    |             Description
```

```
------------------------+-----------+--------------------------------------
 flight_no              | char(6)   | Flight number
 departure_airport      | char(3)   | Departure airport code
 departure_airport_name | text      | Departure airport name
 departure_city         | text      | City of departure
 arrival_airport        | char(3)   | Arrival airport code
 arrival_airport_name   | text      | Arrival airport name
 arrival_city           | text      | City of arrival
 aircraft_code          | char(3)   | Aircraft code, IATA
 duration               | interval  | Flight duration
 days_of_week           | integer[] | Days of the week on which flights are performed
```

M.4.14. Function `bookings.now`

The demo database contains “snapshots” of data — similar to a backup copy of a real system captured at some point in time. For example, if a flight has the `Departed` status, it means that the aircraft had already departed and was airborne at the time of the backup copy.

The “snapshot” time is saved in the `bookings.now()` function. You can use this function in demo queries for cases where you would use the `now()` function in a real database.

In addition, the return value of this function determines the version of the demo database. The latest version available is of August 15, 2017.

M.4.15. Function `bookings.lang`

Some fields in the demo database are available in English and Russian. Translations to other languages are not provided, but are easy to add. The `bookings.lang` returns the value of the *`bookings.lang`* parameter, that is, the language in which these fields will be displayed.

This function is used in the `aircrafts` and `airports` views and is not intended to be used directly in queries.

M.5. Usage

M.5.1. Schema `bookings`

The `bookings` schema contains all objects of the demo database. When you connect to the database, `search_path` configuration parameter is automatically set to `bookings, public`, so you do not need to specify the schema name explicitly.

However, for the `bookings.now` function, you always have to specify the schema to distinguish this function from the standard `now` function.

M.5.2. Translations

By default, values of several translatable fields are shown in Russian. These are `airport_name` and `city` of the `airports` view, as well as `model` of the `aircrafts` view.

You can choose to display these fields in another language (although only the English translation is provided in the demo database). To switch to English, set the *`bookings.lang`* parameter to `en`. It may be convenient to choose the language at the database level:

```
ALTER DATABASE demo SET bookings.lang = en;
```

You have to reconnect to the database for this command to take effect. For other methods of settings configuration parameters, see Section 19.1.

In the examples below, the English language is selected for translatable fields.

M.5.3. Sample Queries

To better understand the contents of the demo database, let's take a look at the results of several simple queries.

The results displayed below were received on a small database version (demo-small) of August 15, 2017. If the same queries return different data on your system, check your demo database version (using the `bookings.now` function). Some minor deviations may be caused by the difference between your local time and Moscow time, or your locale settings.

All flights are operated by several types of aircraft:

```
SELECT * FROM aircrafts;
```

```
 aircraft_code |        model         | range
---------------+----------------------+-------
 773           | Boeing 777-300       | 11100
 763           | Boeing 767-300       |  7900
 SU9           | Sukhoi SuperJet-100  |  3000
 320           | Airbus A320-200      |  5700
 321           | Airbus A321-200      |  5600
 319           | Airbus A319-100      |  6700
 733           | Boeing 737-300       |  4200
 CN1           | Cessna 208 Caravan   |  1200
 CR2           | Bombardier CRJ-200   |  2700
(9 rows)
```

For each aircraft type, a separate list of seats is supported. For example, in a small Cessna 208 Caravan, one can select the following seats:

```
SELECT   a.aircraft_code,
         a.model,
         s.seat_no,
         s.fare_conditions
FROM     aircrafts a
         JOIN seats s ON a.aircraft_code = s.aircraft_code
WHERE    a.model = 'Cessna 208 Caravan'
ORDER BY s.seat_no;
```

```
 aircraft_code |       model        | seat_no | fare_conditions
---------------+--------------------+---------+-----------------
 CN1           | Cessna 208 Caravan | 1A      | Economy
 CN1           | Cessna 208 Caravan | 1B      | Economy
 CN1           | Cessna 208 Caravan | 2A      | Economy
 CN1           | Cessna 208 Caravan | 2B      | Economy
 CN1           | Cessna 208 Caravan | 3A      | Economy
 CN1           | Cessna 208 Caravan | 3B      | Economy
 CN1           | Cessna 208 Caravan | 4A      | Economy
 CN1           | Cessna 208 Caravan | 4B      | Economy
 CN1           | Cessna 208 Caravan | 5A      | Economy
 CN1           | Cessna 208 Caravan | 5B      | Economy
 CN1           | Cessna 208 Caravan | 6A      | Economy
 CN1           | Cessna 208 Caravan | 6B      | Economy
(12 rows)
```

Bigger aircraft have more seats of various travel classes:

```
SELECT   s2.aircraft_code,
```

```
         string_agg (s2.fare_conditions || '(' || s2.num::text || ')',
                     ', ') as fare_conditions
FROM     (
          SELECT   s.aircraft_code, s.fare_conditions, count(*) as num
          FROM     seats s
          GROUP BY s.aircraft_code, s.fare_conditions
          ORDER BY s.aircraft_code, s.fare_conditions
         ) s2
GROUP BY s2.aircraft_code
ORDER BY s2.aircraft_code;
```

```
 aircraft_code |             fare_conditions
---------------+-----------------------------------------
 319           | Business(20), Economy(96)
 320           | Business(20), Economy(120)
 321           | Business(28), Economy(142)
 733           | Business(12), Economy(118)
 763           | Business(30), Economy(192)
 773           | Business(30), Comfort(48), Economy(324)
 CN1           | Economy(12)
 CR2           | Economy(50)
 SU9           | Business(12), Economy(85)
(9 rows)
```

The demo database contains the list of airports of almost all major Russian cities. Most cities have only one airport. The exceptions are:

```
SELECT   a.airport_code as code,
         a.airport_name,
         a.city,
         a.coordinates
FROM     airports a
WHERE    a.city IN (
            SELECT   aa.city
            FROM     airports aa
            GROUP BY aa.city
            HAVING   COUNT(*) > 1
         )
ORDER BY a.city, a.airport_code;
```

```
 code |      airport_name      |   city    |           coordinates
------+------------------------+-----------+-------------------------
 DME  | Domodedovo             | Moscow    | (37.9062995910645,55.4087982177734)
      | International Airport  |           |
 SVO  | Sheremetyevo           | Moscow    | (37.4146,55.972599)
      | International Airport  |           |
 VKO  | Vnukovo                | Moscow    | (37.2615013123,55.5914993286)
      | International Airport  |           |
 ULV  | Ulyanovsk              | Ulyanovsk | (48.2266998291,54.2682991028)
      | Baratayevka Airport    |           |
 ULY  | Ulyanovsk East Airport | Ulyanovsk | (48.8027000427246,54.4010009765625)
(5 rows)
```

To learn about your flying options from one point to another, it is convenient to use the `routes` materialized view that aggregates information on all flights. For example, here are the destinations where you can get from Volgograd on specific days of the week, with flight duration:

```
SELECT r.arrival_city as city,
       r.arrival_airport as code,
       r.arrival_airport_name as airport_name,
       r.days_of_week,
       r.duration
FROM   routes r
WHERE  r.departure_city = 'Volgograd';
```

```
    city     | code |            airport_name             |  days_of_week   | duration
-------------+------+-------------------------------------+-----------------+----------
 Moscow      | SVO  | Sheremetyevo International Airport | {1,2,3,4,5,6,7} | 01:15:00
 Chelyabinsk | CEK  | Chelyabinsk Balandino Airport      | {1,2,3,4,5,6,7} | 01:50:00
 Rostov      | ROV  | Rostov-on-Don Airport              | {1,2,3,4,5,6,7} | 00:30:00
 Moscow      | VKO  | Vnukovo International Airport      | {1,2,3,4,5,6,7} | 01:10:00
 Cheboksary  | CSY  | Cheboksary Airport                 | {1,2,3,4,5,6,7} | 02:45:00
 Tomsk       | TOF  | Bogashevo Airport                  | {1}             | 03:50:00
(6 rows)
```

The database was formed at the moment returned by the `bookings.now()` function:

```
SELECT bookings.now() as now;
```

```
          now
------------------------
 2017-08-15 18:00:00+03
```

In relation to this moment, all flights are classified as past and future flights:

```
SELECT   status,
         count(*) as count,
         min(scheduled_departure) as min_scheduled_departure,
         max(scheduled_departure) as max_scheduled_departure
FROM     flights
GROUP BY status
ORDER BY min_scheduled_departure;
```

```
  status   | count | min_scheduled_departure | max_scheduled_departure
-----------+-------+-------------------------+-------------------------
 Arrived   | 16707 | 2017-07-16 01:50:00+03  | 2017-08-15 17:25:00+03
 Cancelled |   414 | 2017-07-19 11:35:00+03  | 2017-09-14 20:55:00+03
 Departed  |    58 | 2017-08-15 09:55:00+03  | 2017-08-15 17:50:00+03
 Delayed   |    41 | 2017-08-15 15:15:00+03  | 2017-08-16 17:25:00+03
 On Time   |   518 | 2017-08-15 17:55:00+03  | 2017-08-16 18:00:00+03
 Scheduled | 15383 | 2017-08-16 18:05:00+03  | 2017-09-14 20:40:00+03
(6 rows)
```

Let's find the next flight from Yekaterinburg to Moscow. The `flight` table is not very convenient for such queries, as it does not include information on the cities of departure and arrival. That is why we will use the `flights_v` view:

```
\x
SELECT   f.*
FROM     flights_v f
WHERE    f.departure_city = 'Yekaterinburg'
AND      f.arrival_city = 'Moscow'
```

```
AND      f.scheduled_departure > bookings.now()
ORDER BY f.scheduled_departure
LIMIT    1;
```

```
-[ RECORD 1 ]-------------+---------------------------------
flight_id                 | 10927
flight_no                 | PG0226
scheduled_departure       | 2017-08-16 08:10:00+03
scheduled_departure_local | 2017-08-16 10:10:00
scheduled_arrival         | 2017-08-16 09:55:00+03
scheduled_arrival_local   | 2017-08-16 09:55:00
scheduled_duration        | 01:45:00
departure_airport         | SVX
departure_airport_name    | Koltsovo Airport
departure_city            | Yekaterinburg
arrival_airport           | SVO
arrival_airport_name      | Sheremetyevo International Airport
arrival_city              | Moscow
status                    | On Time
aircraft_code             | 773
actual_departure          |
actual_departure_local    |
actual_arrival            |
actual_arrival_local      |
actual_duration           |
```

Note that the `flights_v` view shows both Moscow time and local time at the airports of departure and arrival.

M.5.4. Bookings

Each booking can include several tickets, one for each passenger. The ticket, in its turn, can include several flight segments. The complete information about the booking is stored in three tables: `bookings`, `tickets`, and `ticket_flights`.

Let's find several most expensive bookings:

```
SELECT   *
FROM     bookings
ORDER BY total_amount desc
LIMIT    10;
```

```
 book_ref |       book_date        | total_amount
----------+------------------------+--------------
 3B54BB   | 2017-07-05 17:08:00+03 |   1204500.00
 3AC131   | 2017-07-31 01:06:00+03 |   1087100.00
 65A6EA   | 2017-07-03 06:28:00+03 |   1065600.00
 D7E9AA   | 2017-08-08 05:29:00+03 |   1062800.00
 EF479E   | 2017-08-02 15:58:00+03 |   1035100.00
 521C53   | 2017-07-08 09:25:00+03 |    985500.00
 514CA6   | 2017-07-27 05:07:00+03 |    955000.00
 D70BD9   | 2017-07-05 12:47:00+03 |    947500.00
 EC7EDA   | 2017-07-02 16:13:00+03 |    946800.00
 8E4370   | 2017-07-28 02:04:00+03 |    945700.00
(10 rows)
```

Let's take a look at the tickets included into the booking with code `521C53`:

```
SELECT ticket_no,
       passenger_id,
       passenger_name
FROM   tickets
WHERE  book_ref = '521C53';
```

```
   ticket_no   | passenger_id |   passenger_name
---------------+--------------+--------------------
 0005432661914 | 8234 547529  | IVAN IVANOV
 0005432661915 | 2034 201228  | ANTONINA KUZNECOVA
(2 rows)
```

If we would like to know, which flight segments are included into Antonina Kuznecova's ticket, we can use the following query:

```
SELECT   to_char(f.scheduled_departure, 'DD.MM.YYYY') AS when,
         f.departure_city || ' (' || f.departure_airport || ')' AS departure,
         f.arrival_city || ' (' || f.arrival_airport || ')' AS arrival,
         tf.fare_conditions AS class,
         tf.amount
FROM     ticket_flights tf
         JOIN flights_v f ON tf.flight_id = f.flight_id
WHERE    tf.ticket_no = '0005432661915'
ORDER BY f.scheduled_departure;
```

