PostgreSQL 7.3.2 Programmer’s Guide

The PostgreSQL Global Development Group

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by The PostgreSQL Global Development Group

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Preface

1. What is PostgreSQL?

PostgreSQL is an object-relational database management system (ORDBMS) based on POSTGRES, Version 4.2[1], developed at the University of California at Berkeley Computer Science Department. The POSTGRES project, led by Professor Michael Stonebraker, was sponsored by the Defense Advanced Research Projects Agency (DARPA), the Army Research Office (ARO), the National Science Foundation (NSF), and ESL, Inc.

PostgreSQL is an open-source descendant of this original Berkeley code. It provides SQL92/SQL99 language support and other modern features.

POSTGRES pioneered many of the object-relational concepts now becoming available in some commercial databases. Traditional relational database management systems (RDBMS) support a data model consisting of a collection of named relations, containing attributes of a specific type. In current commercial systems, possible types include floating point numbers, integers, character strings, money, and dates. It is commonly recognized that this model is inadequate for future data-processing applications. The relational model successfully replaced previous models in part because of its “Spartan simplicity”. However, this simplicity makes the implementation of certain applications very difficult. PostgreSQL offers substantial additional power by incorporating the following additional concepts in such a way that users can easily extend the system:

- inheritance
- data types
- functions

Other features provide additional power and flexibility:

- constraints
- triggers
- rules
- transactional integrity

These features put PostgreSQL into the category of databases referred to as *object-relational*. Note that this is distinct from those referred to as *object-oriented*, which in general are not as well suited to supporting traditional relational database languages. So, although PostgreSQL has some object-oriented features, it is firmly in the relational database world. In fact, some commercial databases have recently incorporated features pioneered by PostgreSQL.

1. http://s2k-ftp.CS.Berkeley.EDU:8000/postgres/postgres.html

2. A Short History of PostgreSQL

The object-relational database management system now known as PostgreSQL (and briefly called Postgres95) is derived from the POSTGRES package written at the University of California at Berkeley. With over a decade of development behind it, PostgreSQL is the most advanced open-source database available anywhere, offering multiversion concurrency control, supporting almost all SQL constructs (including subselects, transactions, and user-defined types and functions), and having a wide range of language bindings available (including C, C++, Java, Perl, Tcl, and Python).

2.1. The Berkeley POSTGRES Project

Implementation of the POSTGRES DBMS began in 1986. The initial concepts for the system were presented in *The design of POSTGRES* and the definition of the initial data model appeared in *The POSTGRES data model*. The design of the rule system at that time was described in *The design of the POSTGRES rules system*. The rationale and architecture of the storage manager were detailed in *The design of the POSTGRES storage system*.

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

POSTGRES has been used to implement many different research and production applications. These include: a financial data analysis system, a jet engine performance monitoring package, an asteroid tracking database, a medical information database, and several geographic information systems. POSTGRES has also been used as an educational tool at several universities. Finally, Illustra Information Technologies (later merged into Informix[2], which is now owned by IBM[3].) picked up the code and commercialized it. POSTGRES became the primary data manager for the Sequoia 2000[4] scientific computing project in late 1992.

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

2.2. Postgres95

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

Postgres95 code was completely ANSI C and trimmed in size by 25%. Many internal changes improved performance and maintainability. Postgres95 release 1.0.x ran about 30-50% faster on the Wisconsin

2. http://www.informix.com/
3. http://www.ibm.com/
4. http://meteora.ucsd.edu/s2k/s2k_home.html

Benchmark compared to POSTGRES, Version 4.2. Apart from bug fixes, the following were the major enhancements:

- The query language PostQUEL was replaced with SQL (implemented in the server). Subqueries were not supported until PostgreSQL (see below), but they could be imitated in Postgres95 with user-defined SQL functions. Aggregates were re-implemented. Support for the GROUP BY query clause was also added. The `libpq` interface remained available for C programs.
- In addition to the monitor program, a new program (psql) was provided for interactive SQL queries using GNU Readline.
- A new front-end library, `libpgtcl`, supported Tcl-based clients. A sample shell, `pgtclsh`, provided new Tcl commands to interface Tcl programs with the Postgres95 backend.
- The large-object interface was overhauled. The Inversion large objects were the only mechanism for storing large objects. (The Inversion file system was removed.)
- The instance-level rule system was removed. Rules were still available as rewrite rules.
- A short tutorial introducing regular SQL features as well as those of Postgres95 was distributed with the source code
- GNU make (instead of BSD make) was used for the build. Also, Postgres95 could be compiled with an unpatched GCC (data alignment of doubles was fixed).

2.3. PostgreSQL

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

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

Major enhancements in PostgreSQL include:

- Table-level locking has been replaced by multiversion concurrency control, which allows readers to continue reading consistent data during writer activity and enables hot backups from pg_dump while the database stays available for queries.
- Important backend features, including subselects, defaults, constraints, and triggers, have been implemented.
- Additional SQL92-compliant language features have been added, including primary keys, quoted identifiers, literal string type coercion, type casting, and binary and hexadecimal integer input.
- Built-in types have been improved, including new wide-range date/time types and additional geometric type support.
- Overall backend code speed has been increased by approximately 20-40%, and backend start-up time has decreased by 80% since version 6.0 was released.

3. What's In This Book

This book is for PostgreSQL application programmers. It is divided into three parts.

The first part of this book describes the client programming interfaces distributed with PostgreSQL. Each of these chapters can be read independently. Note that there are many other programming interfaces for client programs that are distributed separately and contain their own documentation. Readers of the first part should be familiar with using SQL commands to manipulate and query the database (see the *PostgreSQL User's Guide*) and of course with the programming language that the interface uses.

The second part of this book is about extending the server functionality with user-defined functions, data types, triggers, etc. These are advanced topics which should probably be approached only after all the other user documentation about PostgreSQL has been understood.

The third part of this book described the available server-side programming languages. This information is related to the second part and is only useful to readers that have read at least the first few chapters thereof.

This book covers PostgreSQL 7.3.2 only. For information on other versions, please read the documentation that accompanies that release.

4. Overview of Documentation Resources

The PostgreSQL documentation is organized into several books:

PostgreSQL Tutorial

An informal introduction for new users.

PostgreSQL User's Guide

Documents the SQL query language environment, including data types and functions, as well as user-level performance tuning. Every PostgreSQL user should read this.

PostgreSQL Administrator's Guide

Installation and server management information. Everyone who runs a PostgreSQL server, either for personal use or for other users, needs to read this.

PostgreSQL Programmer's Guide

Advanced information for application programmers. Topics include type and function extensibility, library interfaces, and application design issues.

PostgreSQL Reference Manual

Reference pages for SQL command syntax, and client and server programs. This book is auxiliary to the User's, Administrator's, and Programmer's Guides.

PostgreSQL Developer's Guide

Information for PostgreSQL developers. This is intended for those who are contributing to the PostgreSQL project; application development information appears in the *Programmer's Guide*.

In addition to this manual set, there are other resources to help you with PostgreSQL installation and use:

man pages

The *Reference Manual*'s pages in the traditional Unix man format. There is no difference in content.

FAQs

Frequently Asked Questions (FAQ) lists document both general issues and some platform-specific issues.

READMEs

README files are available for some contributed packages.

Web Site

The PostgreSQL web site[5] carries details on the latest release, upcoming features, and other information to make your work or play with PostgreSQL more productive.

Mailing Lists

The mailing lists are a good place to have your questions answered, to share experiences with other users, and to contact the developers. Consult the User's Lounge[6] section of the PostgreSQL web site for details.

Yourself!

PostgreSQL is an open-source effort. As such, it depends on the user community for ongoing support. As you begin to use PostgreSQL, you will rely on others for help, either through the documentation or through the mailing lists. Consider contributing your knowledge back. If you learn something which is not in the documentation, write it up and contribute it. If you add features to the code, contribute them.

Even those without a lot of experience can provide corrections and minor changes in the documentation, and that is a good way to start. The <`pgsql-docs@postgresql.org`> mailing list is the place to get going.

5. Terminology and Notation

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

We use `/usr/local/pgsql/` as the root directory of the installation and `/usr/local/pgsql/data` as the directory with the database files. These directories may vary on your site, details can be derived in the *Administrator's Guide*.

5. http://www.postgresql.org
6. http://www.postgresql.org/users-lounge/

In a command synopsis, brackets ([and]) indicate an optional phrase or keyword. Anything in braces ({ and }) and containing vertical bars (|) indicates that you must choose one alternative.

Examples will show commands executed from various accounts and programs. Commands executed from a Unix shell may be preceded with a dollar sign ("$"). Commands executed from particular user accounts such as root or postgres are specially flagged and explained. SQL commands may be preceded with "=>" or will have no leading prompt, depending on the context.

> **Note:** The notation for flagging commands is not universally consistent throughout the documentation set. Please report problems to the documentation mailing list <pgsql-docs@postgresql.org>.

6. Bug Reporting Guidelines

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

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

We cannot promise to fix every bug right away. If the bug is obvious, critical, or affects a lot of users, chances are good that someone will look into it. It could also happen that we tell you to update to a newer version to see if the bug happens there. Or we might decide that the bug cannot be fixed before some major rewrite we might be planning is done. Or perhaps it is simply too hard and there are more important things on the agenda. If you need help immediately, consider obtaining a commercial support contract.

6.1. Identifying Bugs

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

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

Here "program" refers to any executable, not only the backend server.

Being slow or resource-hogging is not necessarily a bug. Read the documentation or ask on one of the mailing lists for help in tuning your applications. Failing to comply to the SQL standard is not necessarily a bug either, unless compliance for the specific feature is explicitly claimed.

Before you continue, check on the TODO list and in the FAQ to see if your bug is already known. If you cannot decode the information on the TODO list, report your problem. The least we can do is make the TODO list clearer.

6.2. What to report

The most important thing to remember about bug reporting is to state all the facts and only facts. Do not speculate what you think went wrong, what "it seemed to do", or which part of the program has a fault. If you are not familiar with the implementation you would probably guess wrong and not help us a bit. And even if you are, educated explanations are a great supplement to but no substitute for facts. If we are going to fix the bug we still have to see it happen for ourselves first. Reporting the bare facts is relatively straightforward (you can probably copy and paste them from the screen) but all too often important details are left out because someone thought it does not matter or the report would be understood anyway.

The following items should be contained in every bug report:

- The exact sequence of steps *from program start-up* necessary to reproduce the problem. This should be self-contained; it is not enough to send in a bare select statement without the preceding create table and insert statements, if the output should depend on the data in the tables. We do not have the time to reverse-engineer your database schema, and if we are supposed to make up our own data we would probably miss the problem. The best format for a test case for query-language related problems is a file that can be run through the psql frontend that shows the problem. (Be sure to not have anything in your `~/.psqlrc` start-up file.) An easy start at this file is to use pg_dump to dump out the table declarations and data needed to set the scene, then add the problem query. You are encouraged to minimize the size of your example, but this is not absolutely necessary. If the bug is reproducible, we will find it either way.

  If your application uses some other client interface, such as PHP, then please try to isolate the offending queries. We will probably not set up a web server to reproduce your problem. In any case remember to provide the exact input files, do not guess that the problem happens for "large files" or "mid-size databases", etc. since this information is too inexact to be of use.

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

  > **Note:** In case of fatal errors, the error message reported by the client might not contain all the information available. Please also look at the log output of the database server. If you do not keep your server's log output, this would be a good time to start doing so.

- The output you expected is very important to state. If you just write “This command gives me that output.” or “This is not what I expected.”, we might run it ourselves, scan the output, and think it looks OK and is exactly what we expected. We should not have to spend the time to decode the exact semantics behind your commands. Especially refrain from merely saying that “This is not what SQL says/Oracle does.” Digging out the correct behavior from SQL is not a fun undertaking, nor do we all know how all the other relational databases out there behave. (If your problem is a program crash, you can obviously omit this item.)
- Any command line options and other start-up options, including concerned environment variables or configuration files that you changed from the default. Again, be exact. If you are using a prepackaged distribution that starts the database server at boot time, you should try to find out how that is done.
- Anything you did at all differently from the installation instructions.
- The PostgreSQL version. You can run the command `SELECT version();` to find out the version of the server you are connected to. Most executable programs also support a `--version` option; at least `postmaster --version` and `psql --version` should work. If the function or the options do not exist then your version is more than old enough to warrant an upgrade. You can also look into the `README` file in the source directory or at the name of your distribution file or package name. If you run a prepackaged version, such as RPMs, say so, including any subversion the package may have. If you are talking about a CVS snapshot, mention that, including its date and time.

  If your version is older than 7.3.2 we will almost certainly tell you to upgrade. There are tons of bug fixes in each new release, that is why we make new releases.

- Platform information. This includes the kernel name and version, C library, processor, memory information. In most cases it is sufficient to report the vendor and version, but do not assume everyone knows what exactly “Debian” contains or that everyone runs on Pentiums. If you have installation problems then information about compilers, make, etc. is also necessary.

Do not be afraid if your bug report becomes rather lengthy. That is a fact of life. It is better to report everything the first time than us having to squeeze the facts out of you. On the other hand, if your input files are huge, it is fair to ask first whether somebody is interested in looking into it.

Do not spend all your time to figure out which changes in the input make the problem go away. This will probably not help solving it. If it turns out that the bug cannot be fixed right away, you will still have time to find and share your work-around. Also, once again, do not waste your time guessing why the bug exists. We will find that out soon enough.

When writing a bug report, please choose non-confusing terminology. The software package in total is called “PostgreSQL”, sometimes “Postgres” for short. If you are specifically talking about the backend server, mention that, do not just say “PostgreSQL crashes”. A crash of a single backend server process is quite different from crash of the parent “postmaster” process; please don’t say “the postmaster crashed” when you mean a single backend went down, nor vice versa. Also, client programs such as the interactive frontend “psql” are completely separate from the backend. Please try to be specific about whether the problem is on the client or server side.

6.3. Where to report bugs

In general, send bug reports to the bug report mailing list at <`pgsql-bugs@postgresql.org`>. You are requested to use a descriptive subject for your email message, perhaps parts of the error message.

Another method is to fill in the bug report web-form available at the project's web site http://www.postgresql.org/. Entering a bug report this way causes it to be mailed to the <`pgsql-bugs@postgresql.org`> mailing list.

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

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

If you have a problem with the documentation, the best place to report it is the documentation mailing list <`pgsql-docs@postgresql.org`>. Please be specific about what part of the documentation you are unhappy with.

If your bug is a portability problem on a non-supported platform, send mail to <`pgsql-ports@postgresql.org`>, so we (and you) can work on porting PostgreSQL to your platform.

> **Note:** Due to the unfortunate amount of spam going around, all of the above email addresses are closed mailing lists. That is, you need to be subscribed to a list to be allowed to post on it. (You need not be subscribed to use the bug report web-form, however.) If you would like to send mail but do not want to receive list traffic, you can subscribe and set your subscription option to `nomail`. For more information send mail to <`majordomo@postgresql.org`> with the single word `help` in the body of the message.

I. Client Interfaces

This part of the manual is the description of the client-side programming interfaces and support libraries for various languages.

Chapter 1. libpq - C Library

1.1. Introduction

libpq is the C application programmer's interface to PostgreSQL. libpq is a set of library routines that allow client programs to pass queries to the PostgreSQL backend server and to receive the results of these queries. libpq is also the underlying engine for several other PostgreSQL application interfaces, including libpq++ (C++), `libpgtcl` (Tcl), Perl, and `ecpg`. So some aspects of libpq's behavior will be important to you if you use one of those packages.

Three short programs are included at the end of this section to show how to write programs that use `libpq`. There are several complete examples of `libpq` applications in the following directories:

```
src/test/examples
src/bin/psql
```

Frontend programs that use `libpq` must include the header file `libpq-fe.h` and must link with the `libpq` library.

1.2. Database Connection Functions

The following routines deal with making a connection to a PostgreSQL backend server. The application program can have several backend connections open at one time. (One reason to do that is to access more than one database.) Each connection is represented by a `PGconn` object which is obtained from `PQconnectdb` or `PQsetdbLogin`. Note that these functions will always return a non-null object pointer, unless perhaps there is too little memory even to allocate the `PGconn` object. The `PQstatus` function should be called to check whether a connection was successfully made before queries are sent via the connection object.

- `PQconnectdb` Makes a new connection to the database server.

  ```
  PGconn *PQconnectdb(const char *conninfo)
  ```

  This routine opens a new database connection using the parameters taken from the string `conninfo`. Unlike `PQsetdbLogin` below, the parameter set can be extended without changing the function signature, so use either of this routine or the nonblocking analogues `PQconnectStart` and `PQconnectPoll` is preferred for application programming. The passed string can be empty to use all default parameters, or it can contain one or more parameter settings separated by whitespace.

  Each parameter setting is in the form `keyword = value`. (To write an empty value or a value containing spaces, surround it with single quotes, e.g., `keyword = 'a value'`. Single quotes and backslashes within the value must be escaped with a backslash, e.g., `\'` or `\\`.) Spaces around the equal sign are optional. The currently recognized parameter keywords are:

`host`

Name of host to connect to. If this begins with a slash, it specifies Unix-domain communication rather than TCP/IP communication; the value is the name of the directory in which the socket file is stored. The default is to connect to a Unix-domain socket in `/tmp`.

`hostaddr`

IP address of host to connect to. This should be in standard numbers-and-dots form, as used by the BSD functions `inet_aton` et al. If a nonzero-length string is specified, TCP/IP communication is used.

Using `hostaddr` instead of host allows the application to avoid a host name look-up, which may be important in applications with time constraints. However, Kerberos authentication requires the host name. The following therefore applies. If host is specified without `hostaddr`, a host name lookup is forced. If `hostaddr` is specified without host, the value for `hostaddr` gives the remote address; if Kerberos is used, this causes a reverse name query. If both host and `hostaddr` are specified, the value for `hostaddr` gives the remote address; the value for host is ignored, unless Kerberos is used, in which case that value is used for Kerberos authentication. Note that authentication is likely to fail if libpq is passed a host name that is not the name of the machine at `hostaddr`.

Without either a host name or host address, libpq will connect using a local Unix domain socket.

`port`

Port number to connect to at the server host, or socket file name extension for Unix-domain connections.

`dbname`

The database name.

`user`

User name to connect as.

`password`

Password to be used if the server demands password authentication.

`connect_timeout`

Time space in seconds given to connect routine. Zero or not set means infinite.

`options`

Trace/debug options to be sent to the server.

`tty`

A file or tty for optional debug output from the backend.

`requiressl`

Set to 1 to require SSL connection to the server. Libpq will then refuse to connect if the server does not accept an SSL connection. Set to 0 (default) to negotiate with server. This option is only available if PostgreSQL is compiled with SSL support.

If any parameter is unspecified, then the corresponding environment variable (see Section 1.10) is checked. If the environment variable is not set either, then hardwired defaults are used. The return value is a pointer to an abstract `struct` representing the connection to the backend.

- `PQsetdbLogin` Makes a new connection to the database server.

  ```
  PGconn *PQsetdbLogin(const char *pghost,
                       const char *pgport,
                       const char *pgoptions,
                       const char *pgtty,
                       const char *dbName,
                       const char *login,
                       const char *pwd)
  ```

  This is the predecessor of `PQconnectdb` with a fixed number of parameters but the same functionality.

- `PQsetdb` Makes a new connection to the database server.

  ```
  PGconn *PQsetdb(char *pghost,
                  char *pgport,
                  char *pgoptions,
                  char *pgtty,
                  char *dbName)
  ```

  This is a macro that calls `PQsetdbLogin` with null pointers for the *`login`* and *`pwd`* parameters. It is provided primarily for backward compatibility with old programs.

- `PQconnectStart`, `PQconnectPoll` Make a connection to the database server in a nonblocking manner.

  ```
  PGconn *PQconnectStart(const char *conninfo)
  ```

  ```
  PostgresPollingStatusType PQconnectPoll(PGconn *conn)
  ```

  These two routines are used to open a connection to a database server such that your application's thread of execution is not blocked on remote I/O whilst doing so.

  The database connection is made using the parameters taken from the string `conninfo`, passed to `PQconnectStart`. This string is in the same format as described above for `PQconnectdb`.

  Neither `PQconnectStart` nor `PQconnectPoll` will block, as long as a number of restrictions are met:

  - The `hostaddr` and `host` parameters are used appropriately to ensure that name and reverse name queries are not made. See the documentation of these parameters under `PQconnectdb` above for details.
  - If you call `PQtrace`, ensure that the stream object into which you trace will not block.
  - You ensure for yourself that the socket is in the appropriate state before calling `PQconnectPoll`, as described below.

  To begin, call `conn=PQconnectStart("`*`connection_info_string`*`")`. If `conn` is NULL, then libpq has been unable to allocate a new `PGconn` structure. Otherwise, a valid `PGconn` pointer is returned (though not yet representing a valid connection to the database). On return from `PQconnectStart`, call `status=PQstatus(conn)`. If status equals `CONNECTION_BAD`, `PQconnectStart` has failed.

If `PQconnectStart` succeeds, the next stage is to poll libpq so that it may proceed with the connection sequence. Loop thus: Consider a connection "inactive" by default. If `PQconnectPoll` last returned `PGRES_POLLING_ACTIVE`, consider it "active" instead. If `PQconnectPoll(conn)` last returned `PGRES_POLLING_READING`, perform a `select()` for reading on `PQsocket(conn)`. If it last returned `PGRES_POLLING_WRITING`, perform a `select()` for writing on `PQsocket(conn)`. If you have yet to call `PQconnectPoll`, i.e. after the call to `PQconnectStart`, behave as if it last returned `PGRES_POLLING_WRITING`. If the `select()` shows that the socket is ready, consider it "active". If it has been decided that this connection is "active", call `PQconnectPoll(conn)` again. If this call returns `PGRES_POLLING_FAILED`, the connection procedure has failed. If this call returns `PGRES_POLLING_OK`, the connection has been successfully made.

Note that the use of `select()` to ensure that the socket is ready is merely a (likely) example; those with other facilities available, such as a `poll()` call, may of course use that instead.

At any time during connection, the status of the connection may be checked, by calling `PQstatus`. If this is `CONNECTION_BAD`, then the connection procedure has failed; if this is `CONNECTION_OK`, then the connection is ready. Either of these states should be equally detectable from the return value of `PQconnectPoll`, as above. Other states may be shown during (and only during) an asynchronous connection procedure. These indicate the current stage of the connection procedure, and may be useful to provide feedback to the user for example. These statuses may include:

`CONNECTION_STARTED`

Waiting for connection to be made.

`CONNECTION_MADE`

Connection OK; waiting to send.

`CONNECTION_AWAITING_RESPONSE`

Waiting for a response from the server.

`CONNECTION_AUTH_OK`

Received authentication; waiting for connection start-up to continue.

`CONNECTION_SETENV`

Negotiating environment (part of the connection start-up).

Note that, although these constants will remain (in order to maintain compatibility), an application should never rely upon these appearing in a particular order, or at all, or on the status always being one of these documented values. An application may do something like this:

```
switch(PQstatus(conn))
{
    case CONNECTION_STARTED:
        feedback = "Connecting...";
        break;

    case CONNECTION_MADE:
        feedback = "Connected to server...";
        break;
.
```

```
.
.
    default:
        feedback = "Connecting...";
}
```

Note that if `PQconnectStart` returns a non-NULL pointer, you must call `PQfinish` when you are finished with it, in order to dispose of the structure and any associated memory blocks. This must be done even if a call to `PQconnectStart` or `PQconnectPoll` failed.

`PQconnectPoll` will currently block if libpq is compiled with `USE_SSL` defined. This restriction may be removed in the future.

These functions leave the socket in a nonblocking state as if `PQsetnonblocking` had been called.

- `PQconndefaults` Returns the default connection options.

  ```
  PQconninfoOption *PQconndefaults(void)

  struct PQconninfoOption
  {
      char   *keyword;   /* The keyword of the option */
      char   *envvar;    /* Fallback environment variable name */
      char   *compiled;  /* Fallback compiled in default value */
      char   *val;       /* Option’s current value, or NULL */
      char   *label;     /* Label for field in connect dialog */
      char   *dispchar;  /* Character to display for this field
                            in a connect dialog. Values are:
                            ""        Display entered value as is
                            "*"       Password field - hide value
                            "D"       Debug option - don’t show by default */
      int     dispsize;  /* Field size in characters for dialog */
  }
  ```

  Returns a connection options array. This may be used to determine all possible `PQconnectdb` options and their current default values. The return value points to an array of `PQconninfoOption structs`, which ends with an entry having a NULL keyword pointer. Note that the default values (`val` fields) will depend on environment variables and other context. Callers must treat the connection options data as read-only.

  After processing the options array, free it by passing it to `PQconninfoFree`. If this is not done, a small amount of memory is leaked for each call to `PQconndefaults`.

  In PostgreSQL versions before 7.0, `PQconndefaults` returned a pointer to a static array, rather than a dynamically allocated array. That was not thread-safe, so the behavior has been changed.

- `PQfinish` Close the connection to the backend. Also frees memory used by the `PGconn` object.

  ```
  void PQfinish(PGconn *conn)
  ```

Note that even if the backend connection attempt fails (as indicated by `PQstatus`), the application should call `PQfinish` to free the memory used by the `PGconn` object. The `PGconn` pointer should not be used after `PQfinish` has been called.

- `PQreset` Reset the communication port with the backend.

  ```
  void PQreset(PGconn *conn)
  ```

  This function will close the connection to the backend and attempt to reestablish a new connection to the same server, using all the same parameters previously used. This may be useful for error recovery if a working connection is lost.

- `PQresetStart` `PQresetPoll` Reset the communication port with the backend, in a nonblocking manner.

  ```
  int PQresetStart(PGconn *conn);
  ```

  ```
  PostgresPollingStatusType PQresetPoll(PGconn *conn);
  ```

  These functions will close the connection to the backend and attempt to reestablish a new connection to the same server, using all the same parameters previously used. This may be useful for error recovery if a working connection is lost. They differ from `PQreset` (above) in that they act in a nonblocking manner. These functions suffer from the same restrictions as `PQconnectStart` and `PQconnectPoll`.

  Call `PQresetStart`. If it returns 0, the reset has failed. If it returns 1, poll the reset using `PQresetPoll` in exactly the same way as you would create the connection using `PQconnectPoll`.

libpq application programmers should be careful to maintain the `PGconn` abstraction. Use the accessor functions below to get at the contents of `PGconn`. Avoid directly referencing the fields of the `PGconn` structure because they are subject to change in the future. (Beginning in PostgreSQL release 6.4, the definition of `struct PGconn` is not even provided in `libpq-fe.h`. If you have old code that accesses `PGconn` fields directly, you can keep using it by including `libpq-int.h` too, but you are encouraged to fix the code soon.)

- `PQdb` Returns the database name of the connection.

  ```
  char *PQdb(const PGconn *conn)
  ```

  `PQdb` and the next several functions return the values established at connection. These values are fixed for the life of the `PGconn` object.

- `PQuser` Returns the user name of the connection.

  ```
  char *PQuser(const PGconn *conn)
  ```

- `PQpass` Returns the password of the connection.

  ```
  char *PQpass(const PGconn *conn)
  ```

- `PQhost` Returns the server host name of the connection.

  ```
  char *PQhost(const PGconn *conn)
  ```

- `PQport` Returns the port of the connection.

  ```
  char *PQport(const PGconn *conn)
  ```

- `PQtty` Returns the debug tty of the connection.

  ```
  char *PQtty(const PGconn *conn)
  ```

- `PQoptions` Returns the backend options used in the connection.

  ```
  char *PQoptions(const PGconn *conn)
  ```

- `PQstatus` Returns the status of the connection.

  ```
  ConnStatusType PQstatus(const PGconn *conn)
  ```

  The status can be one of a number of values. However, only two of these are seen outside of an asynchronous connection procedure - `CONNECTION_OK` or `CONNECTION_BAD`. A good connection to the database has the status `CONNECTION_OK`. A failed connection attempt is signaled by status `CONNECTION_BAD`. Ordinarily, an OK status will remain so until `PQfinish`, but a communications failure might result in the status changing to `CONNECTION_BAD` prematurely. In that case the application could try to recover by calling `PQreset`.

  See the entry for `PQconnectStart` and `PQconnectPoll` with regards to other status codes that might be seen.

- `PQerrorMessage` Returns the error message most recently generated by an operation on the connection.

  ```
  char *PQerrorMessage(const PGconn* conn);
  ```

  Nearly all libpq functions will set `PQerrorMessage` if they fail. Note that by libpq convention, a non-empty `PQerrorMessage` will include a trailing newline.

- `PQbackendPID` Returns the process ID of the backend server handling this connection.

  ```
  int PQbackendPID(const PGconn *conn);
  ```

  The backend PID is useful for debugging purposes and for comparison to NOTIFY messages (which include the PID of the notifying backend). Note that the PID belongs to a process executing on the database server host, not the local host!

- `PQgetssl` Returns the SSL structure used in the connection, or NULL if SSL is not in use.

  ```
  SSL *PQgetssl(const PGconn *conn);
  ```

  This structure can be used to verify encryption levels, check server certificate and more. Refer to the SSL documentation for information about this structure.

  You must define `USE_SSL` in order to get the prototype for this function. Doing this will also automatically include `ssl.h` from OpenSSL.

1.3. Command Execution Functions

Once a connection to a database server has been successfully established, the functions described here are used to perform SQL queries and commands.

1.3.1. Main Routines

- `PQexec` Submit a command to the server and wait for the result.

  ```
  PGresult *PQexec(PGconn *conn,
                   const char *query);
  ```

  Returns a `PGresult` pointer or possibly a NULL pointer. A non-NULL pointer will generally be returned except in out-of-memory conditions or serious errors such as inability to send the command to the backend. If a NULL is returned, it should be treated like a `PGRES_FATAL_ERROR` result. Use `PQerrorMessage` to get more information about the error.

The `PGresult` structure encapsulates the result returned by the backend. `libpq` application programmers should be careful to maintain the `PGresult` abstraction. Use the accessor functions below to get at the contents of `PGresult`. Avoid directly referencing the fields of the `PGresult` structure because they are subject to change in the future. (Beginning in PostgreSQL 6.4, the definition of `struct PGresult` is not even provided in `libpq-fe.h`. If you have old code that accesses `PGresult` fields directly, you can keep using it by including `libpq-int.h` too, but you are encouraged to fix the code soon.)

- `PQresultStatus` Returns the result status of the command.

  ```
  ExecStatusType PQresultStatus(const PGresult *res)
  ```

  `PQresultStatus` can return one of the following values:

  - `PGRES_EMPTY_QUERY` -- The string sent to the backend was empty.
  - `PGRES_COMMAND_OK` -- Successful completion of a command returning no data
  - `PGRES_TUPLES_OK` -- The query successfully executed
  - `PGRES_COPY_OUT` -- Copy Out (from server) data transfer started
  - `PGRES_COPY_IN` -- Copy In (to server) data transfer started
  - `PGRES_BAD_RESPONSE` -- The server's response was not understood
  - `PGRES_NONFATAL_ERROR`
  - `PGRES_FATAL_ERROR`

  If the result status is `PGRES_TUPLES_OK`, then the routines described below can be used to retrieve the rows returned by the query. Note that a SELECT command that happens to retrieve zero rows still shows `PGRES_TUPLES_OK`. `PGRES_COMMAND_OK` is for commands that can never return rows (INSERT, UPDATE, etc.). A response of `PGRES_EMPTY_QUERY` often exposes a bug in the client software.

- `PQresStatus` Converts the enumerated type returned by `PQresultStatus` into a string constant describing the status code.

  ```
  char *PQresStatus(ExecStatusType status);
  ```

- `PQresultErrorMessage` returns the error message associated with the query, or an empty string if there was no error.

  ```
  char *PQresultErrorMessage(const PGresult *res);
  ```

  Immediately following a `PQexec` or `PQgetResult` call, `PQerrorMessage` (on the connection) will return the same string as `PQresultErrorMessage` (on the result). However, a `PGresult` will retain its error message until destroyed, whereas the connection's error message will change when subsequent operations are done. Use `PQresultErrorMessage` when you want to know the status associated with a particular `PGresult`; use `PQerrorMessage` when you want to know the status from the latest operation on the connection.

- `PQclear` Frees the storage associated with the `PGresult`. Every query result should be freed via `PQclear` when it is no longer needed.

  ```
  void PQclear(PQresult *res);
  ```

  You can keep a `PGresult` object around for as long as you need it; it does not go away when you issue a new query, nor even if you close the connection. To get rid of it, you must call `PQclear`. Failure to do this will result in memory leaks in the frontend application.

- `PQmakeEmptyPGresult` Constructs an empty `PGresult` object with the given status.

  ```
  PGresult* PQmakeEmptyPGresult(PGconn *conn, ExecStatusType status);
  ```

  This is libpq's internal routine to allocate and initialize an empty `PGresult` object. It is exported because some applications find it useful to generate result objects (particularly objects with error status) themselves. If *`conn`* is not NULL and status indicates an error, the connection's current error message is copied into the `PGresult.` Note that `PQclear` should eventually be called on the object, just as with a `PGresult` returned by libpq itself.

1.3.2. Escaping strings for inclusion in SQL queries

`PQescapeString` Escapes a string for use within an SQL query.

```
size_t PQescapeString (char *to, const char *from, size_t length);
```

If you want to include strings that have been received from a source that is not trustworthy (for example, because a random user entered them), you cannot directly include them in SQL queries for security reasons. Instead, you have to quote special characters that are otherwise interpreted by the SQL parser.

`PQescapeString` performs this operation. The *`from`* points to the first character of the string that is to be escaped, and the *`length`* parameter counts the number of characters in this string (a terminating zero byte is neither necessary nor counted). *`to`* shall point to a buffer that is able to hold at least one more character than twice the value of *`length`*, otherwise the behavior is undefined. A call to `PQescapeString` writes an escaped version of the *`from`* string to the *`to`* buffer, replacing special characters so that they cannot cause any harm, and adding a terminating zero byte. The single quotes that must surround PostgreSQL string literals are not part of the result string.

`PQescapeString` returns the number of characters written to *`to`*, not including the terminating zero byte. Behavior is undefined when the *`to`* and *`from`* strings overlap.

1.3.3. Escaping binary strings for inclusion in SQL queries

`PQescapeBytea` Escapes a binary string (`bytea` type) for use within an SQL query.

```
unsigned char *PQescapeBytea(unsigned char *from,
                                         size_t from_length,
                                         size_t *to_length);
```

Certain ASCII characters *must* be escaped (but all characters *may* be escaped) when used as part of a `bytea` string literal in an SQL statement. In general, to escape a character, it is converted into the three digit octal number equal to the decimal ASCII value, and preceded by two backslashes. The single quote (') and backslash (\) characters have special alternate escape sequences. See the *User's Guide* for more information. `PQescapeBytea` performs this operation, escaping only the minimally required characters.

The *from* parameter points to the first character of the string that is to be escaped, and the *from_length* parameter reflects the number of characters in this binary string (a terminating zero byte is neither necessary nor counted). The *to_length* parameter shall point to a buffer suitable to hold the resultant escaped string length. The result string length includes the terminating zero byte of the result.

`PQescapeBytea` returns an escaped version of the *from* parameter binary string, to a caller-provided buffer. The return string has all special characters replaced so that they can be properly processed by the PostgreSQL string literal parser, and the `bytea` input function. A terminating zero byte is also added. The single quotes that must surround PostgreSQL string literals are not part of the result string.

`PQunescapeBytea` Converts an escaped string representation of binary data into binary data - the reverse of `PQescapeBytea`.

```
unsigned char *PQunescapeBytea(unsigned char *from, size_t *to_length);
```

The *from* parameter points to an escaped string such as might be returned by `PQgetvalue` of a `BYTEA` column. `PQunescapeBytea` converts this string representation into its binary representation, filling the supplied buffer. It returns a pointer to the buffer which is NULL on error, and the size of the buffer in *to_length*. The pointer may subsequently be used as an argument to the function `free(3)`.

1.3.4. Retrieving SELECT Result Information

- `PQntuples` Returns the number of tuples (rows) in the query result.

  ```
  int PQntuples(const PGresult *res);
  ```

- `PQnfields` Returns the number of fields (columns) in each row of the query result.

  ```
  int PQnfields(const PGresult *res);
  ```

- `PQfname` Returns the field (column) name associated with the given field index. Field indices start at 0.

  ```
  char *PQfname(const PGresult *res,
                      int field_index);
  ```

- `PQfnumber` Returns the field (column) index associated with the given field name.

  ```
  int PQfnumber(const PGresult *res,
  ```

```
                     const char *field_name);
```

-1 is returned if the given name does not match any field.

- `PQftype` Returns the field type associated with the given field index. The integer returned is an internal coding of the type. Field indices start at 0.

  ```
  Oid PQftype(const PGresult *res,
              int field_index);
  ```

  You can query the system table `pg_type` to obtain the name and properties of the various data types. The OIDs of the built-in data types are defined in `src/include/catalog/pg_type.h` in the source tree.

- `PQfmod` Returns the type-specific modification data of the field associated with the given field index. Field indices start at 0.

  ```
  int PQfmod(const PGresult *res,
             int field_index);
  ```

- `PQfsize` Returns the size in bytes of the field associated with the given field index. Field indices start at 0.

  ```
  int PQfsize(const PGresult *res,
              int field_index);
  ```

  `PQfsize` returns the space allocated for this field in a database tuple, in other words the size of the server's binary representation of the data type. -1 is returned if the field is variable size.

- `PQbinaryTuples` Returns 1 if the `PGresult` contains binary tuple data, 0 if it contains ASCII data.

  ```
  int PQbinaryTuples(const PGresult *res);
  ```

  Currently, binary tuple data can only be returned by a query that extracts data from a binary cursor.

1.3.5. Retrieving SELECT Result Values

- `PQgetvalue` Returns a single field (column) value of one tuple (row) of a `PGresult`. Tuple and field indices start at 0.

  ```
  char* PQgetvalue(const PGresult *res,
                   int tup_num,
                   int field_num);
  ```

  For most queries, the value returned by `PQgetvalue` is a null-terminated character string representation of the attribute value. But if `PQbinaryTuples()` is 1, the value returned by `PQgetvalue` is the binary representation of the type in the internal format of the backend server (but not including the size word, if the field is variable-length). It is then the programmer's responsibility to cast and convert the data to the correct C type. The pointer returned by `PQgetvalue` points to storage that is part of the `PGresult` structure. One should not modify it, and one must explicitly copy the value into other storage if it is to be used past the lifetime of the `PGresult` structure itself.

- `PQgetisnull` Tests a field for a NULL entry. Tuple and field indices start at 0.

  ```
  int PQgetisnull(const PGresult *res,
  ```

```
                    int tup_num,
                    int field_num);
```

This function returns 1 if the field contains a NULL, 0 if it contains a non-null value. (Note that `PQgetvalue` will return an empty string, not a null pointer, for a NULL field.)

- `PQgetlength` Returns the length of a field (attribute) value in bytes. Tuple and field indices start at 0.

  ```
  int PQgetlength(const PGresult *res,
                  int tup_num,
                  int field_num);
  ```

  This is the actual data length for the particular data value, that is the size of the object pointed to by `PQgetvalue`. Note that for character-represented values, this size has little to do with the binary size reported by `PQfsize`.

- `PQprint` Prints out all the tuples and, optionally, the attribute names to the specified output stream.

  ```
  void PQprint(FILE* fout,      /* output stream */
               const PGresult *res,
               const PQprintOpt *po);

  struct {
      pqbool  header;      /* print output field headings and row count */
      pqbool  align;       /* fill align the fields */
      pqbool  standard;    /* old brain dead format */
      pqbool  html3;       /* output html tables */
      pqbool  expanded;    /* expand tables */
      pqbool  pager;       /* use pager for output if needed */
      char    *fieldSep;   /* field separator */
      char    *tableOpt;   /* insert to HTML table ... */
      char    *caption;    /* HTML caption */
      char    **fieldName; /* null terminated array of replacement field names */
  } PQprintOpt;
  ```

  This function was formerly used by psql to print query results, but this is no longer the case and this function is no longer actively supported.

1.3.6. Retrieving Non-SELECT Result Information

- `PQcmdStatus` Returns the command status string from the SQL command that generated the `PGresult`.

  ```
  char * PQcmdStatus(PGresult *res);
  ```

- `PQcmdTuples` Returns the number of rows affected by the SQL command.

  ```
  char * PQcmdTuples(PGresult *res);
  ```

  If the SQL command that generated the `PGresult` was INSERT, UPDATE or DELETE, this returns a string containing the number of rows affected. If the command was anything else, it returns the empty string.

- `PQoidValue` Returns the object ID of the inserted row, if the SQL command was an INSERT that inserted exactly one row into a table that has OIDs. Otherwise, returns `InvalidOid`.

  ```
  Oid PQoidValue(const PGresult *res);
  ```

  The type `Oid` and the constant `InvalidOid` will be defined if you include the libpq header file. They will both be some integer type.

- `PQoidStatus` Returns a string with the object ID of the inserted row, if the SQL command was an INSERT. (The string will be `0` if the INSERT did not insert exactly one row, or if the target table does not have OIDs.) If the command was not an INSERT, returns an empty string.

  ```
  char * PQoidStatus(const PGresult *res);
  ```

  This function is deprecated in favor of `PQoidValue` and is not thread-safe.

1.4. Asynchronous Query Processing

The `PQexec` function is adequate for submitting commands in simple synchronous applications. It has a couple of major deficiencies however:

- `PQexec` waits for the command to be completed. The application may have other work to do (such as maintaining a user interface), in which case it won't want to block waiting for the response.
- Since control is buried inside `PQexec`, it is hard for the frontend to decide it would like to try to cancel the ongoing command. (It can be done from a signal handler, but not otherwise.)
- `PQexec` can return only one `PGresult` structure. If the submitted command string contains multiple SQL commands, all but the last `PGresult` are discarded by `PQexec`.

Applications that do not like these limitations can instead use the underlying functions that `PQexec` is built from: `PQsendQuery` and `PQgetResult`.

Older programs that used this functionality as well as `PQputline` and `PQputnbytes` could block waiting to send data to the backend. To address that issue, the function `PQsetnonblocking` was added.

Old applications can neglect to use `PQsetnonblocking` and get the older potentially blocking behavior. Newer programs can use `PQsetnonblocking` to achieve a completely nonblocking connection to the backend.

- `PQsetnonblocking` Sets the nonblocking status of the connection.

  ```
  int PQsetnonblocking(PGconn *conn, int arg)
  ```

  Sets the state of the connection to nonblocking if *`arg`* is 1, blocking if *`arg`* is 0. Returns 0 if OK, -1 if error.

  In the nonblocking state, calls to `PQputline`, `PQputnbytes`, `PQsendQuery` and `PQendcopy` will not block but instead return an error if they need to be called again.

  When a database connection has been set to nonblocking mode and `PQexec` is called, it will temporarily set the state of the connection to blocking until the `PQexec` completes.