```
    when    |      departure       |       arrival        |  class   |  amount
------------+----------------------+----------------------+----------+-----------
 29.07.2017 | Moscow (SVO)         | Anadyr (DYR)         | Business | 185300.00
 02.08.2017 | Anadyr (DYR)         | Khabarovsk (KHV)     | Business |  92200.00
 03.08.2017 | Khabarovsk (KHV)     | Blagoveshchensk (BQS)| Business |  18000.00
 08.08.2017 | Blagoveshchensk (BQS)| Khabarovsk (KHV)     | Business |  18000.00
 12.08.2017 | Khabarovsk (KHV)     | Anadyr (DYR)         | Economy  |  30700.00
 17.08.2017 | Anadyr (DYR)         | Moscow (SVO)         | Business | 185300.00
(6 rows)
```

As we can see, high booking cost is explained by multiple long-haul flights in business class.

Some of the flight segments in this ticket have earlier dates than the `bookings.now()` return value: it means that these flights had already happened. The last flight had not happened yet at the time of the database creation. After the check-in, a boarding pass with the allocated seat number is issued. We can check the exact seats occupied by Antonina (note the outer left join with table `boarding_passes`):

```
SELECT   to_char(f.scheduled_departure, 'DD.MM.YYYY') AS when,
         f.departure_city || ' (' || f.departure_airport || ')' AS departure,
         f.arrival_city || ' (' || f.arrival_airport || ')' AS arrival,
         f.status,
         bp.seat_no
FROM     ticket_flights tf
         JOIN flights_v f ON tf.flight_id = f.flight_id
         LEFT JOIN boarding_passes bp ON tf.flight_id = bp.flight_id
                                     AND tf.ticket_no = bp.ticket_no
WHERE    tf.ticket_no = '0005432661915'
ORDER BY f.scheduled_departure;
```

```
    when    |      departure       |       arrival        |  status   | seat_no
------------+----------------------+----------------------+-----------+---------
```

```
 29.07.2017 | Moscow (SVO)          | Anadyr (DYR)          | Arrived   | 5C
 02.08.2017 | Anadyr (DYR)          | Khabarovsk (KHV)      | Arrived   | 1D
 03.08.2017 | Khabarovsk (KHV)      | Blagoveshchensk (BQS)| Arrived   | 2C
 08.08.2017 | Blagoveshchensk (BQS)| Khabarovsk (KHV)      | Arrived   | 2D
 12.08.2017 | Khabarovsk (KHV)      | Anadyr (DYR)          | Arrived   | 20B
 17.08.2017 | Anadyr (DYR)          | Moscow (SVO)          | Scheduled |
(6 rows)
```

M.5.5. New Booking

Let's try to send Aleksandr Radishchev from Saint Petersburg to Moscow — the route that made him famous. Naturally, he will travel for free and in business class. We have already found a flight for tomorrow, and a return flight a week later.

```
BEGIN;

INSERT INTO bookings (book_ref, book_date, total_amount)
VALUES      ('_QWE12', bookings.now(), 0);

INSERT INTO tickets (ticket_no, book_ref, passenger_id, passenger_name)
VALUES      ('_000000000001', '_QWE12', '1749 051790', 'ALEKSANDR RADISHCHEV');

INSERT INTO ticket_flights (ticket_no, flight_id, fare_conditions, amount)
VALUES      ('_000000000001', 8525, 'Business', 0),
            ('_000000000001', 4967, 'Business', 0);

COMMIT;
```

To avoid conflicts with the range of values present in the database, identifiers are started with an underscore.

We will check in Aleksandr for tomorrow's flight right away:

```
INSERT INTO boarding_passes (ticket_no, flight_id, boarding_no, seat_no)
VALUES      ('_000000000001', 8525, 1, '1A');
```

Now let's check the booking information:

```
SELECT   b.book_ref,
         t.ticket_no,
         t.passenger_id,
         t.passenger_name,
         tf.fare_conditions,
         tf.amount,
         f.scheduled_departure_local,
         f.scheduled_arrival_local,
         f.departure_city || ' (' || f.departure_airport || ')' AS departure,
         f.arrival_city || ' (' || f.arrival_airport || ')' AS arrival,
         f.status,
         bp.seat_no
FROM     bookings b
         JOIN tickets t ON b.book_ref = t.book_ref
         JOIN ticket_flights tf ON tf.ticket_no = t.ticket_no
         JOIN flights_v f ON tf.flight_id = f.flight_id
         LEFT JOIN boarding_passes bp ON tf.flight_id = bp.flight_id
                                     AND tf.ticket_no = bp.ticket_no
WHERE    b.book_ref = '_QWE12'
```

```
ORDER BY t.ticket_no, f.scheduled_departure;

-[ RECORD 1 ]-------------+--------------------
book_ref                  | _QWE12
ticket_no                 | _000000000001
passenger_id              | 1749 051790
passenger_name            | ALEKSANDR RADISHCHEV
fare_conditions           | Business
amount                    | 0.00
scheduled_departure_local | 2017-08-16 09:45:00
scheduled_arrival_local   | 2017-08-16 10:35:00
departure                 | St. Petersburg (LED)
arrival                   | Moscow (SVO)
status                    | On Time
seat_no                   | 1A
-[ RECORD 2 ]-------------+--------------------
book_ref                  | _QWE12
ticket_no                 | _000000000001
passenger_id              | 1749 051790
passenger_name            | ALEKSANDR RADISHCHEV
fare_conditions           | Business
amount                    | 0.00
scheduled_departure_local | 2017-08-23 10:20:00
scheduled_arrival_local   | 2017-08-23 11:10:00
departure                 | Moscow (SVO)
arrival                   | St. Petersburg (LED)
status                    | Scheduled
seat_no                   |
```

We hope that these simple examples helped you get an idea of this demo database.

Appendix N. Acronyms

This is a list of acronyms commonly used in the Postgres Pro documentation and in discussions about Postgres Pro.

ANSI

American National Standards Institute

API

Application Programming Interface

ASCII

American Standard Code for Information Interchange

BKI

Backend Interface

CA

Certificate Authority

CIDR

Classless Inter-Domain Routing

CPAN

Comprehensive Perl Archive Network

CRL

Certificate Revocation List

CSV

Comma Separated Values

CTE

Common Table Expression

CVE

Common Vulnerabilities and Exposures

DBA

Database Administrator

DBI

Database Interface (Perl)

DBMS

Database Management System

DDL

Data Definition Language, SQL commands such as `CREATE TABLE`, `ALTER USER`

DML

Data Manipulation Language, SQL commands such as `INSERT`, `UPDATE`, `DELETE`

DST
: *Daylight Saving Time*

ECPG
: Embedded C for Postgres Pro

ESQL
: *Embedded SQL*

FAQ
: *Frequently Asked Questions*

FSM
: Free Space Map

GEQO
: Genetic Query Optimizer

GIN
: Generalized Inverted Index

GiST
: Generalized Search Tree

Git
: *Git*

GMT
: *Greenwich Mean Time*

GSSAPI
: *Generic Security Services Application Programming Interface*

GUC
: Grand Unified Configuration, the Postgres Pro subsystem that handles server configuration

HBA
: Host-Based Authentication

HOT
: Heap-Only Tuples

IEC
: *International Electrotechnical Commission*

IEEE
: *Institute of Electrical and Electronics Engineers*

IPC
: *Inter-Process Communication*

ISO
: *International Organization for Standardization*

ISSN
: *International Standard Serial Number*

JDBC
: *Java Database Connectivity*

JIT
: *Just-in-Time compilation*

JSON
: *JavaScript Object Notation*

LDAP
: *Lightweight Directory Access Protocol*

LSN
: Log Sequence Number, see `pg_lsn` and WAL Internals.

MITM
: *Man-in-the-middle attack*

MSVC
: *Microsoft Visual C*

MVCC
: Multi-Version Concurrency Control

NLS
: *National Language Support*

ODBC
: *Open Database Connectivity*

OID
: Object Identifier

OLAP
: *Online Analytical Processing*

OLTP
: *Online Transaction Processing*

ORDBMS
: *Object-Relational Database Management System*

PAM
: *Pluggable Authentication Modules*

PGSQL
: Postgres Pro

PGXS
: Postgres Pro Extension System

PID

Process Identifier

PITR

Point-In-Time Recovery (Continuous Archiving)

PL

Procedural Languages (server-side)

POSIX

Portable Operating System Interface

RDBMS

Relational Database Management System

RFC

Request For Comments

SGML

Standard Generalized Markup Language

SNI

Server Name Indication, *RFC 6066*

SPI

Server Programming Interface

SP-GiST

Space-Partitioned Generalized Search Tree

SQL

Structured Query Language

SRF

Set-Returning Function

SSH

Secure Shell

SSL

Secure Sockets Layer

SSPI

Security Support Provider Interface

SYSV

Unix System V

TCP/IP

Transmission Control Protocol (TCP) / Internet Protocol (IP)

TID

Tuple Identifier

TLS

Transport Layer Security

TOAST

The Oversized-Attribute Storage Technique

TPC

Transaction Processing Performance Council

URL

Uniform Resource Locator

UTC

Coordinated Universal Time

UTF

Unicode Transformation Format

UTF8

Eight-Bit Unicode Transformation Format

UUID

Universally Unique Identifier

WAL

Write-Ahead Log

XID

Transaction Identifier

XML

Extensible Markup Language

Appendix O. Glossary

This is a list of terms and their meaning in the context of PostgreSQL and relational database systems in general.

ACID
: *Atomicity*, *Consistency*, *Isolation*, and *Durability*. This set of properties of database transactions is intended to guarantee validity in concurrent operation and even in event of errors, power failures, etc.

Aggregate function (routine)
: A *function* that combines (*aggregates*) multiple input values, for example by counting, averaging or adding, yielding a single output value.

  For more information, see Section 9.21.

  See Also Window function (routine).

Analytic function
: See Window function (routine).

Analyze (operation)
: The process of collecting statistics from data in *tables* and other *relations* to help the *query planner* to make decisions about how to execute *queries*.

  (Don't confuse this term with the `ANALYZE` option to the EXPLAIN command.)

  For more information, see ANALYZE.

Atomic
: In reference to a *datum*: the fact that its value cannot be broken down into smaller components.

  In reference to a *database transaction*: see *atomicity*.

Atomicity
: The property of a *transaction* that either all its operations complete as a single unit or none do. In addition, if a system failure occurs during the execution of a transaction, no partial results are visible after recovery. This is one of the ACID properties.

Attribute
: An element with a certain name and data type found within a *tuple*.

Autovacuum (process)
: A set of background processes that routinely perform *vacuum* and *analyze* operations.

  For more information, see Section 24.1.6.

Backend (process)
: Process of an *instance* which acts on behalf of a *client session* and handles its requests.

  (Don't confuse this term with the similar terms *Background Worker* or *Background Writer*).

Background worker (process)
: Process within an *instance*, which runs system- or user-supplied code. Serves as infrastructure for several features in PostgreSQL, such as *logical replication* and *parallel queries*. In addition, *Extensions* can add custom background worker processes.

  For more information, see Chapter 50.

Background writer (process)
: A process that writes dirty *data pages* from *shared memory* to the file system. It wakes up periodically, but works only for a short period in order to distribute its expensive I/O activity over time to avoid generating larger I/O peaks which could block other processes.

  For more information, see Section 19.4.5.

Base Backup	A binary copy of all *database cluster* files. It is generated by the tool pg_basebackup. In combination with WAL files it can be used as the starting point for recovery, log shipping, or streaming replication.
Bloat	Space in data pages which does not contain current row versions, such as unused (free) space or outdated row versions.
Cast	A conversion of a *datum* from its current data type to another data type. For more information, see CREATE CAST.
Catalog	The SQL standard uses this term to indicate what is called a *database* in PostgreSQL's terminology. (Don't confuse this term with *system catalog*). For more information, see Section 22.1.
Check constraint	A type of *constraint* defined on a *relation* which restricts the values allowed in one or more *attributes*. The check constraint can make reference to any attribute of the same row in the relation, but cannot reference other rows of the same relation or other relations. For more information, see Section 5.4.
Checkpoint	A point in the *WAL* sequence at which it is guaranteed that the heap and index data files have been updated with all information from *shared memory* modified before that checkpoint; a *checkpoint record* is written and flushed to WAL to mark that point. A checkpoint is also the act of carrying out all the actions that are necessary to reach a checkpoint as defined above. This process is initiated when predefined conditions are met, such as a specified amount of time has passed, or a certain volume of records has been written; or it can be invoked by the user with the command `CHECKPOINT`. For more information, see Section 29.5.