More of libpq is expected to be made safe for `PQsetnonblocking` functionality in the near future.

- `PQisnonblocking` Returns the blocking status of the database connection.

  ```
  int PQisnonblocking(const PGconn *conn)
  ```

  Returns 1 if the connection is set to nonblocking mode, 0 if blocking.

- `PQsendQuery` Submit a command to the server without waiting for the result(s). 1 is returned if the command was successfully dispatched, 0 if not (in which case, use `PQerrorMessage` to get more information about the failure).

  ```
  int PQsendQuery(PGconn *conn,
                  const char *query);
  ```

  After successfully calling `PQsendQuery`, call `PQgetResult` one or more times to obtain the results. `PQsendQuery` may not be called again (on the same connection) until `PQgetResult` has returned NULL, indicating that the command is done.

- `PQgetResult` Wait for the next result from a prior `PQsendQuery`, and return it. NULL is returned when the query is complete and there will be no more results.

  ```
  PGresult *PQgetResult(PGconn *conn);
  ```

  `PQgetResult` must be called repeatedly until it returns NULL, indicating that the command is done. (If called when no command is active, `PQgetResult` will just return NULL at once.) Each non-NULL result from `PQgetResult` should be processed using the same `PGresult` accessor functions previously described. Don't forget to free each result object with `PQclear` when done with it. Note that `PQgetResult` will block only if a query is active and the necessary response data has not yet been read by `PQconsumeInput`.

Using `PQsendQuery` and `PQgetResult` solves one of `PQexec`'s problems: If a command string contains multiple SQL commands, the results of those commands can be obtained individually. (This allows a simple form of overlapped processing, by the way: the frontend can be handling the results of one query while the backend is still working on later queries in the same command string.) However, calling `PQgetResult` will still cause the frontend to block until the backend completes the next SQL command. This can be avoided by proper use of three more functions:

- `PQconsumeInput` If input is available from the backend, consume it.

  ```
  int PQconsumeInput(PGconn *conn);
  ```

  `PQconsumeInput` normally returns 1 indicating "no error", but returns 0 if there was some kind of trouble (in which case `PQerrorMessage` is set). Note that the result does not say whether any input data was actually collected. After calling `PQconsumeInput`, the application may check `PQisBusy` and/or `PQnotifies` to see if their state has changed.

  `PQconsumeInput` may be called even if the application is not prepared to deal with a result or notification just yet. The routine will read available data and save it in a buffer, thereby causing a `select()` read-ready indication to go away. The application can thus use `PQconsumeInput` to clear the `select()` condition immediately, and then examine the results at leisure.

- `PQisBusy` Returns 1 if a query is busy, that is, `PQgetResult` would block waiting for input. A 0 return indicates that `PQgetResult` can be called with assurance of not blocking.

  ```
  int PQisBusy(PGconn *conn);
  ```

  `PQisBusy` will not itself attempt to read data from the backend; therefore `PQconsumeInput` must be invoked first, or the busy state will never end.

- `PQflush` Attempt to flush any data queued to the backend, returns 0 if successful (or if the send queue is empty) or `EOF` if it failed for some reason.

  ```
  int PQflush(PGconn *conn);
  ```

  `PQflush` needs to be called on a nonblocking connection before calling `select()` to determine if a response has arrived. If 0 is returned it ensures that there is no data queued to the backend that has not actually been sent. Only applications that have used `PQsetnonblocking` have a need for this.

- `PQsocket` Obtain the file descriptor number for the backend connection socket. A valid descriptor will be >= 0; a result of -1 indicates that no backend connection is currently open.

  ```
  int PQsocket(const PGconn *conn);
  ```

  `PQsocket` should be used to obtain the backend socket descriptor in preparation for executing `select()`. This allows an application using a blocking connection to wait for either backend responses or other conditions. If the result of `select()` indicates that data can be read from the backend socket, then `PQconsumeInput` should be called to read the data; after which, `PQisBusy`, `PQgetResult`, and/or `PQnotifies` can be used to process the response.

  Nonblocking connections (that have used `PQsetnonblocking`) should not use `select()` until `PQflush` has returned 0 indicating that there is no buffered data waiting to be sent to the backend.

A typical frontend using these functions will have a main loop that uses `select` to wait for all the conditions that it must respond to. One of the conditions will be input available from the backend, which in `select`'s terms is readable data on the file descriptor identified by `PQsocket`. When the main loop detects input ready, it should call `PQconsumeInput` to read the input. It can then call `PQisBusy`, followed by `PQgetResult` if `PQisBusy` returns false (0). It can also call `PQnotifies` to detect NOTIFY messages (see Section 1.6).

A frontend that uses `PQsendQuery`/`PQgetResult` can also attempt to cancel a command that is still being processed by the backend.

- `PQrequestCancel` Request that PostgreSQL abandon processing of the current command.

  ```
  int PQrequestCancel(PGconn *conn);
  ```

  The return value is 1 if the cancel request was successfully dispatched, 0 if not. (If not, `PQerrorMessage` tells why not.) Successful dispatch is no guarantee that the request will have any effect, however. Regardless of the return value of `PQrequestCancel`, the application must continue with the normal result-reading sequence using `PQgetResult`. If the cancellation is effective, the current command will terminate early and return an error result. If the cancellation fails (say, because the backend was already done processing the command), then there will be no visible result at all.

Note that if the current command is part of a transaction, cancellation will abort the whole transaction.

`PQrequestCancel` can safely be invoked from a signal handler. So, it is also possible to use it in conjunction with plain `PQexec`, if the decision to cancel can be made in a signal handler. For example, psql invokes `PQrequestCancel` from a SIGINT signal handler, thus allowing interactive cancellation of queries that it issues through `PQexec`. Note that `PQrequestCancel` will have no effect if the connection is not currently open or the backend is not currently processing a command.

1.5. The Fast-Path Interface

PostgreSQL provides a fast-path interface to send function calls to the backend. This is a trapdoor into system internals and can be a potential security hole. Most users will not need this feature.

- `PQfn` Request execution of a backend function via the fast-path interface.

  ```
  PGresult* PQfn(PGconn* conn,
                 int fnid,
                 int *result_buf,
                 int *result_len,
                 int result_is_int,
                 const PQArgBlock *args,
                 int nargs);
  ```

  The *`fnid`* argument is the object identifier of the function to be executed. *`result_buf`* is the buffer in which to place the return value. The caller must have allocated sufficient space to store the return value (there is no check!). The actual result length will be returned in the integer pointed to by *`result_len`*. If a 4-byte integer result is expected, set *`result_is_int`* to 1; otherwise set it to 0. (Setting *`result_is_int`* to 1 tells libpq to byte-swap the value if necessary, so that it is delivered as a proper int value for the client machine. When *`result_is_int`* is 0, the byte string sent by the backend is returned unmodified.) *`args`* and *`nargs`* specify the arguments to be passed to the function.

  ```
  typedef struct {
      int len;
      int isint;
      union {
          int *ptr;
          int integer;
      } u;
  } PQArgBlock;
  ```

  `PQfn` always returns a valid `PGresult*`. The result status should be checked before the result is used. The caller is responsible for freeing the `PGresult` with `PQclear` when it is no longer needed.

1.6. Asynchronous Notification

PostgreSQL supports asynchronous notification via the `LISTEN` and `NOTIFY` commands. A backend registers its interest in a particular notification condition with the `LISTEN` command (and can stop listening with the `UNLISTEN` command). All backends listening on a particular condition will be notified asynchronously when a `NOTIFY` of that condition name is executed by any backend. No additional information is passed from the notifier to the listener. Thus, typically, any actual data that needs to be communicated is transferred through a database relation. Commonly the condition name is the same as the associated relation, but it is not necessary for there to be any associated relation.

`libpq` applications submit `LISTEN` and `UNLISTEN` commands as ordinary SQL command. Subsequently, arrival of `NOTIFY` messages can be detected by calling `PQnotifies`.

- `PQnotifies` Returns the next notification from a list of unhandled notification messages received from the backend. Returns NULL if there are no pending notifications. Once a notification is returned from `PQnotifies`, it is considered handled and will be removed from the list of notifications.

  ```
  PGnotify* PQnotifies(PGconn *conn);

  typedef struct pgNotify {
      char *relname;              /* name of relation containing data */
      int  be_pid;                /* process id of backend */
  } PGnotify;
  ```

  After processing a `PGnotify` object returned by `PQnotifies`, be sure to free it with `free()` to avoid a memory leak.

  > **Note:** In PostgreSQL 6.4 and later, the `be_pid` is that of the notifying backend, whereas in earlier versions it was always the PID of your own backend.

The second sample program gives an example of the use of asynchronous notification.

`PQnotifies()` does not actually read backend data; it just returns messages previously absorbed by another libpq function. In prior releases of libpq, the only way to ensure timely receipt of NOTIFY messages was to constantly submit queries, even empty ones, and then check `PQnotifies()` after each `PQexec()`. While this still works, it is deprecated as a waste of processing power.

A better way to check for NOTIFY messages when you have no useful queries to make is to call `PQconsumeInput()`, then check `PQnotifies()`. You can use `select()` to wait for backend data to arrive, thereby using no CPU power unless there is something to do. (See `PQsocket()` to obtain the file descriptor number to use with `select()`.) Note that this will work OK whether you submit queries with `PQsendQuery`/`PQgetResult` or simply use `PQexec`. You should, however, remember to check `PQnotifies()` after each `PQgetResult` or `PQexec`, to see if any notifications came in during the processing of the query.

1.7. Functions Associated with the COPY Command

The COPY command in PostgreSQL has options to read from or write to the network connection used by `libpq`. Therefore, functions are necessary to access this network connection directly so applications may take advantage of this capability.

These functions should be executed only after obtaining a `PGRES_COPY_OUT` or `PGRES_COPY_IN` result object from `PQexec` or `PQgetResult`.

- `PQgetline` Reads a newline-terminated line of characters (transmitted by the backend server) into a buffer string of size length.

  ```
  int PQgetline(PGconn *conn,
                char *string,
                int length)
  ```

  Like `fgets`, this routine copies up to length-1 characters into string. It is like `gets`, however, in that it converts the terminating newline into a zero byte. `PQgetline` returns `EOF` at the end of input, 0 if the entire line has been read, and 1 if the buffer is full but the terminating newline has not yet been read.

  Notice that the application must check to see if a new line consists of the two characters `\.`, which indicates that the backend server has finished sending the results of the copy command. If the application might receive lines that are more than length-1 characters long, care is needed to be sure one recognizes the `\.` line correctly (and does not, for example, mistake the end of a long data line for a terminator line). The code in `src/bin/psql/copy.c` contains example routines that correctly handle the copy protocol.

- `PQgetlineAsync` Reads a newline-terminated line of characters (transmitted by the backend server) into a buffer without blocking.

  ```
  int PQgetlineAsync(PGconn *conn,
                     char *buffer,
                     int bufsize)
  ```

  This routine is similar to `PQgetline`, but it can be used by applications that must read COPY data asynchronously, that is without blocking. Having issued the COPY command and gotten a `PGRES_COPY_OUT` response, the application should call `PQconsumeInput` and `PQgetlineAsync` until the end-of-data signal is detected. Unlike `PQgetline`, this routine takes responsibility for detecting end-of-data. On each call, `PQgetlineAsync` will return data if a complete newline-terminated data line is available in libpq's input buffer, or if the incoming data line is too long to fit in the buffer offered by the caller. Otherwise, no data is returned until the rest of the line arrives.

  The routine returns -1 if the end-of-copy-data marker has been recognized, or 0 if no data is available, or a positive number giving the number of bytes of data returned. If -1 is returned, the caller must next call `PQendcopy`, and then return to normal processing. The data returned will not extend beyond a newline character. If possible a whole line will be returned at one time. But if the buffer offered by the caller is too small to hold a line sent by the backend, then a partial data line will be returned. This can be detected by testing whether the last returned byte is `\n` or not. The returned string is not null-terminated. (If you want to add a terminating null, be sure to pass a *`bufsize`* one smaller than the room actually available.)

- `PQputline` Sends a null-terminated string to the backend server. Returns 0 if OK, `EOF` if unable to send the string.

  ```
  int PQputline(PGconn *conn,
                const char *string);
  ```

Note the application must explicitly send the two characters `\.` on a final line to indicate to the backend that it has finished sending its data.

- `PQputnbytes` Sends a non-null-terminated string to the backend server. Returns 0 if OK, `EOF` if unable to send the string.

```
int PQputnbytes(PGconn *conn,
                const char *buffer,
                int nbytes);
```

  This is exactly like `PQputline`, except that the data buffer need not be null-terminated since the number of bytes to send is specified directly.

- `PQendcopy` Synchronizes with the backend. This function waits until the backend has finished the copy. It should either be issued when the last string has been sent to the backend using `PQputline` or when the last string has been received from the backend using `PGgetline`. It must be issued or the backend may get "out of sync" with the frontend. Upon return from this function, the backend is ready to receive the next SQL command. The return value is 0 on successful completion, nonzero otherwise.

```
int PQendcopy(PGconn *conn);
```

  As an example:

```
PQexec(conn, "CREATE TABLE foo (a int4, b char(16), d double precision)");
PQexec(conn, "COPY foo FROM STDIN");
PQputline(conn, "3\thello world\t4.5\n");
PQputline(conn,"4\tgoodbye world\t7.11\n");
...
PQputline(conn,"\\.\n");
PQendcopy(conn);
```

When using `PQgetResult`, the application should respond to a `PGRES_COPY_OUT` result by executing `PQgetline` repeatedly, followed by `PQendcopy` after the terminator line is seen. It should then return to the `PQgetResult` loop until `PQgetResult` returns NULL. Similarly a `PGRES_COPY_IN` result is processed by a series of `PQputline` calls followed by `PQendcopy`, then return to the `PQgetResult` loop. This arrangement will ensure that a copy in or copy out command embedded in a series of SQL commands will be executed correctly.

Older applications are likely to submit a copy in or copy out via `PQexec` and assume that the transaction is done after `PQendcopy`. This will work correctly only if the copy in/out is the only SQL command in the command string.

1.8. libpq Tracing Functions

- `PQtrace` Enable tracing of the frontend/backend communication to a debugging file stream.

```
void PQtrace(PGconn *conn
             FILE *debug_port)
```

- `PQuntrace` Disable tracing started by `PQtrace`.

```
void PQuntrace(PGconn *conn)
```

1.9. libpq Control Functions

- `PQsetNoticeProcessor` Control reporting of notice and warning messages generated by libpq.

```
typedef void (*PQnoticeProcessor) (void *arg, const char *message);

PQnoticeProcessor
PQsetNoticeProcessor(PGconn *conn,
                     PQnoticeProcessor proc,
                     void *arg);
```

By default, libpq prints notice messages from the backend on `stderr`, as well as a few error messages that it generates by itself. This behavior can be overridden by supplying a callback function that does something else with the messages. The callback function is passed the text of the error message (which includes a trailing newline), plus a void pointer that is the same one passed to `PQsetNoticeProcessor`. (This pointer can be used to access application-specific state if needed.) The default notice processor is simply

```
static void
defaultNoticeProcessor(void * arg, const char * message)
{
    fprintf(stderr, "%s", message);
}
```

To use a special notice processor, call `PQsetNoticeProcessor` just after creation of a new `PGconn` object.

The return value is the pointer to the previous notice processor. If you supply a callback function pointer of NULL, no action is taken, but the current pointer is returned.

Once you have set a notice processor, you should expect that that function could be called as long as either the `PGconn` object or `PGresult` objects made from it exist. At creation of a `PGresult`, the `PGconn`'s current notice processor pointer is copied into the `PGresult` for possible use by routines like `PQgetvalue`.

1.10. Environment Variables

The following environment variables can be used to select default connection parameter values, which will be used by `PQconnectdb`, `PQsetdbLogin` and `PQsetdb` if no value is directly specified by the calling code. These are useful to avoid hard-coding database connection information into simple client applications.

- PGHOST sets the default server name. If this begins with a slash, it specifies Unix-domain communication rather than TCP/IP communication; the value is the name of the directory in which the socket file is stored (default /tmp).
- PGPORT sets the default TCP port number or Unix-domain socket file extension for communicating with the PostgreSQL backend.
- PGDATABASE sets the default PostgreSQL database name.
- PGUSER sets the user name used to connect to the database and for authentication.
- PGPASSWORD sets the password used if the backend demands password authentication. This functionality is deprecated for security reasons; consider migrating to use the $HOME/.pgpass file.
- PGREALM sets the Kerberos realm to use with PostgreSQL, if it is different from the local realm. If PGREALM is set, PostgreSQL applications will attempt authentication with servers for this realm and use separate ticket files to avoid conflicts with local ticket files. This environment variable is only used if Kerberos authentication is selected by the backend.
- PGOPTIONS sets additional run-time options for the PostgreSQL backend.
- PGTTY sets the file or tty on which debugging messages from the backend server are displayed.
- PGREQUIRESSL sets whether or not the connection must be made over SSL. If set to “1”, libpq will refuse to connect if the server does not accept an SSL connection. This option is only available if PostgreSQL is compiled with SSL support.
- PGCONNECT_TIMEOUT sets the maximum number of seconds that libpq will wait when attempting to connect to the PostgreSQL server. This option should be set to at least 2 seconds.

The following environment variables can be used to specify user-level default behavior for every PostgreSQL session:

- PGDATESTYLE sets the default style of date/time representation.
- PGTZ sets the default time zone.
- PGCLIENTENCODING sets the default client encoding (if multibyte support was selected when configuring PostgreSQL).

The following environment variables can be used to specify default internal behavior for every PostgreSQL session:

- PGGEQO sets the default mode for the genetic optimizer.

Refer to the SET SQL command for information on correct values for these environment variables.

1.11. Files

The file `.pgpass` in the home directory is a file that can contain passwords to be used if the connection requires a password. This file should have the format:

```
hostname:port:database:username:password
```

Any of these may be a literal name, or `*`, which matches anything. The first matching entry will be used, so put more-specific entries first. When an entry contains `:` or `\`, it must be escaped with `\`.

The permissions on `.pgpass` must disallow any access to world or group; achieve this by the command `chmod 0600 .pgpass`. If the permissions are less strict than this, the file will be ignored.

1.12. Threading Behavior

`libpq` is thread-safe as of PostgreSQL 7.0, so long as no two threads attempt to manipulate the same `PGconn` object at the same time. In particular, you cannot issue concurrent queries from different threads through the same connection object. (If you need to run concurrent queries, start up multiple connections.)

`PGresult` objects are read-only after creation, and so can be passed around freely between threads.

The deprecated functions `PQoidStatus` and `fe_setauthsvc` are not thread-safe and should not be used in multithread programs. `PQoidStatus` can be replaced by `PQoidValue`. There is no good reason to call `fe_setauthsvc` at all.

`Libpq` clients using the `crypt` encryption method rely on the `crypt()` operating system function, which is often not thread-safe. It is better to use `MD5` encryption, which is thread-safe on all platforms.

1.13. Building Libpq Programs

To build (i.e., compile and link) your libpq programs you need to do all of the following things:

- Include the `libpq-fe.h` header file:

  ```
  #include <libpq-fe.h>
  ```

  If you failed to do that then you will normally get error messages from your compiler similar to

  ```
  foo.c: In function ‘main’:
  foo.c:34: ‘PGconn’ undeclared (first use in this function)
  foo.c:35: ‘PGresult’ undeclared (first use in this function)
  foo.c:54: ‘CONNECTION_BAD’ undeclared (first use in this function)
  foo.c:68: ‘PGRES_COMMAND_OK’ undeclared (first use in this function)
  foo.c:95: ‘PGRES_TUPLES_OK’ undeclared (first use in this function)
  ```

- Point your compiler to the directory where the PostgreSQL header files were installed, by supplying the `-Idirectory` option to your compiler. (In some cases the compiler will look into the directory in question by default, so you can omit this option.) For instance, your compile command line could look like:

  ```
  cc -c -I/usr/local/pgsql/include testprog.c
  ```

If you are using makefiles then add the option to the `CPPFLAGS` variable:

```
CPPFLAGS += -I/usr/local/pgsql/include
```

If there is any chance that your program might be compiled by other users then you should not hardcode the directory location like that. Instead, you can run the utility `pg_config` to find out where the header files are on the local system:

```
$ pg_config --includedir
/usr/local/include
```

Failure to specify the correct option to the compiler will result in an error message such as

```
testlibpq.c:8:22: libpq-fe.h: No such file or directory
```

- When linking the final program, specify the option `-lpq` so that the libpq library gets pulled in, as well as the option `-L`*`directory`* to point it to the directory where the libpq library resides. (Again, the compiler will search some directories by default.) For maximum portability, put the `-L` option before the `-lpq` option. For example:

  ```
  cc -o testprog testprog1.o testprog2.o -L/usr/local/pgsql/lib -lpq
  ```

  You can find out the library directory using `pg_config` as well:

  ```
  $ pg_config --libdir
  /usr/local/pgsql/lib
  ```

  Error messages that point to problems in this area could look like the following.

  ```
  testlibpq.o: In function ‘main’:
  testlibpq.o(.text+0x60): undefined reference to ‘PQsetdbLogin’
  testlibpq.o(.text+0x71): undefined reference to ‘PQstatus’
  testlibpq.o(.text+0xa4): undefined reference to ‘PQerrorMessage’
  ```

  This means you forgot `-lpq`.

  ```
  /usr/bin/ld: cannot find -lpq
  ```

  This means you forgot the `-L` or did not specify the right path.