Checkpointer (process)	A specialized process responsible for executing checkpoints.
Class (archaic)	See Relation.
Client (process)	Any process, possibly remote, that establishes a *session* by *connecting* to an *instance* to interact with a *database*.
Column	An *attribute* found in a *table* or *view*.
Commit	The act of finalizing a *transaction* within the *database*, which makes it visible to other transactions and assures its *durability*. For more information, see COMMIT.
Concurrency	The concept that multiple independent operations happen within the *database* at the same time. In PostgreSQL, concurrency is controlled by the *multiversion concurrency control* mechanism.
Connection	An established line of communication between a client process and a *backend* process, usually over a network, supporting a *session*. This term is sometimes used as a synonym for session. For more information, see Section 19.3.

Consistency	The property that the data in the *database* is always in compliance with *integrity constraints*. Transactions may be allowed to violate some of the constraints transiently before it commits, but if such violations are not resolved by the time it commits, such a transaction is automatically *rolled back*. This is one of the ACID properties.
Constraint	A restriction on the values of data allowed within a *table*, or in attributes of a *domain*. For more information, see Section 5.4.
Data area	See Data directory.
Database	A named collection of *local SQL objects*. For more information, see Section 22.1.
Database cluster	A collection of databases and global SQL objects, and their common static and dynamic metadata. Sometimes referred to as a *cluster*. In PostgreSQL, the term *cluster* is also sometimes used to refer to an instance. (Don't confuse this term with the SQL command `CLUSTER`.)
Database server	See Instance.
Data directory	The base directory on the file system of a *server* that contains all data files and subdirectories associated with a *database cluster* (with the exception of *tablespaces*, and optionally *WAL*). The environment variable `PGDATA` is commonly used to refer to the data directory. A *cluster*'s storage space comprises the data directory plus any additional tablespaces. For more information, see Section 70.1.
Data page	The basic structure used to store relation data. All pages are of the same size. Data pages are typically stored on disk, each in a specific file, and can be read to *shared buffers* where they can be modified, becoming *dirty*. They become clean when written to disk. New pages, which initially exist in memory only, are also dirty until written.
Datum	The internal representation of one value of an SQL data type.
Delete	An SQL command which removes *rows* from a given *table* or *relation*. For more information, see DELETE.
Durability	The assurance that once a *transaction* has been *committed*, the changes remain even after a system failure or crash. This is one of the ACID properties.
Extension	A software add-on package that can be installed on an *instance* to get extra features. For more information, see Section 40.17.
File segment	A physical file which stores data for a given *relation*. File segments are limited in size by a configuration value (typically 1 gigabyte), so if a relation exceeds that size, it is split into multiple segments. For more information, see Section 70.1. (Don't confuse this term with the similar term *WAL segment*).

Foreign data wrapper

A means of representing data that is not contained in the local *database* so that it appears as if were in local *table(s)*. With a foreign data wrapper it is possible to define a *foreign server* and *foreign tables*.

For more information, see CREATE FOREIGN DATA WRAPPER.

Foreign key

A type of *constraint* defined on one or more *columns* in a *table* which requires the value(s) in those *columns* to identify zero or one *row* in another (or, infrequently, the same) *table*.

Foreign server

A named collection of *foreign tables* which all use the same *foreign data wrapper* and have other configuration values in common.

For more information, see CREATE SERVER.

Foreign table (relation)

A *relation* which appears to have *rows* and *columns* similar to a regular *table*, but will forward requests for data through its *foreign data wrapper*, which will return *result sets* structured according to the definition of the *foreign table*.

For more information, see CREATE FOREIGN TABLE.

Fork

Each of the separate segmented file sets in which a relation is stored. The *main fork* is where the actual data resides. There also exist two secondary forks for metadata: the *free space map* and the *visibility map*. *Unlogged relations* also have an *init fork*.

Free space map (fork)

A storage structure that keeps metadata about each data page of a table's main fork. The free space map entry for each page stores the amount of free space that's available for future tuples, and is structured to be efficiently searched for available space for a new tuple of a given size.

For more information, see Section 70.3.

Function (routine)

A type of routine that receives zero or more arguments, returns zero or more output values, and is constrained to run within one transaction. Functions are invoked as part of a query, for example via `SELECT`. Certain functions can return *sets*; those are called *set-returning functions*.

Functions can also be used for *triggers* to invoke.

For more information, see CREATE FUNCTION.

GMT

See UTC.

Grant

An SQL command that is used to allow a *user* or *role* to access specific objects within the *database*.

For more information, see GRANT.

Heap

Contains the values of *row* attributes (i.e., the data) for a *relation*. The heap is realized within one or more *file segments* in the relation's *main fork*.

Host

A computer that communicates with other computers over a network. This is sometimes used as a synonym for *server*. It is also used to refer to a computer where *client processes* run.

Index (relation)

A *relation* that contains data derived from a *table* or *materialized view*. Its internal structure supports fast retrieval of and access to the original data.

For more information, see CREATE INDEX.

Insert	An SQL command used to add new data into a *table*. For more information, see INSERT.
Instance	A group of backend and auxiliary processes that communicate using a common shared memory area. One *postmaster process* manages the instance; one instance manages exactly one *database cluster* with all its databases. Many instances can run on the same *server* as long as their TCP ports do not conflict. The instance handles all key features of a DBMS: read and write access to files and shared memory, assurance of the ACID properties, *connections* to *client processes*, privilege verification, crash recovery, replication, etc.
Isolation	The property that the effects of a transaction are not visible to *concurrent transactions* before it commits. This is one of the ACID properties. For more information, see Section 13.2.
Join	An operation and SQL keyword used in *queries* for combining data from multiple *relations*.
Key	A means of identifying a *row* within a *table* or other *relation* by values contained within one or more *attributes* in that relation.
Lock	A mechanism that allows a process to limit or prevent simultaneous access to a resource.
Log file	Log files contain human-readable text lines about events. Examples include login failures, long-running queries, etc. For more information, see Section 24.3.
Logged	A *table* is considered *logged* if changes to it are sent to the *WAL*. By default, all regular tables are logged. A table can be specified as *unlogged* either at creation time or via the `ALTER TABLE` command.
Logger (process)	If activated, the process writes information about database events into the current *log file*. When reaching certain time- or volume-dependent criteria, a new log file is created. Also called *syslogger*. For more information, see Section 19.8.