If your codes references the header file `libpq-int.h` and you refuse to fix your code to not use it, starting in PostgreSQL 7.2, this file will be found in *`includedir`*`/postgresql/internal/libpq-int.h`, so you need to add the appropriate `-I` option to your compiler command line.

1.14. Example Programs

Example 1-1. libpq Example Program 1

```
/*
 * testlibpq.c
 *
 * Test the C version of libpq, the PostgreSQL frontend
 * library.
 */
#include <stdio.h>
#include <libpq-fe.h>

void
exit_nicely(PGconn *conn)
{
    PQfinish(conn);
    exit(1);
}

main()
{
    char       *pghost,
               *pgport,
               *pgoptions,
               *pgtty;
    char       *dbName;
    int         nFields;
    int         i,
                j;

    /* FILE *debug; */

    PGconn     *conn;
    PGresult   *res;

    /*
     * begin, by setting the parameters for a backend connection if the
     * parameters are null, then the system will try to use reasonable
     * defaults by looking up environment variables or, failing that,
     * using hardwired constants
     */
    pghost = NULL;              /* host name of the backend server */
    pgport = NULL;              /* port of the backend server */
    pgoptions = NULL;           /* special options to start up the backend
                                 * server */
    pgtty = NULL;               /* debugging tty for the backend server */
    dbName = "template1";

    /* make a connection to the database */
    conn = PQsetdb(pghost, pgport, pgoptions, pgtty, dbName);

    /*
```

```
 * check to see that the backend connection was successfully made
 */
if (PQstatus(conn) == CONNECTION_BAD)
{
    fprintf(stderr, "Connection to database ’%s’ failed.\n", dbName);
    fprintf(stderr, "%s", PQerrorMessage(conn));
    exit_nicely(conn);
}

/* debug = fopen("/tmp/trace.out","w"); */
/* PQtrace(conn, debug);  */

/* start a transaction block */
res = PQexec(conn, "BEGIN");
if (!res || PQresultStatus(res) != PGRES_COMMAND_OK)
{
    fprintf(stderr, "BEGIN command failed\n");
    PQclear(res);
    exit_nicely(conn);
}

/*
 * should PQclear PGresult whenever it is no longer needed to avoid
 * memory leaks
 */
PQclear(res);

/*
 * fetch rows from the pg_database, the system catalog of
 * databases
 */
res = PQexec(conn, "DECLARE mycursor CURSOR FOR SELECT * FROM pg_database");
if (!res || PQresultStatus(res) != PGRES_COMMAND_OK)
{
    fprintf(stderr, "DECLARE CURSOR command failed\n");
    PQclear(res);
    exit_nicely(conn);
}
PQclear(res);
res = PQexec(conn, "FETCH ALL in mycursor");
if (!res || PQresultStatus(res) != PGRES_TUPLES_OK)
{
    fprintf(stderr, "FETCH ALL command didn’t return tuples properly\n");
    PQclear(res);
    exit_nicely(conn);
}

/* first, print out the attribute names */
nFields = PQnfields(res);
for (i = 0; i < nFields; i++)
    printf("%-15s", PQfname(res, i));
printf("\n\n");
```

```
    /* next, print out the rows */
    for (i = 0; i < PQntuples(res); i++)
    {
        for (j = 0; j < nFields; j++)
            printf("%-15s", PQgetvalue(res, i, j));
        printf("\n");
    }
    PQclear(res);

    /* close the cursor */
    res = PQexec(conn, "CLOSE mycursor");
    PQclear(res);

    /* commit the transaction */
    res = PQexec(conn, "COMMIT");
    PQclear(res);

    /* close the connection to the database and cleanup */
    PQfinish(conn);

    /* fclose(debug); */
    return 0;

}
```

Example 1-2. libpq Example Program 2

```
/*
 * testlibpq2.c
 *  Test of the asynchronous notification interface
 *
 * Start this program, then from psql in another window do
 *   NOTIFY TBL2;
 *
 * Or, if you want to get fancy, try this:
 * Populate a database with the following:
 *
 *   CREATE TABLE TBL1 (i int4);
 *
 *   CREATE TABLE TBL2 (i int4);
 *
 *   CREATE RULE r1 AS ON INSERT TO TBL1 DO
 *     (INSERT INTO TBL2 values (new.i); NOTIFY TBL2);
 *
 * and do
 *
 *   INSERT INTO TBL1 values (10);
 *
 */
#include <stdio.h>
#include "libpq-fe.h"
```

```
void
exit_nicely(PGconn *conn)
{
    PQfinish(conn);
    exit(1);
}

main()
{
    char       *pghost,
               *pgport,
               *pgoptions,
               *pgtty;
    char       *dbName;
    int         nFields;
    int         i,
                j;

    PGconn     *conn;
    PGresult   *res;
    PGnotify   *notify;

    /*
     * begin, by setting the parameters for a backend connection if the
     * parameters are null, then the system will try to use reasonable
     * defaults by looking up environment variables or, failing that,
     * using hardwired constants
     */
    pghost = NULL;              /* host name of the backend server */
    pgport = NULL;              /* port of the backend server */
    pgoptions = NULL;           /* special options to start up the backend
                                 * server */
    pgtty = NULL;               /* debugging tty for the backend server */
    dbName = getenv("USER");    /* change this to the name of your test
                                 * database */

    /* make a connection to the database */
    conn = PQsetdb(pghost, pgport, pgoptions, pgtty, dbName);

    /*
     * check to see that the backend connection was successfully made
     */
    if (PQstatus(conn) == CONNECTION_BAD)
    {
        fprintf(stderr, "Connection to database ’%s’ failed.\n", dbName);
        fprintf(stderr, "%s", PQerrorMessage(conn));
        exit_nicely(conn);
    }

    res = PQexec(conn, "LISTEN TBL2");
    if (!res || PQresultStatus(res) != PGRES_COMMAND_OK)
    {
        fprintf(stderr, "LISTEN command failed\n");
```

```
            PQclear(res);
            exit_nicely(conn);
        }

        /*
         * should PQclear PGresult whenever it is no longer needed to avoid
         * memory leaks
         */
        PQclear(res);

        while (1)
        {

            /*
             * wait a little bit between checks; waiting with select()
             * would be more efficient.
             */
            sleep(1);
            /* collect any asynchronous backend messages */
            PQconsumeInput(conn);
            /* check for asynchronous notify messages */
            while ((notify = PQnotifies(conn)) != NULL)
            {
                fprintf(stderr,
                     "ASYNC NOTIFY of ’%s’ from backend pid ’%d’ received\n",
                        notify->relname, notify->be_pid);
                free(notify);
            }
        }

        /* close the connection to the database and cleanup */
        PQfinish(conn);

        return 0;
    }
```

Example 1-3. libpq Example Program 3

```
    /*
     * testlibpq3.c Test the C version of Libpq, the PostgreSQL frontend
     * library. tests the binary cursor interface
     *
     *
     *
     * populate a database by doing the following:
     *
     * CREATE TABLE test1 (i int4, d real, p polygon);
     *
     * INSERT INTO test1 values (1, 3.567, polygon ’(3.0, 4.0, 1.0, 2.0)’);
     *
     * INSERT INTO test1 values (2, 89.05, polygon ’(4.0, 3.0, 2.0, 1.0)’);
     *
```

```
 * the expected output is:
 *
 * tuple 0: got i = (4 bytes) 1, d = (4 bytes) 3.567000, p = (4
 * bytes) 2 points   boundbox = (hi=3.000000/4.000000, lo =
 * 1.000000,2.000000) tuple 1: got i = (4 bytes) 2, d = (4 bytes)
 * 89.050003, p = (4 bytes) 2 points   boundbox =
 * (hi=4.000000/3.000000, lo = 2.000000,1.000000)
 *
 *
 */
#include <stdio.h>
#include "libpq-fe.h"
#include "utils/geo_decls.h"    /* for the POLYGON type */

void
exit_nicely(PGconn *conn)
{
    PQfinish(conn);
    exit(1);
}

main()
{
    char       *pghost,
               *pgport,
               *pgoptions,
               *pgtty;
    char       *dbName;
    int         nFields;
    int         i,
                j;
    int         i_fnum,
                d_fnum,
                p_fnum;
    PGconn     *conn;
    PGresult   *res;

    /*
     * begin, by setting the parameters for a backend connection if the
     * parameters are null, then the system will try to use reasonable
     * defaults by looking up environment variables or, failing that,
     * using hardwired constants
     */
    pghost = NULL;              /* host name of the backend server */
    pgport = NULL;              /* port of the backend server */
    pgoptions = NULL;           /* special options to start up the backend
                                 * server */
    pgtty = NULL;               /* debugging tty for the backend server */

    dbName = getenv("USER");    /* change this to the name of your test
                                 * database */

    /* make a connection to the database */
```

```
conn = PQsetdb(pghost, pgport, pgoptions, pgtty, dbName);

/*
 * check to see that the backend connection was successfully made
 */
if (PQstatus(conn) == CONNECTION_BAD)
{
    fprintf(stderr, "Connection to database ’%s’ failed.\n", dbName);
    fprintf(stderr, "%s", PQerrorMessage(conn));
    exit_nicely(conn);
}

/* start a transaction block */
res = PQexec(conn, "BEGIN");
if (!res || PQresultStatus(res) != PGRES_COMMAND_OK)
{
    fprintf(stderr, "BEGIN command failed\n");
    PQclear(res);
    exit_nicely(conn);
}

/*
 * should PQclear PGresult whenever it is no longer needed to avoid
 * memory leaks
 */
PQclear(res);

/*
 * fetch rows from the pg_database, the system catalog of
 * databases
 */
res = PQexec(conn, "DECLARE mycursor BINARY CURSOR FOR SELECT * FROM test1");
if (!res || PQresultStatus(res) != PGRES_COMMAND_OK)
{
    fprintf(stderr, "DECLARE CURSOR command failed\n");
    PQclear(res);
    exit_nicely(conn);
}
PQclear(res);

res = PQexec(conn, "FETCH ALL in mycursor");
if (!res || PQresultStatus(res) != PGRES_TUPLES_OK)
{
    fprintf(stderr, "FETCH ALL command didn’t return tuples properly\n");
    PQclear(res);
    exit_nicely(conn);
}

i_fnum = PQfnumber(res, "i");
d_fnum = PQfnumber(res, "d");
p_fnum = PQfnumber(res, "p");

for (i = 0; i < 3; i++)
```

```
    {
        printf("type[%d] = %d, size[%d] = %d\n",
               i, PQftype(res, i),
               i, PQfsize(res, i));
    }
    for (i = 0; i < PQntuples(res); i++)
    {
        int         *ival;
        float       *dval;
        int          plen;
        POLYGON     *pval;

        /* we hard-wire this to the 3 fields we know about */
        ival = (int *) PQgetvalue(res, i, i_fnum);
        dval = (float *) PQgetvalue(res, i, d_fnum);
        plen = PQgetlength(res, i, p_fnum);

        /*
         * plen doesn't include the length field so need to
         * increment by VARHDSZ
         */
        pval = (POLYGON *) malloc(plen + VARHDRSZ);
        pval->size = plen;
        memmove((char *) &pval->npts, PQgetvalue(res, i, p_fnum), plen);
        printf("tuple %d: got\n", i);
        printf(" i = (%d bytes) %d,\n",
               PQgetlength(res, i, i_fnum), *ival);
        printf(" d = (%d bytes) %f,\n",
               PQgetlength(res, i, d_fnum), *dval);
        printf(" p = (%d bytes) %d points \tboundbox = (hi=%f/%f, lo = %f,%f)\n",
               PQgetlength(res, i, d_fnum),
               pval->npts,
               pval->boundbox.xh,
               pval->boundbox.yh,
               pval->boundbox.xl,
               pval->boundbox.yl);
    }
    PQclear(res);

    /* close the cursor */
    res = PQexec(conn, "CLOSE mycursor");
    PQclear(res);

    /* commit the transaction */
    res = PQexec(conn, "COMMIT");
    PQclear(res);

    /* close the connection to the database and cleanup */
    PQfinish(conn);

    return 0;
}
```

Chapter 2. Large Objects

2.1. Introduction

In PostgreSQL releases prior to 7.1, the size of any row in the database could not exceed the size of a data page. Since the size of a data page is 8192 bytes (the default, which can be raised up to 32768), the upper limit on the size of a data value was relatively low. To support the storage of larger atomic values, PostgreSQL provided and continues to provide a large object interface. This interface provides file-oriented access to user data that has been declared to be a large object.

POSTGRES 4.2, the indirect predecessor of PostgreSQL, supported three standard implementations of large objects: as files external to the POSTGRES server, as external files managed by the POSTGRES server, and as data stored within the POSTGRES database. This caused considerable confusion among users. As a result, only support for large objects as data stored within the database is retained in PostgreSQL. Even though this is slower to access, it provides stricter data integrity. For historical reasons, this storage scheme is referred to as *Inversion large objects*. (You will see the term Inversion used occasionally to mean the same thing as large object.) Since PostgreSQL 7.1, all large objects are placed in one system table called `pg_largeobject`.

PostgreSQL 7.1 introduced a mechanism (nicknamed "TOAST") that allows data rows to be much larger than individual data pages. This makes the large object interface partially obsolete. One remaining advantage of the large object interface is that it allows random access to the data, i.e., the ability to read or write small chunks of a large value. It is planned to equip TOAST with such functionality in the future.

This section describes the implementation and the programming and query language interfaces to PostgreSQL large object data. We use the libpq C library for the examples in this section, but most programming interfaces native to PostgreSQL support equivalent functionality. Other interfaces may use the large object interface internally to provide generic support for large values. This is not described here.

2.2. Implementation Features

The large object implementation breaks large objects up into "chunks" and stores the chunks in tuples in the database. A B-tree index guarantees fast searches for the correct chunk number when doing random access reads and writes.

2.3. Interfaces

The facilities PostgreSQL provides to access large objects, both in the backend as part of user-defined functions or the front end as part of an application using the interface, are described below. For users familiar with POSTGRES 4.2, PostgreSQL has a new set of functions providing a more coherent interface.

Note: All large object manipulation *must* take place within an SQL transaction. This requirement is strictly enforced as of PostgreSQL 6.5, though it has been an implicit requirement in previous versions, resulting in misbehavior if ignored.

The PostgreSQL large object interface is modeled after the Unix file-system interface, with analogues of `open(2)`, `read(2)`, `write(2)`, `lseek(2)`, etc. User functions call these routines to retrieve only the data of interest from a large object. For example, if a large object type called `mugshot` existed that stored photographs of faces, then a function called `beard` could be declared on `mugshot` data. `beard` could look at the lower third of a photograph, and determine the color of the beard that appeared there, if any. The entire large-object value need not be buffered, or even examined, by the `beard` function. Large objects may be accessed from dynamically-loaded C functions or database client programs that link the library. PostgreSQL provides a set of routines that support opening, reading, writing, closing, and seeking on large objects.

2.3.1. Creating a Large Object

The routine

```
Oid lo_creat(PGconn *conn, int mode)
```

creates a new large object. *mode* is a bit mask describing several different attributes of the new object. The symbolic constants listed here are defined in the header file `libpq/libpq-fs.h`. The access type (read, write, or both) is controlled by or'ing together the bits `INV_READ` and `INV_WRITE`. The low-order sixteen bits of the mask have historically been used at Berkeley to designate the storage manager number on which the large object should reside. These bits should always be zero now. The commands below create a large object:

```
inv_oid = lo_creat(INV_READ|INV_WRITE);
```

2.3.2. Importing a Large Object

To import an operating system file as a large object, call

```
Oid lo_import(PGconn *conn, const char *filename)
```

filename specifies the operating system name of the file to be imported as a large object.

2.3.3. Exporting a Large Object

To export a large object into an operating system file, call

```
int lo_export(PGconn *conn, Oid lobjId, const char *filename)
```

The *lobjId* argument specifies the OID of the large object to export and the *filename* argument specifies the operating system name name of the file.

2.3.4. Opening an Existing Large Object

To open an existing large object, call

```
int lo_open(PGconn *conn, Oid lobjId, int mode)
```

The *lobjId* argument specifies the OID of the large object to open. The *mode* bits control whether the object is opened for reading (`INV_READ`), writing (`INV_WRITE`), or both. A large object cannot be opened before it is created. `lo_open` returns a large object descriptor for later use in `lo_read`, `lo_write`, `lo_lseek`, `lo_tell`, and `lo_close`.

2.3.5. Writing Data to a Large Object

The routine

```
int lo_write(PGconn *conn, int fd, const char *buf, size_t len)
```

writes *len* bytes from *buf* to large object *fd*. The *fd* argument must have been returned by a previous `lo_open`. The number of bytes actually written is returned. In the event of an error, the return value is negative.

2.3.6. Reading Data from a Large Object

The routine

```
int lo_read(PGconn *conn, int fd, char *buf, size_t len)
```

reads *len* bytes from large object *fd* into *buf*. The *fd* argument must have been returned by a previous `lo_open`. The number of bytes actually read is returned. In the event of an error, the return value is negative.

2.3.7. Seeking on a Large Object

To change the current read or write location on a large object, call

```
int lo_lseek(PGconn *conn, int fd, int offset, int whence)
```

This routine moves the current location pointer for the large object described by *fd* to the new location specified by *offset*. The valid values for *whence* are `SEEK_SET`, `SEEK_CUR`, and `SEEK_END`.

2.3.8. Closing a Large Object Descriptor

A large object may be closed by calling

```
int lo_close(PGconn *conn, int fd)
```

where *fd* is a large object descriptor returned by `lo_open`. On success, `lo_close` returns zero. On error, the return value is negative.

2.3.9. Removing a Large Object

To remove a large object from the database, call

```
int lo_unlink(PGconn *conn, Oid lobjId)
```

The *lobjId* argument specifies the OID of the large object to remove. In the event of an error, the return value is negative.

2.4. Server-side Built-in Functions

There are two built-in registered functions, `lo_import` and `lo_export` which are convenient for use in SQL queries. Here is an example of their use

```
CREATE TABLE image (
    name            text,
    raster          oid
);

INSERT INTO image (name, raster)
    VALUES ('beautiful image', lo_import('/etc/motd'));

SELECT lo_export(image.raster, '/tmp/motd') FROM image
    WHERE name = 'beautiful image';
```

2.5. Accessing Large Objects from Libpq

Example 2-1 is a sample program which shows how the large object interface in libpq can be used. Parts of the program are commented out but are left in the source for the reader's benefit. This program can be found in `src/test/examples/testlo.c` in the source distribution. Frontend applications which use the large object interface in libpq should include the header file `libpq/libpq-fs.h` and link with the libpq library.

Example 2-1. Large Objects with Libpq Example Program

```
/*-------------------------------------------------------------
 *
 * testlo.c--
 *    test using large objects with libpq
 *
 * Copyright (c) 1994, Regents of the University of California
 *
 *-------------------------------------------------------------
 */
#include <stdio.h>
#include "libpq-fe.h"
#include "libpq/libpq-fs.h"
```

```
#define BUFSIZE          1024

/*
 * importFile
 *    import file "in_filename" into database as large object "lobjOid"
 *
 */
Oid
importFile(PGconn *conn, char *filename)
{
    Oid         lobjId;
    int         lobj_fd;
    char        buf[BUFSIZE];
    int         nbytes,
                tmp;
    int         fd;

    /*
     * open the file to be read in
     */
    fd = open(filename, O_RDONLY, 0666);
    if (fd < 0)
    {                           /* error */
        fprintf(stderr, "can’t open unix file %s\n", filename);
    }

    /*
     * create the large object
     */
    lobjId = lo_creat(conn, INV_READ | INV_WRITE);
    if (lobjId == 0)
        fprintf(stderr, "can’t create large object\n");

    lobj_fd = lo_open(conn, lobjId, INV_WRITE);

    /*
     * read in from the Unix file and write to the inversion file
     */
    while ((nbytes = read(fd, buf, BUFSIZE)) > 0)
    {
        tmp = lo_write(conn, lobj_fd, buf, nbytes);
        if (tmp < nbytes)
            fprintf(stderr, "error while reading large object\n");
    }

    (void) close(fd);
    (void) lo_close(conn, lobj_fd);

    return lobjId;
}

void
```

```
pickout(PGconn *conn, Oid lobjId, int start, int len)
{
    int         lobj_fd;
    char       *buf;
    int         nbytes;
    int         nread;

    lobj_fd = lo_open(conn, lobjId, INV_READ);
    if (lobj_fd < 0)
    {
        fprintf(stderr, "can't open large object %d\n",
                lobjId);
    }

    lo_lseek(conn, lobj_fd, start, SEEK_SET);
    buf = malloc(len + 1);

    nread = 0;
    while (len - nread > 0)
    {
        nbytes = lo_read(conn, lobj_fd, buf, len - nread);
        buf[nbytes] = ' ';
        fprintf(stderr, ">>> %s", buf);
        nread += nbytes;
    }
    free(buf);
    fprintf(stderr, "\n");
    lo_close(conn, lobj_fd);
}

void
overwrite(PGconn *conn, Oid lobjId, int start, int len)
{
    int         lobj_fd;
    char       *buf;
    int         nbytes;
    int         nwritten;
    int         i;

    lobj_fd = lo_open(conn, lobjId, INV_READ);
    if (lobj_fd < 0)
    {
        fprintf(stderr, "can't open large object %d\n",
                lobjId);
    }

    lo_lseek(conn, lobj_fd, start, SEEK_SET);
    buf = malloc(len + 1);

    for (i = 0; i < len; i++)
        buf[i] = 'X';
    buf[i] = ' ';
```

```
    nwritten = 0;
    while (len - nwritten > 0)
    {
        nbytes = lo_write(conn, lobj_fd, buf + nwritten, len - nwritten);
        nwritten += nbytes;
    }
    free(buf);
    fprintf(stderr, "\n");
    lo_close(conn, lobj_fd);
}

/*
 * exportFile *    export large object "lobjOid" to file "out_filename"
 *
 */
void
exportFile(PGconn *conn, Oid lobjId, char *filename)
{
    int         lobj_fd;
    char        buf[BUFSIZE];
    int         nbytes,
                tmp;
    int         fd;

    /*
     * create an inversion "object"
     */
    lobj_fd = lo_open(conn, lobjId, INV_READ);
    if (lobj_fd < 0)
    {
        fprintf(stderr, "can't open large object %d\n",
                lobjId);
    }

    /*
     * open the file to be written to
     */
    fd = open(filename, O_CREAT | O_WRONLY, 0666);
    if (fd < 0)
    {                           /* error */
        fprintf(stderr, "can't open unix file %s\n",
                filename);
    }

    /*
     * read in from the Unix file and write to the inversion file
     */
    while ((nbytes = lo_read(conn, lobj_fd, buf, BUFSIZE)) > 0)
    {
        tmp = write(fd, buf, nbytes);
        if (tmp < nbytes)
        {
            fprintf(stderr, "error while writing %s\n",
```

```
                    filename);
            }
        }

        (void) lo_close(conn, lobj_fd);
        (void) close(fd);

        return;
}

void
exit_nicely(PGconn *conn)
{
        PQfinish(conn);
        exit(1);
}

int
main(int argc, char **argv)
{
        char       *in_filename,
                   *out_filename;
        char       *database;
        Oid         lobjOid;
        PGconn     *conn;
        PGresult   *res;

        if (argc != 4)
        {
            fprintf(stderr, "Usage: %s database_name in_filename out_filename\n",
                    argv[0]);
            exit(1);
        }

        database = argv[1];
        in_filename = argv[2];
        out_filename = argv[3];

        /*
         * set up the connection
         */
        conn = PQsetdb(NULL, NULL, NULL, NULL, database);

        /* check to see that the backend connection was successfully made */
        if (PQstatus(conn) == CONNECTION_BAD)
        {
            fprintf(stderr, "Connection to database ’%s’ failed.\n", database);
            fprintf(stderr, "%s", PQerrorMessage(conn));
            exit_nicely(conn);
        }

        res = PQexec(conn, "begin");
        PQclear(res);
```

```
    printf("importing file %s\n", in_filename);
/*  lobjOid = importFile(conn, in_filename); */
    lobjOid = lo_import(conn, in_filename);
/*
    printf("as large object %d.\n", lobjOid);

    printf("picking out bytes 1000-2000 of the large object\n");
    pickout(conn, lobjOid, 1000, 1000);

    printf("overwriting bytes 1000-2000 of the large object with X’s\n");
    overwrite(conn, lobjOid, 1000, 1000);
*/

    printf("exporting large object to file %s\n", out_filename);
/*    exportFile(conn, lobjOid, out_filename); */
    lo_export(conn, lobjOid, out_filename);

    res = PQexec(conn, "end");
    PQclear(res);
    PQfinish(conn);
    exit(0);
}
```

Chapter 3. pgtcl - Tcl Binding Library

3.1. Introduction

pgtcl is a Tcl package for client programs to interface with PostgreSQL servers. It makes most of the functionality of libpq available to Tcl scripts.

This package was originally written by Jolly Chen.

Table 3-1 gives an overview over the commands available in pgtcl. These commands are described further on subsequent pages.

Table 3-1. `pgtcl` Commands

Command	Description
`pg_connect`	opens a connection to the backend server
`pg_disconnect`	closes a connection
`pg_conndefaults`	get connection options and their defaults
`pg_exec`	send a query to the backend
`pg_result`	manipulate the results of a query
`pg_select`	loop over the result of a SELECT statement
`pg_execute`	send a query and optionally loop over the results
`pg_listen`	establish a callback for NOTIFY messages
`pg_on_connection_loss`	establish a callback for unexpected connection loss
`pg_lo_creat`	create a large object
`pg_lo_open`	open a large object
`pg_lo_close`	close a large object
`pg_lo_read`	read a large object
`pg_lo_write`	write a large object
`pg_lo_lseek`	seek to a position in a large object
`pg_lo_tell`	return the current seek position of a large object
`pg_lo_unlink`	delete a large object
`pg_lo_import`	import a Unix file into a large object
`pg_lo_export`	export a large object into a Unix file

The `pg_lo_*` routines are interfaces to the large object features of PostgreSQL. The functions are designed to mimic the analogous file system functions in the standard Unix file system interface. The `pg_lo_*` routines should be used within a `BEGIN`/`COMMIT` transaction block because the file descriptor returned by `pg_lo_open` is only valid for the current transaction. `pg_lo_import` and `pg_lo_export` *must* be used in a `BEGIN`/`COMMIT` transaction block.

Example 3-1 shows a small example of how to use the routines.

Example 3-1. pgtcl Example Program

```
# getDBs :
#   get the names of all the databases at a given host and port number
#   with the defaults being the localhost and port 5432
#   return them in alphabetical order
proc getDBs { {host "localhost"} {port "5432"} } {
    # datnames is the list to be result
    set conn [pg_connect template1 -host $host -port $port]
    set res [pg_exec $conn "SELECT datname FROM pg_database ORDER BY datname"]
    set ntups [pg_result $res -numTuples]
    for {set i 0} {$i < $ntups} {incr i} {
 lappend datnames [pg_result $res -getTuple $i]
    }
    pg_result $res -clear
    pg_disconnect $conn
    return $datnames
}
```

3.2. Loading pgtcl into your application

Before using pgtcl commands, you must load `libpgtcl` into your Tcl application. This is normally done with the Tcl `load` command. Here is an example:

```
load libpgtcl[info sharedlibextension]
```

The use of `info sharedlibextension` is recommended in preference to hard-wiring `.so` or `.sl` into the program.

The `load` command will fail unless the system's dynamic loader knows where to look for the `libpgtcl` shared library file. You may need to work with `ldconfig`, or set the environment variable `LD_LIBRARY_PATH`, or use some equivalent facility for your platform to make it work. Refer to the PostgreSQL installation instructions for more information.

`libpgtcl` in turn depends on `libpq`, so the dynamic loader must also be able to find the `libpq` shared library. In practice this is seldom an issue, since both of these shared libraries are normally stored in the same directory, but it can be a stumbling block in some configurations.

If you use a custom executable for your application, you might choose to statically bind `libpgtcl` into the executable and thereby avoid the `load` command and the potential problems of dynamic linking. See the source code for pgtclsh for an example.

3.3. pgtcl Command Reference Information

pg_connect

Name

`pg_connect` — open a connection to the backend server

Synopsis

```
pg_connect -conninfo connectOptions
pg_connect dbName [-host hostName]
  [-port portNumber] [-tty pqtty]
  [-options optionalBackendArgs]
```

Inputs (new style)

connectOptions

A string of connection options, each written in the form keyword = value. A list of valid options can be found in `libpq`'s `PQconnectdb()` manual entry.

Inputs (old style)

dbName

Specifies a valid database name.

[-host *hostName*]

Specifies the domain name of the backend server for *dbName*.

[-port *portNumber*]

Specifies the IP port number of the backend server for *dbName*.

[-tty *pqtty*]

Specifies file or tty for optional debug output from backend.

[-options *optionalBackendArgs*]

Specifies options for the backend server for *dbName*.

Outputs

dbHandle

If successful, a handle for a database connection is returned. Handles start with the prefix `pgsql`.

Description

`pg_connect` opens a connection to the PostgreSQL backend.

Two syntaxes are available. In the older one, each possible option has a separate option switch in the pg_connect statement. In the newer form, a single option string is supplied that can contain multiple option values. See `pg_conndefaults` for info about the available options in the newer syntax.

Usage

pg_disconnect

Name

`pg_disconnect` — close a connection to the backend server

Synopsis

```
pg_disconnect dbHandle
```

Inputs

dbHandle

Specifies a valid database handle.

Outputs

None

Description

`pg_disconnect` closes a connection to the PostgreSQL backend.

pg_conndefaults

Name

`pg_conndefaults` — obtain information about default connection parameters

Synopsis

```
pg_conndefaults
```

Inputs

None.

Outputs

`option list`

The result is a list describing the possible connection options and their current default values. Each entry in the list is a sublist of the format:

```
{optname label dispchar dispsize value}
```

where the *`optname`* is usable as an option in `pg_connect -conninfo`.

Description

`pg_conndefaults` returns info about the connection options available in `pg_connect -conninfo` and the current default value for each option.

Usage

`pg_conndefaults`

pg_exec

Name

`pg_exec` — send a command string to the server

Synopsis

```
pg_exec dbHandle queryString
```

Inputs

dbHandle

Specifies a valid database handle.

queryString

Specifies a valid SQL query.

Outputs

resultHandle

A Tcl error will be returned if pgtcl was unable to obtain a backend response. Otherwise, a query result object is created and a handle for it is returned. This handle can be passed to `pg_result` to obtain the results of the query.

Description

`pg_exec` submits a query to the PostgreSQL backend and returns a result. Query result handles start with the connection handle and add a period and a result number.

Note that lack of a Tcl error is not proof that the query succeeded! An error message returned by the backend will be processed as a query result with failure status, not by generating a Tcl error in pg_exec.

pg_result

Name

`pg_result` — get information about a query result

Synopsis

```
pg_result resultHandle resultOption
```

Inputs

`resultHandle`

The handle for a query result.

`resultOption`

Specifies one of several possible options.

Options

`-status`

the status of the result.

`-error`

the error message, if the status indicates error; otherwise an empty string.

`-conn`

the connection that produced the result.

`-oid`

if the command was an INSERT, the OID of the inserted tuple; otherwise 0.

`-numTuples`

the number of tuples returned by the query.

`-numAttrs`

the number of attributes in each tuple.

`-assign arrayName`

assign the results to an array, using subscripts of the form `(tupno,attributeName)`.

`-assignbyidx arrayName ?appendstr?`

assign the results to an array using the first attribute's value and the remaining attributes' names as keys. If *`appendstr`* is given then it is appended to each key. In short, all but the first field of each tuple are stored into the array, using subscripts of the form `(firstFieldValue,fieldNameAppendStr)`.

`-getTuple tupleNumber`

returns the fields of the indicated tuple in a list. Tuple numbers start at zero.

`-tupleArray tupleNumber arrayName`

stores the fields of the tuple in array *`arrayName`*, indexed by field names. Tuple numbers start at zero.

`-attributes`

returns a list of the names of the tuple attributes.

`-lAttributes`

returns a list of sublists, `{name ftype fsize}` for each tuple attribute.

`-clear`

clear the result query object.

Outputs

The result depends on the selected option, as described above.

Description

`pg_result` returns information about a query result created by a prior `pg_exec`.

You can keep a query result around for as long as you need it, but when you are done with it, be sure to free it by executing `pg_result -clear`. Otherwise, you have a memory leak, and Pgtcl will eventually start complaining that you've created too many query result objects.

pg_select

Name

`pg_select` — loop over the result of a SELECT statement

Synopsis

```
pg_select dbHandle queryString arrayVar queryProcedure
```

Inputs

dbHandle

Specifies a valid database handle.

queryString

Specifies a valid SQL select query.

arrayVar

Array variable for tuples returned.

queryProcedure

Procedure run on each tuple found.

Outputs

None.

Description

`pg_select` submits a SELECT query to the PostgreSQL backend, and executes a given chunk of code for each tuple in the result. The *queryString* must be a SELECT statement. Anything else returns an error. The *arrayVar* variable is an array name used in the loop. For each tuple, *arrayVar* is filled in with the tuple field values, using the field names as the array indexes. Then the *queryProcedure* is executed.

In addition to the field values, the following special entries are made in the array:

`.headers`

A list of the column names returned by the SELECT.

`.numcols`

The number of columns returned by the SELECT.

`.tupno`

The current tuple number, starting at zero and incrementing for each iteration of the loop body.

Usage

This would work if table `table` has fields `control` and `name` (and, perhaps, other fields):

```
pg_select $pgconn "SELECT * FROM table" array {
 puts [format "%5d %s" $array(control) $array(name)]
}
```

pg_execute

Name

`pg_execute` — send a query and optionally loop over the results

Synopsis

```
pg_execute [-array arrayVar] [-oid oidVar] dbHandle queryString [queryProcedure]
```

Inputs

[-array *arrayVar*]

Specifies the name of an array variable where result tuples are stored, indexed by the field names. This is ignored if *queryString* is not a SELECT statement. For SELECT statements, if this option is not used, result tuples values are stored in individual variables named according to the field names in the result.

[-oid *oidVar*]

Specifies the name of a variable into which the OID from an INSERT statement will be stored.

dbHandle

Specifies a valid database handle.

queryString

Specifies a valid SQL query.

[*queryProcedure*]

Optional command to execute for each result tuple of a SELECT statement.

Outputs

ntuples

The number of tuples affected or returned by the query.

Description

`pg_execute` submits a query to the PostgreSQL backend.

If the query is not a SELECT statement, the query is executed and the number of tuples affected by the query is returned. If the query is an INSERT and a single tuple is inserted, the OID of the inserted tuple is stored in the *oidVar* variable if the optional *-oid* argument is supplied.

If the query is a SELECT statement, the query is executed. For each tuple in the result, the tuple field values are stored in the *arrayVar* variable, if supplied, using the field names as the array indexes, else in variables named by the field names, and then the optional *queryProcedure* is executed if supplied. (Omitting the *queryProcedure* probably makes sense only if the query will return a single tuple.) The number of tuples selected is returned.

The *queryProcedure* can use the Tcl `break`, `continue`, and `return` commands, with the expected behavior. Note that if the *queryProcedure* executes `return`, `pg_execute` does not return *ntuples*.

`pg_execute` is a newer function which provides a superset of the features of `pg_select`, and can replace `pg_exec` in many cases where access to the result handle is not needed.

For backend-handled errors, `pg_execute` will throw a Tcl error and return two element list. The first element is an error code such as `PGRES_FATAL_ERROR`, and the second element is the backend error text. For more serious errors, such as failure to communicate with the backend, `pg_execute` will throw a Tcl error and return just the error message text.

Usage

In the following examples, error checking with `catch` has been omitted for clarity.

Insert a row and save the OID in `result_oid`:

```
pg_execute -oid result_oid $pgconn "insert into mytable values (1)"
```

Print the item and value fields from each row:

```
pg_execute -array d $pgconn "select item, value from mytable" {
   puts "Item=$d(item) Value=$d(value)"
}
```

Find the maximum and minimum values and store them in $s(max) and $s(min):

```
pg_execute -array s $pgconn "select max(value) as max,\
  min(value) as min from mytable"
```

Find the maximum and minimum values and store them in $max and $min:

```
pg_execute $pgconn "select max(value) as max, min(value) as min from mytable"
```

pg_listen

Name

`pg_listen` — set or change a callback for asynchronous NOTIFY messages

Synopsis

```
pg_listen dbHandle notifyName callbackCommand
```

Inputs

dbHandle

Specifies a valid database handle.

notifyName

Specifies the notify condition name to start or stop listening to.

callbackCommand

If present, provides the command string to execute when a matching notification arrives.

Outputs

None

Description

`pg_listen` creates, changes, or cancels a request to listen for asynchronous NOTIFY messages from the PostgreSQL backend. With a *callbackCommand* parameter, the request is established, or the command string of an already existing request is replaced. With no *callbackCommand* parameter, a prior request is canceled.

After a `pg_listen` request is established, the specified command string is executed whenever a NOTIFY message bearing the given name arrives from the backend. This occurs when any PostgreSQL client application issues a NOTIFY command referencing that name. (Note that the name can be, but does not have to be, that of an existing relation in the database.) The command string is executed from the Tcl idle loop. That is the normal idle state of an application written with Tk. In non-Tk Tcl shells, you can execute `update` or `vwait` to cause the idle loop to be entered.

You should not invoke the SQL statements `LISTEN` or `UNLISTEN` directly when using `pg_listen`. Pgtcl takes care of issuing those statements for you. But if you want to send a NOTIFY message yourself, invoke the SQL NOTIFY statement using `pg_exec`.

pg_on_connection_loss

Name

`pg_on_connection_loss` — set or change a callback for unexpected connection loss

Synopsis

```
pg_on_connection_loss dbHandle callbackCommand
```

Inputs

dbHandle

Specifies a valid database handle.

callbackCommand

If present, provides the command string to execute when connection loss is detected.

Outputs

None

Description

`pg_on_connection_loss` creates, changes, or cancels a request to execute a callback command if an unexpected loss of connection to the database occurs. With a *callbackCommand* parameter, the request is established, or the command string of an already existing request is replaced. With no *callbackCommand* parameter, a prior request is canceled.

The callback command string is executed from the Tcl idle loop. That is the normal idle state of an application written with Tk. In non-Tk Tcl shells, you can execute `update` or `vwait` to cause the idle loop to be entered.

pg_lo_creat

Name

`pg_lo_creat` — create a large object

Synopsis

```
pg_lo_creat conn mode
```

Inputs

`conn`

Specifies a valid database connection.

`mode`

Specifies the access mode for the large object

Outputs

`objOid`

The OID of the large object created.

Description

`pg_lo_creat` creates an Inversion Large Object.

Usage

mode can be any or'ing together of `INV_READ` and `INV_WRITE`. The "or" operator is `|`.

```
[pg_lo_creat $conn "INV_READ|INV_WRITE"]
```

pg_lo_open

Name

`pg_lo_open` — open a large object

Synopsis

```
pg_lo_open conn objOid mode
```

Inputs

conn

Specifies a valid database connection.

objOid

Specifies a valid large object OID.

mode

Specifies the access mode for the large object

Outputs

fd

A file descriptor for use in later pg_lo* routines.

Description

`pg_lo_open` open an Inversion Large Object.

Usage

Mode can be either `r`, `w`, or `rw`.

pg_lo_close

Name

`pg_lo_close` — close a large object

Synopsis

```
pg_lo_close conn fd
```

Inputs

conn

Specifies a valid database connection.

fd

A file descriptor for use in later pg_lo* routines.

Outputs

None

Description

`pg_lo_close` closes an Inversion Large Object.

Usage

pg_lo_read

Name

`pg_lo_read` — read a large object

Synopsis

```
pg_lo_read conn fd bufVar len
```

Inputs

conn

Specifies a valid database connection.

fd

File descriptor for the large object from pg_lo_open.

bufVar

Specifies a valid buffer variable to contain the large object segment.

len

Specifies the maximum allowable size of the large object segment.

Outputs

None

Description

`pg_lo_read` reads at most *len* bytes from a large object into a variable named *bufVar*.

Usage

bufVar must be a valid variable name.

pg_lo_write

Name

`pg_lo_write` — write a large object

Synopsis

```
pg_lo_write conn fd buf len
```

Inputs

conn

Specifies a valid database connection.

fd

File descriptor for the large object from pg_lo_open.

buf

Specifies a valid string variable to write to the large object.

len

Specifies the maximum size of the string to write.

Outputs

None

Description

`pg_lo_write` writes at most *len* bytes to a large object from a variable *buf*.

Usage

buf must be the actual string to write, not a variable name.

pg_lo_lseek

Name

`pg_lo_lseek` — seek to a position in a large object

Synopsis

```
pg_lo_lseek conn fd offset whence
```

Inputs

conn

Specifies a valid database connection.

fd

File descriptor for the large object from pg_lo_open.

offset

Specifies a zero-based offset in bytes.

whence

whence can be `SEEK_CUR`, `SEEK_END`, or `SEEK_SET`

Outputs

None

Description

`pg_lo_lseek` positions to *offset* bytes from the beginning of the large object.

Usage

whence can be `SEEK_CUR`, `SEEK_END`, or `SEEK_SET`.

pg_lo_tell

Name

`pg_lo_tell` — return the current seek position of a large object

Synopsis

```
pg_lo_tell conn fd
```

Inputs

conn

Specifies a valid database connection.

fd

File descriptor for the large object from pg_lo_open.

Outputs

offset

A zero-based offset in bytes suitable for input to `pg_lo_lseek`.

Description

`pg_lo_tell` returns the current to *offset* in bytes from the beginning of the large object.

Usage

pg_lo_unlink

Name

`pg_lo_unlink` — delete a large object

Synopsis

```
pg_lo_unlink conn lobjId
```

Inputs

conn

Specifies a valid database connection.

lobjId

Identifier for a large object.

Outputs

None

Description

`pg_lo_unlink` deletes the specified large object.

Usage

pg_lo_import

Name

`pg_lo_import` — import a large object from a file

Synopsis

```
pg_lo_import conn filename
```

Inputs

conn

Specifies a valid database connection.

filename

Unix file name.

Outputs

None

Description

`pg_lo_import` reads the specified file and places the contents into a large object.

Usage

`pg_lo_import` must be called within a BEGIN/END transaction block.

pg_lo_export

Name

`pg_lo_export` — export a large object to a file

Synopsis

```
pg_lo_export conn lobjId filename
```

Inputs

conn

Specifies a valid database connection.

lobjId

Large object identifier.

filename

Unix file name.

Outputs

None

Description

`pg_lo_export` writes the specified large object into a Unix file.

Usage

`pg_lo_export` must be called within a BEGIN/END transaction block.

Chapter 4. ECPG - Embedded SQL in C

This chapter describes the embedded SQL package for PostgreSQL. It works with C and C++. It was written by Linus Tolke (<`linus@epact.se`>) and Michael Meskes (<`meskes@postgresql.org`>).