Log record	Archaic term for a *WAL record*.
Master (server)	See Primary (server).
Materialized	The property that some information has been pre-computed and stored for later use, rather than computing it on-the-fly. This term is used in *materialized view*, to mean that the data derived from the view's query is stored on disk separately from the sources of that data. This term is also used to refer to some multi-step queries to mean that the data resulting from executing a given step is stored in memory (with the possibility of spilling to disk), so that it can be read multiple times by another step.
Materialized view (relation)	A *relation* that is defined by a `SELECT` statement (just like a *view*), but stores data in the same way that a *table* does. It cannot be modified via `INSERT`, `UPDATE`, or `DELETE` operations.

	For more information, see CREATE MATERIALIZED VIEW.
Multi-version concurrency control (MVCC)	A mechanism designed to allow several *transactions* to be reading and writing the same rows without one process causing other processes to stall. In PostgreSQL, MVCC is implemented by creating copies (*versions*) of *tuples* as they are modified; after transactions that can see the old versions terminate, those old versions need to be removed.
Null	A concept of non-existence that is a central tenet of relational database theory. It represents the absence of a definite value.
Optimizer	See Query planner.
Parallel query	The ability to handle parts of executing a *query* to take advantage of parallel processes on servers with multiple CPUs.
Partition	One of several disjoint (not overlapping) subsets of a larger set. In reference to a *partitioned table*: One of the tables that each contain part of the data of the partitioned table, which is said to be the *parent*. The partition is itself a table, so it can also be queried directly; at the same time, a partition can sometimes be a partitioned table, allowing hierarchies to be created. In reference to a *window function* in a *query*, a partition is a user-defined criterion that identifies which neighboring *rows* of the *query*'s *result set* can be considered by the function.
Partitioned table (relation)	A *relation* that is in semantic terms the same as a *table*, but whose storage is distributed across several *partitions*.
Postmaster (process)	The very first process of an *instance*. It starts and manages the other auxiliary processes and creates *backend processes* on demand. For more information, see Section 18.3.
Primary key	A special case of a *unique constraint* defined on a *table* or other *relation* that also guarantees that all of the *attributes* within the *primary key* do not have *null* values. As the name implies, there can be only one primary key per table, though it is possible to have multiple unique constraints that also have no null-capable attributes.
Primary (server)	When two or more *databases* are linked via *replication*, the *server* that is considered the authoritative source of information is called the *primary*, also known as a *master*.
Procedure (routine)	A type of routine. Their distinctive qualities are that they do not return values, and that they are allowed to make transactional statements such as `COMMIT` and `ROLLBACK`. They are invoked via the `CALL` command. For more information, see CREATE PROCEDURE.
Query	A request sent by a client to a *backend*, usually to return results or to modify data on the database.
Query planner	The part of PostgreSQL that is devoted to determining (*planning*) the most efficient way to execute *queries*. Also known as *query optimizer*, *optimizer*, or simply *planner*.
Record	See Tuple.

Recycling	See WAL file.
Referential integrity	A means of restricting data in one *relation* by a *foreign key* so that it must have matching data in another *relation*.
Relation	The generic term for all objects in a *database* that have a name and a list of *attributes* defined in a specific order. *Tables*, *sequences*, *views*, *foreign tables*, *materialized views*, composite types, and *indexes* are all relations. More generically, a relation is a set of tuples; for example, the result of a query is also a relation. In PostgreSQL, *Class* is an archaic synonym for *relation*.
Replica (server)	A *database* that is paired with a *primary* database and is maintaining a copy of some or all of the primary database's data. The foremost reasons for doing this are to allow for greater access to that data, and to maintain availability of the data in the event that the *primary* becomes unavailable.
Replication	The act of reproducing data on one *server* onto another server called a *replica*. This can take the form of *physical replication*, where all file changes from one server are copied verbatim, or *logical replication* where a defined subset of data changes are conveyed using a higher-level representation.
Result set	A *relation* transmitted from a *backend process* to a *client* upon the completion of an SQL command, usually a `SELECT` but it can be an `INSERT`, `UPDATE`, or `DELETE` command if the `RETURNING` clause is specified. The fact that a result set is a relation means that a query can be used in the definition of another query, becoming a *subquery*.
Revoke	A command to prevent access to a named set of *database* objects for a named list of *roles*. For more information, see REVOKE.
Role	A collection of access privileges to the *instance*. Roles are themselves a privilege that can be granted to other roles. This is often done for convenience or to ensure completeness when multiple *users* need the same privileges. For more information, see CREATE ROLE.
Rollback	A command to undo all of the operations performed since the beginning of a *transaction*. For more information, see ROLLBACK.
Routine	A defined set of instructions stored in the database system that can be invoked for execution. A routine can be written in a variety of programming languages. Routines can be *functions* (including set-returning functions and *trigger functions*), *aggregate functions*, and *procedures*. Many routines are already defined within PostgreSQL itself, but user-defined ones can also be added.
Row	See Tuple.
Savepoint	A special mark in the sequence of steps in a *transaction*. Data modifications after this point in time may be reverted to the time of the savepoint.

For more information, see SAVEPOINT.

Schema

A schema is a namespace for *SQL objects*, which all reside in the same *database*. Each SQL object must reside in exactly one schema.

All system-defined SQL objects reside in schema `pg_catalog`.

More generically, the term *schema* is used to mean all data descriptions (*table* definitions, *constraints*, comments, etc) for a given *database* or subset thereof.

For more information, see Section 5.9.

Segment

See File segment.

Select

The SQL command used to request data from a *database*. Normally, `SELECT` commands are not expected to modify the *database* in any way, but it is possible that *functions* invoked within the query could have side effects that do modify data.

For more information, see SELECT.

Sequence (relation)

A type of relation that is used to generate values. Typically the generated values are sequential non-repeating numbers. They are commonly used to generate surrogate *primary key* values.

Server

A computer on which PostgreSQL *instances* run. The term *server* denotes real hardware, a container, or a *virtual machine*.

This term is sometimes used to refer to an instance or to a host.

Session

A state that allows a client and a backend to interact, communicating over a *connection*.

Shared memory

RAM which is used by the processes common to an *instance*. It mirrors parts of *database* files, provides a transient area for *WAL records*, and stores additional common information. Note that shared memory belongs to the complete instance, not to a single database.

The largest part of shared memory is known as *shared buffers* and is used to mirror part of data files, organized into pages. When a page is modified, it is called a dirty page until it is written back to the file system.

For more information, see Section 19.4.1.

SQL object