Admittedly, this documentation is quite incomplete. But since this interface is standardized, additional information can be found in many resources about SQL.

4.1. The Concept

An embedded SQL program consists of code written in an ordinary programming language, in this case C, mixed with SQL commands in specially marked sections. To build the program, the source code is first passed to the embedded SQL preprocessor, which converts it to an ordinary C program, and afterwards it can be processed by a C compilation tool chain.

Embedded SQL has advantages over other methods for handling SQL commands from C code. First, it takes care of the tedious passing of information to and from variables in your C program. Secondly, embedded SQL in C is defined in the SQL standard and supported by many other SQL databases. The PostgreSQL implementation is designed to match this standard as much as possible, and it is usually possible to port embedded SQL programs written for other RDBMS to PostgreSQL with relative ease.

As indicated, programs written for the embedded SQL interface are normal C programs with special code inserted to perform database-related actions. This special code always has the form

```
EXEC SQL ...;
```

These statements syntactically take the place of a C statement. Depending on the particular statement, they may appear in the global context or within a function. Embedded SQL statements follow the case-sensitivity rules of normal SQL code, and not those of C.

The following sections explain all the embedded SQL statements.

4.2. Connecting to the Database Server

One connects to a database using the following statement:

```
EXEC SQL CONNECT TO target [AS connection-name] [USER user-name];
```

The *`target`* can be specified in the following ways:

- *dbname*[@*hostname*][:*port*]
- tcp:postgresql://*hostname*[:*port*][/*dbname*][?*options*]
- unix:postgresql://*hostname*[:*port*][/*dbname*][?*options*]
- *character variable*
- *character string*
- DEFAULT

There are also different ways to specify the user name:

- *userid*
- *userid/password*
- *userid* IDENTIFIED BY *password*
- *userid* USING *password*

The *userid* and *password* may be a constant text, a character variable, or a character string.

The *connection-name* is used to handle multiple connections in one program. It can be omitted if a program uses only one connection.

4.3. Closing a Connection

To close a connection, use the following statement:

```
EXEC SQL DISCONNECT [connection];
```

The *connection* can be specified in the following ways:

- *connection-name*
- DEFAULT
- CURRENT
- ALL

4.4. Running SQL Commands

Any SQL command can be run from within an embedded SQL application. Below are some examples of how to do that.

Creating a table:

```
EXEC SQL CREATE TABLE foo (number integer, ascii char(16));
EXEC SQL CREATE UNIQUE INDEX num1 ON foo(number);
EXEC SQL COMMIT;
```

Inserting rows:

```
EXEC SQL INSERT INTO foo (number, ascii) VALUES (9999, 'doodad');
EXEC SQL COMMIT;
```

Deleting rows:

```
EXEC SQL DELETE FROM foo WHERE number = 9999;
EXEC SQL COMMIT;
```

Singleton Select:

```
EXEC SQL SELECT foo INTO :FooBar FROM table1 WHERE ascii = 'doodad';
```

Select using Cursors:

```
EXEC SQL DECLARE foo_bar CURSOR FOR
    SELECT number, ascii FROM foo
    ORDER BY ascii;
EXEC SQL FETCH foo_bar INTO :FooBar, DooDad;
...
EXEC SQL CLOSE foo_bar;
EXEC SQL COMMIT;
```

Updates:

```
EXEC SQL UPDATE foo
    SET ascii = 'foobar'
    WHERE number = 9999;
EXEC SQL COMMIT;
```

The tokens of the form `:something` are *host variables*, that is, they refer to variables in the C program. They are explained in the next section.

In the default mode, statements are committed only when `EXEC SQL COMMIT` is issued. The embedded SQL interface also supports autocommit of transactions (as known from other interfaces) via the `-t` command-line option to `ecpg` (see below) or via the `EXEC SQL SET AUTOCOMMIT TO ON` statement. In autocommit mode, each query is automatically committed unless it is inside an explicit transaction block. This mode can be explicitly turned off using `EXEC SQL SET AUTOCOMMIT TO OFF`.

4.5. Passing Data

To pass data from the program to the database, for example as parameters in a query, or to pass data from the database back to the program, the C variables that are intended to contain this data need to be declared in a specially marked section, so the embedded SQL preprocessor is made aware of them.

This section starts with

```
EXEC SQL BEGIN DECLARE SECTION;
```

and ends with

```
EXEC SQL END DECLARE SECTION;
```

Between those lines, there must be normal C variable declarations, such as

```
int   x;
char  foo[16], bar[16];
```

The declarations are also echoed to the output file as a normal C variables, so there's no need to declare them again. Variables that are not intended to be used with SQL commands can be declared normally outside these special sections.

The definition of a structure or union also must be listed inside a `DECLARE` section. Otherwise the preprocessor cannot handle these types since it does not know the definition.

The special types `VARCHAR` and `VARCHAR2` are converted into a named `struct` for every variable. A declaration like:

```
VARCHAR var[180];
```

is converted into:

```
struct varchar_var { int len; char arr[180]; } var;
```

This structure is suitable for interfacing with SQL datums of type `VARCHAR`.

To use a properly declared C variable in an SQL statement, write `:varname` where an expression is expected. See the previous section for some examples.

4.6. Error Handling

The embedded SQL interface provides a simplistic and a complex way to handle exceptional conditions in a program. The first method causes a message to printed automatically when a certain condition occurs. For example:

```
EXEC SQL WHENEVER sqlerror sqlprint;
```

or

```
EXEC SQL WHENEVER not found sqlprint;
```

This error handling remains enabled throughout the entire program.

> **Note:** This is *not* an exhaustive example of usage for the `EXEC SQL WHENEVER` statement. Further examples of usage may be found in SQL manuals (e.g., *The LAN TIMES Guide to SQL* by Groff and Weinberg).

For a more powerful error handling, the embedded SQL interface provides a `struct` and a variable with the name `sqlca` as follows:

```
struct sqlca
```

```
{
    char sqlcaid[8];
    long sqlabc;
    long sqlcode;
    struct
    {
        int sqlerrml;
        char sqlerrmc[70];
    } sqlerrm;
    char sqlerrp[8];

    long sqlerrd[6];
    /* 0: empty                                         */
    /* 1: OID of processed tuple if applicable          */
    /* 2: number of rows processed in an INSERT, UPDATE */
    /*    or DELETE statement                           */
    /* 3: empty                                         */
    /* 4: empty                                         */
    /* 5: empty                                         */

    char sqlwarn[8];
    /* 0: set to 'W' if at least one other is 'W'       */
    /* 1: if 'W' at least one character string          */
    /*    value was truncated when it was               */
    /*    stored into a host variable.                  */
    /* 2: empty                                         */
    /* 3: empty                                         */
    /* 4: empty                                         */
    /* 5: empty                                         */
    /* 6: empty                                         */
    /* 7: empty                                         */

    char sqlext[8];
} sqlca;
```

(Many of the empty fields may be used in a future release.)

If no error occurred in the last SQL statement, `sqlca.sqlcode` will be 0 (`ECPG_NO_ERROR`). If `sqlca.sqlcode` is less that zero, this is a serious error, like the database definition does not match the query. If it is greater than zero, it is a normal error like the table did not contain the requested row.

`sqlca.sqlerrm.sqlerrmc` will contain a string that describes the error. The string ends with the line number in the source file.

These are the errors that can occur:

`-12, Out of memory in line %d.`

Should not normally occur. This indicates your virtual memory is exhausted.

`-200 (ECPG_UNSUPPORTED): Unsupported type %s on line %d.`

Should not normally occur. This indicates the preprocessor has generated something that the library does not know about. Perhaps you are running incompatible versions of the preprocessor and the library.

`-201 (ECPG_TOO_MANY_ARGUMENTS): Too many arguments line %d.`

This means that the server has returned more arguments than we have matching variables. Perhaps you have forgotten a couple of the host variables in the `INTO :var1,:var2` list.

`-202 (ECPG_TOO_FEW_ARGUMENTS): Too few arguments line %d.`

This means that the server has returned fewer arguments than we have host variables. Perhaps you have too many host variables in the `INTO :var1,:var2` list.

`-203 (ECPG_TOO_MANY_MATCHES): Too many matches line %d.`

This means the query has returned several rows but the variables specified are not arrays. The `SELECT` command was not unique.

`-204 (ECPG_INT_FORMAT): Not correctly formatted int type: %s line %d.`

This means the host variable is of type `int` and the field in the PostgreSQL database is of another type and contains a value that cannot be interpreted as an `int`. The library uses `strtol()` for this conversion.

`-205 (ECPG_UINT_FORMAT): Not correctly formatted unsigned type: %s line %d.`

This means the host variable is of type `unsigned int` and the field in the PostgreSQL database is of another type and contains a value that cannot be interpreted as an `unsigned int`. The library uses `strtoul()` for this conversion.

`-206 (ECPG_FLOAT_FORMAT): Not correctly formatted floating-point type: %s line %d.`

This means the host variable is of type `float` and the field in the PostgreSQL database is of another type and contains a value that cannot be interpreted as a `float`. The library uses `strtod()` for this conversion.

`-207 (ECPG_CONVERT_BOOL): Unable to convert %s to bool on line %d.`

This means the host variable is of type `bool` and the field in the PostgreSQL database is neither `'t'` nor `'f'`.

`-208 (ECPG_EMPTY): Empty query line %d.`

The query was empty. (This cannot normally happen in an embedded SQL program, so it may point to an internal error.)

`-209 (ECPG_MISSING_INDICATOR): NULL value without indicator in line %d.`

A null value was returned and no null indicator variable was supplied.

`-210 (ECPG_NO_ARRAY): Variable is not an array in line %d.`

An ordinary variable was used in a place that requires an array.

`-211 (ECPG_DATA_NOT_ARRAY): Data read from backend is not an array in line %d.`

The database returned an ordinary variable in a place that requires array value.

`-220 (ECPG_NO_CONN): No such connection %s in line %d.`

The program tried to access a connection that does not exist.

`-221 (ECPG_NOT_CONN): Not connected in line %d.`

The program tried to access a connection that does exist but is not open.

`-230 (ECPG_INVALID_STMT): Invalid statement name %s in line %d.`

The statement you are trying to use has not been prepared.

`-240 (ECPG_UNKNOWN_DESCRIPTOR): Descriptor %s not found in line %d.`

The descriptor specified was not found. The statement you are trying to use has not been prepared.

`-241 (ECPG_INVALID_DESCRIPTOR_INDEX): Descriptor index out of range in line %d.`

The descriptor index specified was out of range.

`-242 (ECPG_UNKNOWN_DESCRIPTOR_ITEM): Descriptor %s not found in line %d.`

The descriptor specified was not found. The statement you are trying to use has not been prepared.

`-243 (ECPG_VAR_NOT_NUMERIC): Variable is not a numeric type in line %d.`

The database returned a numeric value and the variable was not numeric.

`-244 (ECPG_VAR_NOT_CHAR): Variable is not a character type in line %d.`

The database returned a non-numeric value and the variable was numeric.

`-400 (ECPG_PGSQL): Postgres error: %s line %d.`

Some PostgreSQL error. The message contains the error message from the PostgreSQL backend.

`-401 (ECPG_TRANS): Error in transaction processing line %d.`

PostgreSQL signaled that we cannot start, commit, or rollback the transaction.

`-402 (ECPG_CONNECT): Could not connect to database %s in line %d.`

The connect to the database did not work.

`100 (ECPG_NOT_FOUND): Data not found line %d.`

This is a “normal” error that tells you that what you are querying cannot be found or you are at the end of the cursor.

4.7. Including Files

To include an external file into your embedded SQL program, use:

```
EXEC SQL INCLUDE filename;
```

The embedded SQL preprocessor will look for a file named `filename.h`, preprocess it, and include it in the resulting C output. Thus, embedded SQL statements in the included file are handled correctly.

Note that this is *not* the same as

```
#include <filename.h>
```

because the file would not be subject to SQL command preprocessing. Naturally, you can continue to use the C `#include` directive to include other header files.

> **Note:** The include file name is case-sensitive, even though the rest of the `EXEC SQL INCLUDE` command follows the normal SQL case-sensitivity rules.

4.8. Processing Embedded SQL Programs

Now that you have an idea how to form embedded SQL C programs, you probably want to know how to compile them. Before compiling you run the file through the embedded SQL C preprocessor, which converts the SQL statements you used to special function calls. After compiling, you must link with a special library that contains the needed functions. These functions fetch information from the arguments, perform the SQL query using the libpq interface, and put the result in the arguments specified for output.

The preprocessor program is called `ecpg` and is included in a normal PostgreSQL installation. Embedded SQL programs are typically named with an extension `.pgc`. If you have a program file called `prog1.pgc`, you can preprocess it by simply calling

```
ecpg prog1.pgc
```

This will create a file called `prog1.c`. If your input files do not follow the suggested naming pattern, you can specify the output file explicitly using the `-o` option.

The preprocessed file can be compiled normally, for example

```
cc -c prog1.c
```

The generated C source files include headers files from the PostgreSQL installation, so if you installed PostgreSQL in a location that is not searched by default, you have to add an option such as `-I/usr/local/pgsql/include` to the compilation command line.

To link an embedded SQL program, you need to include the `libecpg` library, like so:

```
cc -o myprog prog1.o prog2.o ... -lecpg
```

Again, you might have to add an option like `-L/usr/local/pgsql/lib` to that command line.

If you manage the build process of a larger project using make, it may be convenient to include the following implicit rule to your makefiles:

```
ECPG = ecpg

%.c: %.pgc
        $(ECPG) $<
```

The complete syntax of the `ecpg` command is detailed in the *PostgreSQL Reference Manual*.

4.9. Library Functions

The `libecpg` library primarily contains "hidden" functions that are used to implement the functionality expressed by the embedded SQL commands. But there are some functions that can usefully be called directly. Note that this makes your code unportable.

- `ECPGdebug(int *on*, FILE **stream*)` turns on debug logging if called with the first argument non-zero. Debug logging is done on *`stream`*. Most SQL statement log their arguments and results.

  The most important function, `ECPGdo`, logs all SQL statements with both the expanded string, i.e. the string with all the input variables inserted, and the result from the PostgreSQL server. This can be very useful when searching for errors in your SQL statements.

- `ECPGstatus()` This method returns true if we are connected to a database and false if not.

4.10. Porting From Other RDBMS Packages

The design of ecpg follows the SQL standard. Porting from a standard RDBMS should not be a problem. Unfortunately there is no such thing as a standard RDBMS. Therefore ecpg tries to understand syntax extensions as long as they do not create conflicts with the standard.

The following list shows all the known incompatibilities. If you find one not listed please notify the developers. Note, however, that we list only incompatibilities from a preprocessor of another RDBMS to ecpg and not ecpg features that these RDBMS do not support.

Syntax of `FETCH`

The standard syntax for `FETCH` is:

```
FETCH [direction] [amount] IN|FROM cursor
```

Oracle, however, does not use the keywords `IN` or `FROM`. This feature cannot be added since it would create parsing conflicts.

4.11. For the Developer

This section explain how ecpg works internally. This information can occasionally be useful to help users understand how to use ecpg.

4.11.1. The Preprocessor

The first four lines written by `ecpg` to the output are fixed lines. Two are comments and two are include lines necessary to interface to the library. Then the preprocessor reads through the file and writes output. Normally it just echoes everything to the output.

When it sees an `EXEC SQL` statement, it intervenes and changes it. The command starts with `exec sql` and ends with `;`. Everything in between is treated as an SQL statement and parsed for variable substitution.

Variable substitution occurs when a symbol starts with a colon (`:`). The variable with that name is looked up among the variables that were previously declared within a `EXEC SQL DECLARE` section. Depending on whether the variable is being use for input or output, a pointer to the variable is output to allow access by the function.

For every variable that is part of the SQL query, the function gets other arguments:

- The type as a special symbol.
- A pointer to the value or a pointer to the pointer.
- The size of the variable if it is a `char` or `varchar`.
- The number of elements in the array (for array fetches).
- The offset to the next element in the array (for array fetches).
- The type of the indicator variable as a special symbol.
- A pointer to the value of the indicator variable or a pointer to the pointer of the indicator variable.
- 0
- Number of elements in the indicator array (for array fetches).
- The offset to the next element in the indicator array (for array fetches).

Note that not all SQL commands are treated in this way. For instance, an open cursor statement like

```
EXEC SQL OPEN cursor;
```

is not copied to the output. Instead, the cursor's `DECLARE` command is used because it opens the cursor as well.

Here is a complete example describing the output of the preprocessor of a file `foo.pgc` (details may change with each particular version of the preprocessor):

```
EXEC SQL BEGIN DECLARE SECTION;
int index;
int result;
EXEC SQL END DECLARE SECTION;
...
EXEC SQL SELECT res INTO :result FROM mytable WHERE index = :index;
```

is translated into:

```
/* Processed by ecpg (2.6.0) */
/* These two include files are added by the preprocessor */
#include <ecpgtype.h>;
#include <ecpglib.h>;

/* exec sql begin declare section */

#line 1 "foo.pgc"

 int index;
 int result;
```

```
/* exec sql end declare section */
...
ECPGdo(__LINE__, NULL, "SELECT res FROM mytable WHERE index = ?     ",
        ECPGt_int,&(index),1L,1L,sizeof(int),
        ECPGt_NO_INDICATOR, NULL , 0L, 0L, 0L, ECPGt_EOIT,
        ECPGt_int,&(result),1L,1L,sizeof(int),
        ECPGt_NO_INDICATOR, NULL , 0L, 0L, 0L, ECPGt_EORT);
#line 147 "foo.pgc"
```

(The indentation in this manual is added for readability and not something the preprocessor does.)

4.11.2. The Library

The most important function in the library is `ECPGdo`. It takes a variable number of arguments. Hopefully there are no computers that limit the number of variables that can be accepted by a `varargs()` function. This can easily add up to 50 or so arguments.

The arguments are:

A line number

: This is a line number of the original line; used in error messages only.

A string

: This is the SQL query that is to be issued. It is modified by the input variables, i.e. the variables that where not known at compile time but are to be entered in the query. Where the variables should go the string contains `?`.

Input variables

: As described in the section about the preprocessor, every input variable gets ten arguments.

`ECPGt_EOIT`

: An `enum` telling that there are no more input variables.

Output variables

: As described in the section about the preprocessor, every input variable gets ten arguments. These variables are filled by the function.

`ECPGt_EORT`

: An `enum` telling that there are no more variables.

Chapter 5. JDBC Interface

Author: Originally written by Peter T. Mount (<`peter@retep.org.uk`>), the original author of the JDBC driver.

JDBC is a core API of Java 1.1 and later. It provides a standard set of interfaces to SQL-compliant databases.

PostgreSQL provides a *type 4* JDBC Driver. Type 4 indicates that the driver is written in Pure Java, and communicates in the database system's own network protocol. Because of this, the driver is platform independent; once compiled, the driver can be used on any system.

This chapter is not intended as a complete guide to JDBC programming, but should help to get you started. For more information refer to the standard JDBC API documentation. Also, take a look at the examples included with the source. The basic example is used here.

5.1. Setting up the JDBC Driver

5.1.1. Getting the Driver

Precompiled versions of the driver can be downloaded from the PostgreSQL JDBC web site[1].

Alternatively you can build the driver from source, but you should only need to do this if you are making changes to the source code. For details, refer to the PostgreSQL installation instructions. After installation, the driver should be found in `*PREFIX*/share/java/postgresql.jar`. The resulting driver will be built for the version of Java you are running. If you build with a 1.1 JDK you will build a version that supports the JDBC 1 specification, if you build with a Java 2 JDK (e.g., JDK 1.2 or JDK 1.3) you will build a version that supports the JDBC 2 specification.

5.1.2. Setting up the Class Path

To use the driver, the JAR archive (named `postgresql.jar` if you built from source, otherwise it will likely be named `jdbc7.2-1.1.jar` or `jdbc7.2-1.2.jar` for the JDBC 1 and JDBC 2 versions respectively) needs to be included in the class path, either by putting it in the `CLASSPATH` environment variable, or by using flags on the `java` command line.

For instance, I have an application that uses the JDBC driver to access a large database containing astronomical objects. I have the application and the JDBC driver installed in the `/usr/local/lib` directory, and the Java JDK installed in `/usr/local/jdk1.3.1`. To run the application, I would use:

```
export CLASSPATH=/usr/local/lib/finder.jar❶:/usr/local/pgsql/share/java/postgresql.jar:
java Finder
```

❶ `finder.jar` contains the Finder application.

1. http://jdbc.postgresql.org

Loading the driver from within the application is covered in Section 5.2.

5.1.3. Preparing the Database for JDBC

Because Java only uses TCP/IP connections, the PostgreSQL server must be configured to accept TCP/IP connections. This can be done by setting `tcpip_socket = true` in the `postgresql.conf` file or by supplying the `-i` option flag when starting `postmaster`.

Also, the client authentication setup in the `pg_hba.conf` file may need to be configured. Refer to the *Administrator's Guide* for details. The JDBC Driver supports the trust, ident, password, md5, and crypt authentication methods.

5.2. Using the Driver

5.2.1. Importing JDBC

Any source that uses JDBC needs to import the `java.sql` package, using:

```
import java.sql.*;
```

Important: Do not import the `org.postgresql` package. If you do, your source will not compile, as `javac` will get confused.

5.2.2. Loading the Driver

Before you can connect to a database, you need to load the driver. There are two methods available, and it depends on your code which is the best one to use.

In the first method, your code implicitly loads the driver using the `Class.forName()` method. For PostgreSQL, you would use:

```
Class.forName("org.postgresql.Driver");
```

This will load the driver, and while loading, the driver will automatically register itself with JDBC.

Note: The `forName()` method can throw a `ClassNotFoundException` if the driver is not available.

This is the most common method to use, but restricts your code to use just PostgreSQL. If your code may access another database system in the future, and you do not use any PostgreSQL-specific extensions, then the second method is advisable.

The second method passes the driver as a parameter to the JVM as it starts, using the `-D` argument. Example:

```
java -Djdbc.drivers=org.postgresql.Driver example.ImageViewer
```

In this example, the JVM will attempt to load the driver as part of its initialization. Once done, the `ImageViewer` is started.

Now, this method is the better one to use because it allows your code to be used with other database packages without recompiling the code. The only thing that would also change is the connection URL, which is covered next.

One last thing: When your code then tries to open a `Connection`, and you get a No driver available `SQLException` being thrown, this is probably caused by the driver not being in the class path, or the value in the parameter not being correct.

5.2.3. Connecting to the Database

With JDBC, a database is represented by a URL (Uniform Resource Locator). With PostgreSQL, this takes one of the following forms:

- `jdbc:postgresql:`*`database`*
- `jdbc:postgresql:`*`//host/database`*
- `jdbc:postgresql:`*`//host`*`:`*`port/database`*

where:

`host`

The host name of the server. Defaults to `localhost`.

`port`

The port number the server is listening on. Defaults to the PostgreSQL standard port number (5432).

`database`

The database name.

To connect, you need to get a `Connection` instance from JDBC. To do this, you would use the `DriverManager.getConnection()` method:

```
Connection db = DriverManager.getConnection(url, username, password);
```

5.2.4. Closing the Connection

To close the database connection, simply call the `close()` method to the `Connection`:

```
db.close();
```

5.3. Issuing a Query and Processing the Result

Any time you want to issue SQL statements to the database, you require a `Statement` or `PreparedStatement` instance. Once you have a `Statement` or `PreparedStatement`, you can use issue a query. This will return a `ResultSet` instance, which contains the entire result. Example 5-1 illustrates this process.

Example 5-1. Processing a Simple Query in JDBC

This example will issue a simple query and print out the first column of each row using a `Statement`.

```
Statement st = db.createStatement();
ResultSet rs = st.executeQuery("SELECT * FROM mytable where columnfoo = 500");
while(rs.next()) {
    System.out.print("Column 1 returned ");
    System.out.println(rs.getString(1));
}
rs.close();
st.close();
```

This example will issue the same query as before using a `PreparedStatement` and a bind value in the query.

```
int foovalue = 500;
PreparedStatement st = db.prepareStatement("SELECT * FROM mytable where colum-
nfoo = ?");
st.setInt(1, foovalue);
ResultSet rs = st.executeQuery();
while(rs.next()) {
    System.out.print("Column 1 returned ");
    System.out.println(rs.getString(1));
}
rs.close();
st.close();
```

5.3.1. Using the `Statement` or `PreparedStatement` Interface

The following must be considered when using the `Statement` or `PreparedStatement` interface:

- You can use a single `Statement` instance as many times as you want. You could create one as soon as you open the connection and use it for the connection's lifetime. But you have to remember that only one `ResultSet` can exist per `Statement` or `PreparedStatement` at a given time.
- If you need to perform a query while processing a `ResultSet`, you can simply create and use another `Statement`.
- If you are using threads, and several are using the database, you must use a separate `Statement` for each thread. Refer to Section 5.8 if you are thinking of using threads, as it covers some important points.
- When you are done using the `Statement` or `PreparedStatement` you should close it.

5.3.2. Using the `ResultSet` Interface

The following must be considered when using the `ResultSet` interface:

- Before reading any values, you must call `next()`. This returns true if there is a result, but more importantly, it prepares the row for processing.
- Under the JDBC specification, you should access a field only once. It is safest to stick to this rule, although at the current time, the PostgreSQL driver will allow you to access a field as many times as you want.
- You must close a `ResultSet` by calling `close()` once you have finished using it.
- Once you make another query with the `Statement` used to create a `ResultSet`, the currently open `ResultSet` instance is closed automatically.
- `ResultSet` is currently read only. You can not update data through the `ResultSet`. If you want to update data you need to do it the old fashioned way by issuing a SQL update statement. This is in conformance with the JDBC specification which does not require drivers to provide this functionality.

5.4. Performing Updates

To change data (perform an insert, update, or delete) you use the `executeUpdate()` method. `executeUpdate()` is similar to the `executeQuery()` used to issue a select, however it doesn't return a `ResultSet`, instead it returns the number of records affected by the insert, update, or delete statement.

Example 5-2. Simple Delete Example

This example will issue a simple delete and print out the number of rows deleted.

```
int foovalue = 500;
```

```
    PreparedStatement st = db.prepareStatement("DELETE FROM mytable where colum-
nfoo = ?");
    st.setInt(1, foovalue);
    int rowsDeleted = st.executeUpdate();
    System.out.println(rowsDeleted + " rows deleted");
    st.close();
```

5.5. Creating and Modifying Database Objects

To create, modify or drop a database object like a table or view you use the `execute()` method. `execute` is similar to the `executeQuery()` used to issue a select, however it doesn't return a result.

Example 5-3. Drop Table Example

This example will drop a table.

```
    Statement st = db.createStatement();
    ResultSet rs = st.executeQuery("DROP TABLE mytable");
    st.close();
```

5.6. Storing Binary Data

PostgreSQL provides two distinct ways to store binary data. Binary data can be stored in a table using PostgreSQL's binary data type `bytea`, or by using the *Large Object* feature which stores the binary data in a separate table in a special format, and refers to that table by storing a value of type `OID` in your table.

In order to determine which method is appropriate you need to understand the limitations of each method. The `bytea` data type is not well suited for storing very large amounts of binary data. While a column of type `bytea` can hold up to 1 GB of binary data, it would require a huge amount of memory (RAM) to process such a large value. The Large Object method for storing binary data is better suited to storing very large values, but it has its own limitations. Specifically deleting a row that contains a Large Object does not delete the Large Object. Deleting the Large Object is a separate operation that needs to be performed. Large Objects also have some security issues since anyone connected to the database case view and/or modify any Large Object, even if they don't have permissions to view/update the row containing the Large Object.

7.2 is the first release of the JDBC Driver that supports the `bytea` data type. The introduction of this functionality in 7.2 has introduced a change in behavior as compared to previous releases. In 7.2 the methods `getBytes()`, `setBytes()`, `getBinaryStream()`, and `setBinaryStream()` operate on the `bytea` data type. In 7.1 these methods operated on the `OID` data type associated with Large Objects. It is possible to revert the driver back to the old 7.1 behavior by setting the *`compatible`* property on the `Connection` to a value of `7.1`

To use the `bytea` data type you should simply use the `getBytes()`, `setBytes()`, `getBinaryStream()`, or `setBinaryStream()` methods.

To use the Large Object functionality you can use either the `LargeObject` API provided by the PostgreSQL JDBC Driver, or by using the `getBLOB()` and `setBLOB()` methods.

> **Important:** For PostgreSQL, you must access Large Objects within an SQL transaction. You would open a transaction by using the `setAutoCommit()` method with an input parameter of `false`.

> **Note:** In a future release of the JDBC Driver, the `getBLOB()` and `setBLOB()` methods may no longer interact with Large Objects and will instead work on `bytea` data types. So it is recommended that you use the `LargeObject` API if you intend to use Large Objects.

Example 5-4. Binary Data Examples

For example, suppose you have a table containing the file name of an image and you also want to store the image in a `bytea` column:

```
CREATE TABLE images (imgname text, img bytea);
```

To insert an image, you would use:

```
File file = new File("myimage.gif");
FileInputStream fis = new FileInputStream(file);
PreparedStatement ps = conn.prepareStatement("INSERT INTO images VALUES (?, ?)");
ps.setString(1, file.getName());
ps.setBinaryStream(2, fis, file.length());
ps.executeUpdate();
ps.close();
fis.close();
```

Here, `setBinaryStream()` transfers a set number of bytes from a stream into the column of type `bytea`. This also could have been done using the `setBytes()` method if the contents of the image was already in a `byte[]`.

Retrieving an image is even easier. (We use `PreparedStatement` here, but the `Statement` class can equally be used.)

```
    PreparedStatement ps = con.prepareStatement("SELECT img FROM images WHERE img-
name=?");
    ps.setString(1, "myimage.gif");
    ResultSet rs = ps.executeQuery();
    if (rs != null) {
        while(rs.next()) {
            byte[] imgBytes = rs.getBytes(1);
            // use the stream in some way here
        }
        rs.close();
    }
    ps.close();
```

Here the binary data was retrieved as an `byte[]`. You could have used a `InputStream` object instead.

Alternatively you could be storing a very large file and want to use the `LargeObject` API to store the file:

```
CREATE TABLE imagesLO (imgname text, imgOID OID);
```

To insert an image, you would use:

```
// All LargeObject API calls must be within a transaction
conn.setAutoCommit(false);

// Get the Large Object Manager to perform operations with
LargeObjectManager lobj = ((org.postgresql.PGConnection)conn).getLargeObjectAPI();

//create a new large object
int oid = lobj.create(LargeObjectManager.READ | LargeObjectManager.WRITE);

//open the large object for write
LargeObject obj = lobj.open(oid, LargeObjectManager.WRITE);

// Now open the file
File file = new File("myimage.gif");
FileInputStream fis = new FileInputStream(file);

// copy the data from the file to the large object
byte buf[] = new byte[2048];
int s, tl = 0;
while ((s = fis.read(buf, 0, 2048)) > 0)
{
 obj.write(buf, 0, s);
 tl += s;
}

// Close the large object
obj.close();

//Now insert the row into imagesLO
PreparedStatement ps = conn.prepareStatement("INSERT INTO imagesLO VALUES (?, ?)");
ps.setString(1, file.getName());
ps.setInt(2, oid);
ps.executeUpdate();
ps.close();
fis.close();
```

Retrieving the image from the Large Object:

```
// All LargeObject API calls must be within a transaction
conn.setAutoCommit(false);

// Get the Large Object Manager to perform operations with
LargeObjectManager lobj = ((org.postgresql.PGConnection)conn).getLargeObjectAPI();

PreparedStatement ps = con.prepareStatement("SELECT imgOID FROM imagesLO WHERE imgname=
ps.setString(1, "myimage.gif");
ResultSet rs = ps.executeQuery();
if (rs != null) {
    while(rs.next()) {
 //open the large object for reading
 int oid = rs.getInt(1);
```

```
     LargeObject obj = lobj.open(oid, LargeObjectManager.READ);

     //read the data
     byte buf[] = new byte[obj.size()];
     obj.read(buf, 0, obj.size());
     //do something with the data read here

     // Close the object
     obj.close();
        }
        rs.close();
    }
    ps.close();
```

5.7. PostgreSQL Extensions to the JDBC API

PostgreSQL is an extensible database system. You can add your own functions to the backend, which can then be called from queries, or even add your own data types. As these are facilities unique to PostgreSQL, we support them from Java, with a set of extension API's. Some features within the core of the standard driver actually use these extensions to implement Large Objects, etc.

5.7.1. Accessing the Extensions

To access some of the extensions, you need to use some extra methods in the `org.postgresql.PGConnection` class. In this case, you would need to case the return value of `Driver.getConnection()`. For example:

```
Connection db = Driver.getConnection(url, username, password);
// ...
// later on
Fastpath fp = ((org.postgresql.PGConnection)db).getFastpathAPI();
```

5.7.1.1. Class `org.postgresql.PGConnection`

```
public class PGConnection
```

These are the extra methods used to gain access to PostgreSQL's extensions.

5.7.1.1.1. Methods

- `public Fastpath getFastpathAPI() throws SQLException`

  This returns the Fastpath API for the current connection. It is primarily used by the Large Object API.

  The best way to use this is as follows:

  ```
  import org.postgresql.fastpath.*;
  ```

```
...
Fastpath fp = ((org.postgresql.PGConnection)myconn).getFastpathAPI();
```

where `myconn` is an open `Connection` to PostgreSQL.

Returns: Fastpath object allowing access to functions on the PostgreSQL backend.

Throws: `SQLException` by Fastpath when initializing for first time

-
  ```
  public LargeObjectManager getLargeObjectAPI() throws SQLException
  ```

  This returns the Large Object API for the current connection.

  The best way to use this is as follows:

  ```
  import org.postgresql.largeobject.*;
  ...
  LargeObjectManager lo = ((org.postgresql.PGConnection)myconn).getLargeObjectAPI();
  ```

  where `myconn` is an open `Connection` to PostgreSQL.

  Returns: `LargeObject` object that implements the API

  Throws: `SQLException` by `LargeObject` when initializing for first time

-
  ```
  public void addDataType(String type, String name)
  ```

  This allows client code to add a handler for one of PostgreSQL's more unique data types. Normally, a data type not known by the driver is returned by `ResultSet.getObject()` as a `PGobject` instance. This method allows you to write a class that extends `PGobject`, and tell the driver the type name, and class name to use. The down side to this, is that you must call this method each time a connection is made.

  The best way to use this is as follows:

  ```
   ...
  ((org.postgresql.PGConnection)myconn).addDataType("mytype","my.class.name");
   ...
  ```

  where `myconn` is an open `Connection` to PostgreSQL. The handling class must extend `org.postgresql.util.PGobject`.

5.7.1.2. Class `org.postgresql.Fastpath`

```
public class Fastpath extends Object

java.lang.Object
   |
   +----org.postgresql.fastpath.Fastpath
```

`Fastpath` is an API that exists within the libpq C interface, and allows a client machine to execute a function on the database backend. Most client code will not need to use this method, but it is provided because the Large Object API uses it.

To use, you need to import the `org.postgresql.fastpath` package, using the line:

```
import org.postgresql.fastpath.*;
```

Then, in your code, you need to get a `FastPath` object:

```
Fastpath fp = ((org.postgresql.PGConnection)conn).getFastpathAPI();
```

This will return an instance associated with the database connection that you can use to issue commands. The casing of `Connection` to `org.postgresql.PGConnection` is required, as the `getFastpathAPI()` is an extension method, not part of JDBC. Once you have a `Fastpath` instance, you can use the `fastpath()` methods to execute a backend function.

See Also: `FastpathFastpathArg`, `LargeObject`

5.7.1.2.1. Methods

- ```
  public Object fastpath(int fnid,
                         boolean resulttype,
                         FastpathArg args[]) throws SQLException
  ```

  Send a function call to the PostgreSQL backend.

  Parameters: *`fnid`* - Function id *`resulttype`* - True if the result is an integer, false for other results *`args`* - `FastpathArguments` to pass to fastpath

  Returns: null if no data, Integer if an integer result, or byte[] otherwise

- ```
  public Object fastpath(String name,
                         boolean resulttype,
                         FastpathArg args[]) throws SQLException
  ```

  Send a function call to the PostgreSQL backend by name.

  > **Note:** The mapping for the procedure name to function id needs to exist, usually to an earlier call to `addfunction()`. This is the preferred method to call, as function id's can/may change between versions of the backend. For an example of how this works, refer to org.postgresql.LargeObject

  Parameters: *`name`* - Function name *`resulttype`* - True if the result is an integer, false for other results *`args`* - `FastpathArguments` to pass to fastpath

  Returns: null if no data, Integer if an integer result, or byte[] otherwise

  See Also: `LargeObject`

- ```
  public int getInteger(String name,
                        FastpathArg args[]) throws SQLException
  ```
  ```

This convenience method assumes that the return value is an Integer

Parameters: *name* - Function name *args* - Function arguments

Returns: integer result

Throws: `SQLException` if a database-access error occurs or no result

- ```
  public byte[] getData(String name,
                        FastpathArg args[]) throws SQLException
  ```

  This convenience method assumes that the return value is binary data.

  Parameters: *name* - Function name *args* - Function arguments

  Returns: byte[] array containing result

  Throws: `SQLException` if a database-access error occurs or no result

- ```
  public void addFunction(String name,
                          int fnid)
  ```

  This adds a function to our look-up table. User code should use the `addFunctions` method, which is based upon a query, rather than hard coding the OID. The OID for a function is not guaranteed to remain static, even on different servers of the same version.

- ```
  public void addFunctions(ResultSet rs) throws SQLException
  ```

  This takes a `ResultSet` containing two columns. Column 1 contains the function name, Column 2 the OID. It reads the entire `ResultSet`, loading the values into the function table.

  > **Important:** Remember to `close()` the `ResultSet` after calling this!

  > **Implementation note about function name look-ups:** PostgreSQL stores the function id's and their corresponding names in the `pg_proc` table. To speed things up locally, instead of querying each function from that table when required, a `Hashtable` is used. Also, only the function's required are entered into this table, keeping connection times as fast as possible.
  >
  > The `org.postgresql.LargeObject` class performs a query upon its start-up, and passes the returned `ResultSet` to the `addFunctions()` method here. Once this has been done, the Large Object API refers to the functions by name.
  >
  > Do not think that manually converting them to the OIDs will work. OK, they will for now, but they can change during development (there was some discussion about this for V7.0), so this is implemented to prevent any unwarranted headaches in the future.

  See Also: `LargeObjectManager`

- ```
  public int getID(String name) throws SQLException
  ```

This returns the function id associated by its name If `addFunction()` or `addFunctions()` have not been called for this name, then an `SQLException` is thrown.

5.7.1.3. Class `org.postgresql.fastpath.FastpathArg`

```
public class FastpathArg extends Object

java.lang.Object
   |
   +----org.postgresql.fastpath.FastpathArg
```

Each fastpath call requires an array of arguments, the number and type dependent on the function being called. This class implements methods needed to provide this capability.

For an example on how to use this, refer to the `org.postgresql.LargeObject` package.

See Also: `Fastpath`, `LargeObjectManager`, `LargeObject`

5.7.1.3.1. Constructors

- `public FastpathArg(int value)`

  Constructs an argument that consists of an integer value

  Parameters: value - int value to set

- `public FastpathArg(byte bytes[])`

  Constructs an argument that consists of an array of bytes

  Parameters: bytes - array to store

- ```
  public FastpathArg(byte buf[],
                     int off,
                     int len)
  ```

  Constructs an argument that consists of part of a byte array

  Parameters:

  `buf`

  source array

  `off`

  offset within array
  ```

len

length of data to include

- `public FastpathArg(String s)`

  Constructs an argument that consists of a String.