Any object that can be created with a `CREATE` command. Most objects are specific to one database, and are commonly known as *local objects*.

Most local objects reside in a specific *schema* in their containing database, such as *relations* (all types), *routines* (all types), data types, etc. The names of such objects of the same type in the same schema are enforced to be unique.

There also exist local objects that do not reside in schemas; some examples are *extensions*, *data type casts*, and *foreign data wrappers*. The names of such objects of the same type are enforced to be unique within the database.

Other object types, such as *roles*, *tablespaces*, replication origins, subscriptions for logical replication, and databases themselves are not local SQL objects since they exist entirely outside of any specific database; they are

	called *global objects*. The names of such objects are enforced to be unique within the whole database cluster. For more information, see Section 22.1.
SQL standard	A series of documents that define the SQL language.
Standby (server)	See Replica (server).
Stats collector (process)	This process collects statistical information about the *instance*'s activities. For more information, see Section 27.2.
System catalog	A collection of *tables* which describe the structure of all *SQL objects* of the instance. The system catalog resides in the schema `pg_catalog`. These tables contain data in internal representation and are not typically considered useful for user examination; a number of user-friendlier *views*, also in schema `pg_catalog`, offer more convenient access to some of that information, while additional tables and views exist in schema `information_schema` (see Chapter 39) that expose some of the same and additional information as mandated by the *SQL standard*. For more information, see Section 5.9.
Table	A collection of *tuples* having a common data structure (the same number of *attributes*, in the same order, having the same name and type per position). A table is the most common form of *relation* in PostgreSQL. For more information, see CREATE TABLE.
Tablespace	A named location on the server file system. All *SQL objects* which require storage beyond their definition in the *system catalog* must belong to a single tablespace. Initially, a database cluster contains a single usable tablespace which is used as the default for all SQL objects, called `pg_default`. For more information, see Section 22.6.
Temporary table	*Tables* that exist either for the lifetime of a *session* or a *transaction*, as specified at the time of creation. The data in them is not visible to other sessions, and is not *logged*. Temporary tables are often used to store intermediate data for a multi-step operation. For more information, see CREATE TABLE.
TOAST	A mechanism by which large attributes of table rows are split and stored in a secondary table, called the *TOAST table*. Each relation with large attributes has its own TOAST table. For more information, see Section 70.2.
Transaction	A combination of commands that must act as a single *atomic* command: they all succeed or all fail as a single unit, and their effects are not visible to other *sessions* until the transaction is complete, and possibly even later, depending on the isolation level. For more information, see Section 13.2.
Transaction ID	The numerical, unique, sequentially-assigned identifier that each transaction receives when it first causes a database modification. Frequently abbreviated as *xid*. For more information, see Section 8.19.

Transactions per second (TPS)	Average number of transactions that are executed per second, totaled across all sessions active for a measured run. This is used as a measure of the performance characteristics of an instance.
Trigger	A *function* which can be defined to execute whenever a certain operation (`INSERT`, `UPDATE`, `DELETE`, `TRUNCATE`) is applied to a *relation*. A trigger executes within the same *transaction* as the statement which invoked it, and if the function fails, then the invoking statement also fails. For more information, see CREATE TRIGGER.
Tuple	A collection of *attributes* in a fixed order. That order may be defined by the *table* (or other *relation*) where the tuple is contained, in which case the tuple is often called a *row*. It may also be defined by the structure of a result set, in which case it is sometimes called a *record*.
Unique constraint	A type of *constraint* defined on a *relation* which restricts the values allowed in one or a combination of columns so that each value or combination of values can only appear once in the relation — that is, no other row in the relation contains values that are equal to those. Because *null values* are not considered equal to each other, multiple rows with null values are allowed to exist without violating the unique constraint.
Unlogged	The property of certain *relations* that the changes to them are not reflected in the *WAL*. This disables replication and crash recovery for these relations. The primary use of unlogged tables is for storing transient work data that must be shared across processes. *Temporary tables* are always unlogged.
Update	An SQL command used to modify *rows* that may already exist in a specified *table*. It cannot create or remove rows. For more information, see UPDATE.
User	A *role* that has the `LOGIN` privilege.
User mapping	The translation of login credentials in the local *database* to credentials in a remote data system defined by a *foreign data wrapper*. For more information, see CREATE USER MAPPING.
UTC	Universal Coordinated Time, the primary global time reference, approximately the time prevailing at the zero meridian of longitude. Often but inaccurately referred to as GMT (Greenwich Mean Time).
Vacuum	The process of removing outdated *tuple versions* from tables or materialized views, and other closely related processing required by PostgreSQL's implementation of *MVCC*. This can be initiated through the use of the `VACUUM` command, but can also be handled automatically via *autovacuum* processes. For more information, see Section 24.1 .
View	A *relation* that is defined by a `SELECT` statement, but has no storage of its own. Any time a query references a view, the definition of the view is substituted into the query as if the user had typed it as a subquery instead of the name of the view. For more information, see CREATE VIEW.

Visibility map (fork)	A storage structure that keeps metadata about each data page of a table's main fork. The visibility map entry for each page stores two bits: the first one (`all-visible`) indicates that all tuples in the page are visible to all transactions. The second one (`all-frozen`) indicates that all tuples in the page are marked frozen.
WAL	See Write-ahead log.
WAL archiver (process)	A process that saves copies of *WAL files* for the purpose of creating backups or keeping *replicas* current. For more information, see Section 25.3.
WAL file	Also known as *WAL segment* or *WAL segment file*. Each of the sequentially-numbered files that provide storage space for *WAL*. The files are all of the same predefined size and are written in sequential order, interspersing changes as they occur in multiple simultaneous sessions. If the system crashes, the files are read in order, and each of the changes is replayed to restore the system to the state it was in before the crash. Each WAL file can be released after a *checkpoint* writes all the changes in it to the corresponding data files. Releasing the file can be done either by deleting it, or by changing its name so that it will be used in the future, which is called *recycling*. For more information, see Section 29.7.
WAL record	A low-level description of an individual data change. It contains sufficient information for the data change to be re-executed (*replayed*) in case a system failure causes the change to be lost. WAL records use a non-printable binary format. For more information, see Section 29.7.
WAL segment	See WAL file.
WAL writer (process)	A process that writes *WAL records* from *shared memory* to *WAL files*. For more information, see Section 19.5.
Window function (routine)	A type of *function* used in a *query* that applies to a *partition* of the query's *result set*; the function's result is based on values found in *rows* of the same partition or frame. All *aggregate functions* can be used as window functions, but window functions can also be used to, for example, give ranks to each of the rows in the partition. Also known as *analytic functions*. For more information, see Section 3.5.
Write-ahead log	The journal that keeps track of the changes in the *database cluster* as user- and system-invoked operations take place. It comprises many individual *WAL records* written sequentially to *WAL files*.

Appendix P. Color Support

Most programs in the PostgreSQL package can produce colorized console output. This appendix describes how that is configured.

P.1. When Color is Used

To use colorized output, set the environment variable `PG_COLOR` as follows:

1. If the value is `always`, then color is used.
2. If the value is `auto` and the standard error stream is associated with a terminal device, then color is used.
3. Otherwise, color is not used.

P.2. Configuring the Colors

The actual colors to be used are configured using the environment variable `PG_COLORS` (note plural). The value is a colon-separated list of *`key=value`* pairs. The keys specify what the color is to be used for. The values are SGR (Select Graphic Rendition) specifications, which are interpreted by the terminal.

The following keys are currently in use:

`error`

used to highlight the text “error” in error messages

`warning`

used to highlight the text “warning” in warning messages

`locus`

used to highlight location information (e.g., program name and file name) in messages

The default value is `error=01;31:warning=01;35:locus=01` (`01;31` = bold red, `01;35` = bold magenta, `01` = bold default color).

> **Tip**
>
> This color specification format is also used by other software packages such as GCC, GNU coreutils, and GNU grep.

Appendix Q. Obsolete or Renamed Features

Functionality is sometimes removed from PostgreSQL, feature, setting and file names sometimes change, or documentation moves to different places. This section directs users coming from old versions of the documentation or from external links to the appropriate new location for the information they need.

Q.1. `recovery.conf` file merged into `postgresql.conf`

Postgres Pro 11 and below used a configuration file named `recovery.conf` to manage replicas and standbys. Support for this file was removed in Postgres Pro 12. See the release notes for PostgreSQL 12 for details on this change.

On Postgres Pro 12 and above, archive recovery, streaming replication, and PITR are configured using normal server configuration parameters. These are set in `postgresql.conf` or via ALTER SYSTEM like any other parameter.

The server will not start if a `recovery.conf` exists.

The `trigger_file` setting has been renamed to promote_trigger_file.

The `standby_mode` setting has been removed. A `standby.signal` file in the data directory is used instead. See Standby Server Operation for details.

Q.2. Default Roles Renamed to Predefined Roles

PostgreSQL 13 and below used the term “Default Roles”. However, as these roles are not able to actually be changed and are installed as part of the system at initialization time, the more appropriate term to use is “Predefined Roles”. See Section 21.5 for current documentation regarding Predefined Roles, and the release notes for PostgreSQL 14 for details on this change.

Q.3. `pg_xlogdump` renamed to `pg_waldump`

Postgres Pro 9.6 and below provided a command named `pg_xlogdump` to read write-ahead-log (WAL) files. This command was renamed to `pg_waldump`, see pg_waldump for documentation of `pg_waldump` and see the release notes for PostgreSQL 10 for details on this change.

Q.4. `pg_resetxlog` renamed to `pg_resetwal`

Postgres Pro 9.6 and below provided a command named `pg_resetxlog` to reset the write-ahead-log (WAL) files. This command was renamed to `pg_resetwal`, see pg_resetwal for documentation of `pg_resetwal` and see the release notes for PostgreSQL 10 for details on this change.

Q.5. `pg_receivexlog` renamed to `pg_receivewal`

Postgres Pro 9.6 and below provided a command named `pg_receivexlog` to fetch write-ahead-log (WAL) files. This command was renamed to `pg_receivewal`, see pg_receivewal for documentation of `pg_receivewal` and see the release notes for PostgreSQL 10 for details on this change.

Bibliography

Selected references and readings for SQL and PostgreSQL.

Some white papers and technical reports from the original POSTGRES development team are available at the University of California, Berkeley, Computer Science Department *web site*.

SQL Reference Books

[bowman01] *The Practical SQL Handbook*. Using SQL Variants. Fourth Edition. Judith Bowman, Sandra Emerson, and Marcy Darnovsky. ISBN 0-201-70309-2. Addison-Wesley Professional. 2001.

[date97] *A Guide to the SQL Standard*. A user's guide to the standard database language SQL. Fourth Edition. C. J. Date and Hugh Darwen. ISBN 0-201-96426-0. Addison-Wesley. 1997.

[date04] *An Introduction to Database Systems*. Eighth Edition. C. J. Date. ISBN 0-321-19784-4. Addison-Wesley. 2003.

[elma04] *Fundamentals of Database Systems*. Fourth Edition. Ramez Elmasri and Shamkant Navathe. ISBN 0-321-12226-7. Addison-Wesley. 2003.

[melt93] *Understanding the New SQL*. A complete guide. Jim Melton and Alan R. Simon. ISBN 1-55860-245-3. Morgan Kaufmann. 1993.

[ull88] *Principles of Database and Knowledge-Base Systems*. Classical Database Systems. Jeffrey D. Ullman. Volume 1. Computer Science Press. 1988.

[sqltr-19075-6] *SQL Technical Report*. Part 6: SQL support for JavaScript Object Notation (JSON). First Edition. 2017.

PostgreSQL-specific Documentation

[sim98] *Enhancement of the ANSI SQL Implementation of PostgreSQL*. Stefan Simkovics. Department of Information Systems, Vienna University of Technology. Vienna, Austria. November 29, 1998.

[yu95] *The Postgres95. User Manual*. A. Yu and J. Chen. University of California. Berkeley, California. Sept. 5, 1995.

[fong] *The design and implementation of the POSTGRES query optimizer*. Zelaine Fong. University of California, Berkeley, Computer Science Department.

Proceedings and Articles

[ports12] "*Serializable Snapshot Isolation in PostgreSQL*". D. Ports and K. Grittner. VLDB Conference, August 2012.

[berenson95] "*A Critique of ANSI SQL Isolation Levels*". H. Berenson, P. Bernstein, J. Gray, J. Melton, E. O'Neil, and P. O'Neil. ACM-SIGMOD Conference on Management of Data, June 1995.

[olson93] *Partial indexing in POSTGRES: research project*. Nels Olson. UCB Engin T7.49.1993 O676. University of California. Berkeley, California. 1993.

[ong90] "A Unified Framework for Version Modeling Using Production Rules in a Database System". L. Ong and J. Goh. *ERL Technical Memorandum M90/33*. University of California. Berkeley, California. April, 1990.

[rowe87] "*The POSTGRES data model*". L. Rowe and M. Stonebraker. VLDB Conference, Sept. 1987.

[seshadri95] "*Generalized Partial Indexes*". P. Seshadri and A. Swami. Eleventh International Conference on Data Engineering, 6–10 March 1995. Cat. No.95CH35724. IEEE Computer Society Press. Los Alamitos, California. 1995. 420–7.

[ston86] "*The design of POSTGRES*". M. Stonebraker and L. Rowe. ACM-SIGMOD Conference on Management of Data, May 1986.

[ston87a] "The design of the POSTGRES. rules system". M. Stonebraker, E. Hanson, and C. H. Hong. IEEE Conference on Data Engineering, Feb. 1987.

[ston87b] "*The design of the POSTGRES storage system*". M. Stonebraker. VLDB Conference, Sept. 1987.

[ston89] "*A commentary on the POSTGRES rules system*". M. Stonebraker, M. Hearst, and S. Potamianos. *SIGMOD Record 18(3)*. Sept. 1989.

[ston89b] "*The case for partial indexes*". M. Stonebraker. *SIGMOD Record 18(4)*. Dec. 1989. 4–11.

[ston90a] "*The implementation of POSTGRES*". M. Stonebraker, L. A. Rowe, and M. Hirohama. *Transactions on Knowledge and Data Engineering 2(1)*. IEEE. March 1990.

[ston90b] "*On Rules, Procedures, Caching and Views in Database Systems*". M. Stonebraker, A. Jhingran, J. Goh, and S. Potamianos. ACM-SIGMOD Conference on Management of Data, June 1990.

[ston92] " *An overview of the Sequoia 2000 project* ". M. Stonebraker. *Digest of Papers COMPCON Spring 1992*. 1992. 383–388.

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