5.7.2. Geometric Data Types

PostgreSQL has a set of data types that can store geometric features into a table. These include single points, lines, and polygons. We support these types in Java with the org.postgresql.geometric package. It contains classes that extend the org.postgresql.util.PGobject class. Refer to that class for details on how to implement your own data type handlers.

```
Class org.postgresql.geometric.PGbox

java.lang.Object
   |
   +----org.postgresql.util.PGobject
           |
           +----org.postgresql.geometric.PGbox

   public class PGbox extends PGobject implements Serializable,
Cloneable

   This represents the box data type within PostgreSQL.

Variables

 public PGpoint point[]

          These are the two corner points of the box.

Constructors

 public PGbox(double x1,
              double y1,
              double x2,
              double y2)

        Parameters:
                x1 - first x coordinate
                y1 - first y coordinate
                x2 - second x coordinate
                y2 - second y coordinate
```

```
 public PGbox(PGpoint p1,
              PGpoint p2)

        Parameters:
                p1 - first point
                p2 - second point

 public PGbox(String s) throws SQLException

        Parameters:
                s - Box definition in PostgreSQL syntax

        Throws: SQLException
                if definition is invalid

 public PGbox()

          Required constructor

Methods

 public void setValue(String value) throws SQLException

          This method sets the value of this object. It should be
overridden, but still called by subclasses.

        Parameters:
                value - a string representation of the value of the
object
        Throws: SQLException
                thrown if value is invalid for this type

        Overrides:
                setValue in class PGobject

 public boolean equals(Object obj)

        Parameters:
                obj - Object to compare with

        Returns:
                true if the two boxes are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overridden to allow the object to be cloned

        Overrides:
                clone in class PGobject
```

```
 public String getValue()

        Returns:
                the PGbox in the syntax expected by PostgreSQL

        Overrides:
                getValue in class PGobject

Class org.postgresql.geometric.PGcircle

java.lang.Object
   |
   +----org.postgresql.util.PGobject
           |
           +----org.postgresql.geometric.PGcircle

   public class PGcircle extends PGobject implements Serializable,
Cloneable

   This represents PostgreSQL's circle data type, consisting of a point
and a radius

Variables

 public PGpoint center

          This is the center point

 double radius

          This is the radius

Constructors

 public PGcircle(double x,
                 double y,
                 double r)

        Parameters:
               x - coordinate of center
                y - coordinate of center
                r - radius of circle

 public PGcircle(PGpoint c,
                 double r)

        Parameters:
                c - PGpoint describing the circle's center
                r - radius of circle

 public PGcircle(String s) throws SQLException
```

```
        Parameters:
                s - definition of the circle in PostgreSQL’s syntax.

        Throws: SQLException
                on conversion failure

 public PGcircle()

          This constructor is used by the driver.

Methods

 public void setValue(String s) throws SQLException

        Parameters:
                s - definition of the circle in PostgreSQL’s syntax.

        Throws: SQLException
                on conversion failure

        Overrides:
                setValue in class PGobject

 public boolean equals(Object obj)

        Parameters:
                obj - Object to compare with

        Returns:
                true if the two circles are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overridden to allow the object to be cloned

        Overrides:
                clone in class PGobject

 public String getValue()

        Returns:
                the PGcircle in the syntax expected by PostgreSQL

        Overrides:
                getValue in class PGobject

Class org.postgresql.geometric.PGline

java.lang.Object
   |
```

```
   +----org.postgresql.util.PGobject
           |
           +----org.postgresql.geometric.PGline

   public class PGline extends PGobject implements Serializable,
Cloneable

   This implements a line consisting of two points. Currently line is
not yet implemented in the backend, but this class ensures that when
it’s done were ready for it.

Variables

 public PGpoint point[]

          These are the two points.

Constructors

 public PGline(double x1,
               double y1,
               double x2,
               double y2)

        Parameters:
                x1 - coordinate for first point
                y1 - coordinate for first point
                x2 - coordinate for second point
                y2 - coordinate for second point

 public PGline(PGpoint p1,
               PGpoint p2)

        Parameters:
                p1 - first point
                p2 - second point

 public PGline(String s) throws SQLException

        Parameters:
                s - definition of the line in PostgreSQL’s syntax.

        Throws: SQLException
                on conversion failure

 public PGline()

          required by the driver

Methods

 public void setValue(String s) throws SQLException
```

```
        Parameters:
                s - Definition of the line segment in PostgreSQL's
syntax

        Throws: SQLException
                on conversion failure

        Overrides:
                setValue in class PGobject

 public boolean equals(Object obj)

        Parameters:
                obj - Object to compare with

        Returns:
                true if the two lines are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overridden to allow the object to be cloned

        Overrides:
                clone in class PGobject

 public String getValue()

        Returns:
                the PGline in the syntax expected by PostgreSQL

        Overrides:
                getValue in class PGobject

Class org.postgresql.geometric.PGlseg

java.lang.Object
   |
   +----org.postgresql.util.PGobject
           |
           +----org.postgresql.geometric.PGlseg

   public class PGlseg extends PGobject implements Serializable,
Cloneable

   This implements a lseg (line segment) consisting of two points

Variables

 public PGpoint point[]
```

```
          These are the two points.

Constructors

 public PGlseg(double x1,
               double y1,
               double x2,
               double y2)

        Parameters:

                x1 - coordinate for first point
                y1 - coordinate for first point
                x2 - coordinate for second point
                y2 - coordinate for second point

 public PGlseg(PGpoint p1,
               PGpoint p2)

        Parameters:
                p1 - first point
                p2 - second point

 public PGlseg(String s) throws SQLException

        Parameters:
                s - Definition of the line segment in PostgreSQL’s syntax.

        Throws: SQLException
                on conversion failure

 public PGlseg()

          required by the driver

Methods

 public void setValue(String s) throws SQLException

        Parameters:
                s - Definition of the line segment in PostgreSQL’s
syntax

        Throws: SQLException
                on conversion failure

        Overrides:
                setValue in class PGobject

 public boolean equals(Object obj)

        Parameters:
                obj - Object to compare with
```

```
        Returns:
                true if the two line segments are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overridden to allow the object to be cloned

        Overrides:
               clone in class PGobject

 public String getValue()

        Returns:
                the PGlseg in the syntax expected by PostgreSQL

        Overrides:
                getValue in class PGobject

Class org.postgresql.geometric.PGpath

java.lang.Object
   |
   +----org.postgresql.util.PGobject
           |
           +----org.postgresql.geometric.PGpath

   public class PGpath extends PGobject implements Serializable,
Cloneable

   This implements a path (a multiply segmented line, which may be
closed)

Variables

 public boolean open

          True if the path is open, false if closed

 public PGpoint points[]

          The points defining this path

Constructors

 public PGpath(PGpoint points[],
               boolean open)

        Parameters:
                points - the PGpoints that define the path
```

```
                open - True if the path is open, false if closed

 public PGpath()

          Required by the driver

 public PGpath(String s) throws SQLException

        Parameters:
                s - definition of the path in PostgreSQL’s syntax.

        Throws: SQLException
                on conversion failure

Methods

 public void setValue(String s) throws SQLException

        Parameters:
                s - Definition of the path in PostgreSQL’s syntax

        Throws: SQLException
                on conversion failure

        Overrides:
                setValue in class PGobject

 public boolean equals(Object obj)

        Parameters:
                obj - Object to compare with

        Returns:
                true if the two pathes are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overridden to allow the object to be cloned

        Overrides:
                clone in class PGobject

 public String getValue()

          This returns the path in the syntax expected by
PostgreSQL

        Overrides:
                getValue in class PGobject
```

```
 public boolean isOpen()

     This returns true if the path is open

 public boolean isClosed()

     This returns true if the path is closed

 public void closePath()

     Marks the path as closed

 public void openPath()

     Marks the path as open

Class org.postgresql.geometric.PGpoint

java.lang.Object
   |
   +----org.postgresql.util.PGobject
           |
           +----org.postgresql.geometric.PGpoint

   public class PGpoint extends PGobject implements Serializable,
Cloneable

   This implements a version of java.awt.Point, except it uses double
to represent the coordinates.

   It maps to the point data type in PostgreSQL.

Variables

 public double x

          The X coordinate of the point

 public double y

          The Y coordinate of the point

Constructors

 public PGpoint(double x,
                double y)

        Parameters:
                x - coordinate
                y - coordinate

 public PGpoint(String value) throws SQLException
```

```
          This is called mainly from the other geometric types, when a
point is embedded within their definition.

        Parameters:
                value - Definition of this point in PostgreSQL's
syntax

 public PGpoint()

          Required by the driver

Methods

 public void setValue(String s) throws SQLException

        Parameters:
                s - Definition of this point in PostgreSQL's syntax

        Throws: SQLException
                on conversion failure

        Overrides:
                setValue in class PGobject

 public boolean equals(Object obj)

        Parameters:
                obj - Object to compare with

        Returns:
                true if the two points are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overridden to allow the object to be cloned

        Overrides:
                clone in class PGobject

 public String getValue()

        Returns:
                the PGpoint in the syntax expected by PostgreSQL

        Overrides:
                getValue in class PGobject

 public void translate(int x,
                       int y)
```

```
          Translate the point with the supplied amount.

        Parameters:
                x - integer amount to add on the x axis
                y - integer amount to add on the y axis

 public void translate(double x,
                       double y)

          Translate the point with the supplied amount.

        Parameters:
                x - double amount to add on the x axis
                y - double amount to add on the y axis

 public void move(int x,
                  int y)

          Moves the point to the supplied coordinates.

        Parameters:
                x - integer coordinate
                y - integer coordinate

public void move(double x,
                  double y)

          Moves the point to the supplied coordinates.

        Parameters:
                x - double coordinate
                y - double coordinate

 public void setLocation(int x,
                         int y)

          Moves the point to the supplied coordinates. refer to
          java.awt.Point for description of this

        Parameters:
                x - integer coordinate
                y - integer coordinate

        See Also:
                Point

 public void setLocation(Point p)

          Moves the point to the supplied java.awt.Point refer to
          java.awt.Point for description of this

        Parameters:
                p - Point to move to
```

```
        See Also:
                Point

Class org.postgresql.geometric.PGpolygon

java.lang.Object
   |
   +----org.postgresql.util.PGobject
           |
           +----org.postgresql.geometric.PGpolygon

   public class PGpolygon extends PGobject implements Serializable,
Cloneable

   This implements the polygon data type within PostgreSQL.

Variables

 public PGpoint points[]

          The points defining the polygon

Constructors

 public PGpolygon(PGpoint points[])

          Creates a polygon using an array of PGpoints

        Parameters:
                points - the points defining the polygon

 public PGpolygon(String s) throws SQLException

        Parameters:
                s - definition of the polygon in PostgreSQL’s syntax.

        Throws: SQLException
                on conversion failure

 public PGpolygon()

          Required by the driver

Methods

 public void setValue(String s) throws SQLException

        Parameters:
                s - Definition of the polygon in PostgreSQL’s syntax

        Throws: SQLException
                on conversion failure
```

```
        Overrides:
                setValue in class PGobject

 public boolean equals(Object obj)

        Parameters:
                obj - Object to compare with

        Returns:
                true if the two polygons are identical

        Overrides:
                equals in class PGobject

 public Object clone()

          This must be overridden to allow the object to be cloned

        Overrides:
                clone in class PGobject

 public String getValue()

        Returns:
                the PGpolygon in the syntax expected by PostgreSQL

        Overrides:
                getValue in class PGobject
```

5.7.3. Large Objects

Large objects are supported in the standard JDBC specification. However, that interface is limited, and the API provided by PostgreSQL allows for random access to the objects contents, as if it was a local file.

The org.postgresql.largeobject package provides to Java the libpq C interface's large object API. It consists of two classes, `LargeObjectManager`, which deals with creating, opening and deleting large objects, and `LargeObject` which deals with an individual object.

5.7.3.1. Class `org.postgresql.largeobject.LargeObject`

```
public class LargeObject extends Object

java.lang.Object
   |
   +----org.postgresql.largeobject.LargeObject
```

This class implements the large object interface to PostgreSQL.

It provides the basic methods required to run the interface, plus a pair of methods that provide `InputStream` and `OutputStream` classes for this object.

Normally, client code would use the methods in `BLOB` to access large objects.

However, sometimes lower level access to Large Objects is required, that is not supported by the JDBC specification.

Refer to org.postgresql.largeobject.LargeObjectManager on how to gain access to a Large Object, or how to create one.

See Also: `LargeObjectManager`

5.7.3.1.1. Variables

public static final int SEEK_SET

Indicates a seek from the beginning of a file

public static final int SEEK_CUR

Indicates a seek from the current position

public static final int SEEK_END

Indicates a seek from the end of a file

5.7.3.1.2. Methods

- `public int getOID()`

  Returns the OID of this `LargeObject`

- `public void close() throws SQLException`

  This method closes the object. You must not call methods in this object after this is called.

- `public byte[] read(int len) throws SQLException`

  Reads some data from the object, and return as a byte[] array

- ```
  public int read(byte buf[],
                  int off,
                  int len) throws SQLException
  ```

  Reads some data from the object into an existing array

  Parameters:

  `buf`

  destination array

  `off`

  offset within array
  ```

len

number of bytes to read

- `public void write(byte buf[]) throws SQLException`

  Writes an array to the object

- ```
  public void write(byte buf[],
                    int off,
                    int len) throws SQLException
  ```

  Writes some data from an array to the object

  Parameters:

  buf

  destination array

  off

  offset within array

  len

  number of bytes to write

5.7.3.2. Class `org.postgresql.largeobject.LargeObjectManager`

```
public class LargeObjectManager extends Object

java.lang.Object
   |
   +----org.postgresql.largeobject.LargeObjectManager
```

This class implements the large object interface to PostgreSQL. It provides methods that allow client code to create, open and delete large objects from the database. When opening an object, an instance of `org.postgresql.largeobject.LargeObject` is returned, and its methods then allow access to the object.

This class can only be created by org.postgresql.PGConnection. To get access to this class, use the following segment of code:

```
import org.postgresql.largeobject.*;
Connection  conn;
LargeObjectManager lobj;
```
```

```
// ... code that opens a connection ...
lobj = ((org.postgresql.PGConnection)myconn).getLargeObjectAPI();
```

Normally, client code would use the `BLOB` methods to access large objects. However, sometimes lower level access to Large Objects is required, that is not supported by the JDBC specification.

Refer to org.postgresql.largeobject.LargeObject on how to manipulate the contents of a Large Object.

5.7.3.2.1. Variables

`public static final int WRITE`

This mode indicates we want to write to an object.

`public static final int READ`

This mode indicates we want to read an object.

`public static final int READWRITE`

This mode is the default. It indicates we want read and write access to a large object.

5.7.3.2.2. Methods

- `public LargeObject open(int oid) throws SQLException`

  This opens an existing large object, based on its OID. This method assumes that `READ` and `WRITE` access is required (the default).

- ```
  public LargeObject open(int oid,
                          int mode) throws SQLException
  ```

  This opens an existing large object, based on its OID, and allows setting the access mode.

- `public int create() throws SQLException`

  This creates a large object, returning its OID. It defaults to `READWRITE` for the new object's attributes.

- `public int create(int mode) throws SQLException`

  This creates a large object, returning its OID, and sets the access mode.

- `public void delete(int oid) throws SQLException`

  This deletes a large object.

- `public void unlink(int oid) throws SQLException`
  ```

This deletes a large object. It is identical to the delete method, and is supplied as the C API uses “unlink”.

5.8. Using the driver in a multithreaded or a servlet environment

A problem with many JDBC drivers is that only one thread can use a `Connection` at any one time -- otherwise a thread could send a query while another one is receiving results, and this would be a bad thing for the database engine.

The PostgreSQL JDBC Driver is thread safe. Consequently, if your application uses multiple threads then you do not have to worry about complex algorithms to ensure that only one uses the database at any time.

If a thread attempts to use the connection while another one is using it, it will wait until the other thread has finished its current operation. If it is a regular SQL statement, then the operation consists of sending the statement and retrieving any `ResultSet` (in full). If it is a `Fastpath` call (e.g., reading a block from a `LargeObject`) then it is the time to send and retrieve that block.

This is fine for applications and applets but can cause a performance problem with servlets. With servlets you can have a heavy load on the connection. If you have several threads performing queries then each but one will pause, which may not be what you are after.

To solve this, you would be advised to create a pool of connections. When ever a thread needs to use the database, it asks a manager class for a `Connection`. The manager hands a free connection to the thread and marks it as busy. If a free connection is not available, it opens one. Once the thread has finished with it, it returns it to the manager who can then either close it or add it to the pool. The manager would also check that the connection is still alive and remove it from the pool if it is dead.

So, with servlets, it is up to you to use either a single connection, or a pool. The plus side for a pool is that threads will not be hit by the bottle neck caused by a single network connection. The down side is that it increases the load on the server, as a backend process is created for each `Connection`. It is up to you and your applications requirements.

5.9. Connection Pools And DataSources

5.9.1. JDBC, JDK Version Support

JDBC 2 introduced standard connection pooling features in an add-on API known as the JDBC 2.0 Optional Package (also known as the JDBC 2.0 Standard Extension). These features have since been included in the core JDBC 3 API. The PostgreSQL JDBC drivers support these features with JDK 1.3.x in combination with the JDBC 2.0 Optional Package (JDBC 2), or with JDK 1.4+ (JDBC 3). Most application servers include the JDBC 2.0 Optional Package, but it is also available separately from the Sun JDBC download site[2].

2. http://java.sun.com/products/jdbc/download.html#spec

5.9.2. JDBC Connection Pooling API

The JDBC API provides a client and a server interface for connection pooling. The client interface is `javax.sql.DataSource`, which is what application code will typically use to acquire a pooled database connection. The server interface is `javax.sql.ConnectionPoolDataSource`, which is how most application servers will interface with the PostgreSQL JDBC driver.

In an application server environment, the application server configuration will typically refer to the PostgreSQL `ConnectionPoolDataSource` implementation, while the application component code will typically acquire a `DataSource` implementation provided by the application server (not by PostgreSQL).

In an environment without an application server, PostgreSQL provides two implementations of `DataSource` which an application can use directly. One implementation performs connection pooling, while the other simply provides access to database connections through the `DataSource` interface without any pooling. Again, these implementations should not be used in an application server environment unless the application server does not support the `ConnectionPoolDataSource` interface.

5.9.3. Application Servers: ConnectionPoolDataSource

PostgreSQL includes one implementation of `ConnectionPoolDataSource` for JDBC 2, and one for JDBC 3:

Table 5-1. ConnectionPoolDataSource Implementations

JDBC	Implementation Class
2	`org.postgresql.jdbc2.optional.ConnectionPool`
3	`org.postgresql.jdbc3.Jdbc3ConnectionPool`

Both implementations use the same configuration scheme. JDBC requires that a `ConnectionPoolDataSource` be configured via JavaBean properties, so there are get and set methods for each of these properties:

Table 5-2. ConnectionPoolDataSource Configuration Properties

Property	Type	Description
serverName	`String`	PostgreSQL database server hostname
databaseName	`String`	PostgreSQL database name
portNumber	`int`	TCP/IP port which the PostgreSQL database server is listening on (or 0 to use the default port)
user	`String`	User used to make database connections

Property	Type	Description
password	`String`	Password used to make database connections
defaultAutoCommit	`boolean`	Whether connections should have autoCommit enabled or disabled when they are supplied to the caller. The default is `false`, to disable autoCommit.

Many application servers use a properties-style syntax to configure these properties, so it would not be unusual to enter properties as a block of text.

Example 5-5. `ConnectionPoolDataSource` Configuration Example

If the application server provides a single area to enter all the properties, they might be listed like this:

```
serverName=localhost
databaseName=test
user=testuser
password=testpassword
```

Or, separated by semicolons instead of newlines, like this:

```
serverName=localhost;databaseName=test;user=testuser;password=testpassword
```

5.9.4. Applications: DataSource

PostgreSQL includes two implementations of `DataSource` for JDBC 2, and two for JDBC 3. The pooling implementations do not actually close connections when the client calls the `close` method, but instead return the connections to a pool of available connections for other clients to use. This avoids any overhead of repeatedly opening and closing connections, and allows a large number of clients to share a small number of database connections.

The pooling datasource implementation provided here is not the most feature-rich in the world. Among other things, connections are never closed until the pool itself is closed; there is no way to shrink the pool. As well, connections requested for users other than the default configured user are not pooled. Many application servers provide more advanced pooling features, and use the `ConnectionPoolDataSource` implementation instead.

Table 5-3. DataSource Implementations

JDBC	Pooling	Implementation Class
2	No	`org.postgresql.jdbc2.optional.SimpleDat`
2	Yes	`org.postgresql.jdbc2.optional.PoolingDa`
3	No	`org.postgresql.jdbc3.Jdbc3SimpleDataSou`

JDBC	Pooling	Implementation Class
3	Yes	`org.postgresql.jdbc3.Jdbc3PoolingDataSo`

All the implementations use the same configuration scheme. JDBC requires that a `DataSource` be configured via JavaBean properties, so there are get and set methods for each of these properties.

Table 5-4. DataSource Configuration Properties

Property	Type	Description
serverName	`String`	PostgreSQL database server hostname
databaseName	`String`	PostgreSQL database name
portNumber	`int`	TCP/IP port which the PostgreSQL database server is listening on (or 0 to use the default port)
user	`String`	User used to make database connections
password	`String`	Password used to make database connections

The pooling implementations require some additional configuration properties:

Table 5-5. Additional Pooling DataSource Configuration Properties

Property	Type	Description
dataSourceName	`String`	Every pooling `DataSource` must have a unique name
initialConnections	`int`	The number of database connections to be created when the pool is initialized.
maxConnections	`int`	The maximum number of open database connections to allow. When more connections are requested, the caller will hang until a connection is returned to the pool.

Here's an example of typical application code using a pooling `DataSource`:

Example 5-6. `DataSource` Code Example

Code to initialize a pooling DataSource might look like this:

```
Jdbc3PoolingDataSource source = new Jdbc3PoolingDataSource();
source.setDataSourceName("A Data Source");
```

```
source.setServerName("localhost");
source.setDatabaseName("test");
source.setUser("testuser");
source.setPassword("testpassword");
source.setMaxConnections(10);
```

Then code to use a connection from the pool might look like this. Note that it is critical that the connections are closed, or else the pool will "leak" connections, and eventually lock all the clients out.

```
Connection con = null;
try {
    con = source.getConnection();
    // use connection
} catch(SQLException e) {
    // log error
} finally {
    if(con != null) {
        try {con.close();}catch(SQLException e) {}
    }
}
```

5.9.5. DataSources and JNDI

All the `ConnectionPoolDataSource` and `DataSource` implementations can be stored in JNDI. In the case of the non-pooling implementations, a new instance will be created every time the object is retrieved from JNDI, with the same settings as the instance which was stored. For the pooling implementations, the same instance will be retrieved as long as it is available (e.g. not a different JVM retrieving the pool from JNDI), or a new instance with the same settings created otherwise.

In the application server environment, typically the application server's `DataSource` instance will be stored in JNDI, instead of the PostgreSQL `ConnectionPoolDataSource` implementation.

In an application environment, the application may store the `DataSource` in JNDI so that it doesn't have to make a reference to the `DataSource` available to all application components that may need to use it:

Example 5-7. `DataSource` JNDI Code Example

Application code to initialize a pooling DataSource and add it to JNDI might look like this:

```
Jdbc3PoolingDataSource source = new Jdbc3PoolingDataSource();
source.setDataSourceName("A Data Source");
source.setServerName("localhost");
source.setDatabaseName("test");
source.setUser("testuser");
source.setPassword("testpassword");
source.setMaxConnections(10);
new InitialContext().rebind("DataSource", source);
```

Then code to use a connection from the pool might look like this:

```
Connection con = null;
try {
    DataSource source = (DataSource)new InitialContext().lookup("DataSource");
    con = source.getConnection();
```

```
    // use connection
} catch(SQLException e) {
    // log error
} catch(NamingException e) {
    // DataSource wasn’t found in JNDI
} finally {
    if(con != null) {
        try {con.close();}catch(SQLException e) {}
    }
}
```

5.9.6. Specific Application Server Configurations

Configuration examples for specific application servers will be included here.

5.10. Further Reading

If you have not yet read it, I’d advise you read the JDBC API Documentation (supplied with Sun’s JDK), and the JDBC Specification. Both are available from http://java.sun.com/products/jdbc/index.html.

http://jdbc.postgresql.org contains updated information not included in this document, and also includes precompiled drivers.

Chapter 6. PyGreSQL - Python Interface

Author: Written by D'Arcy J.M. Cain (<darcy@druid.net>). Based heavily on code written by Pascal Andre <andre@chimay.via.ecp.fr>. Copyright © 1995, Pascal Andre. Further modifications Copyright © 1997-2000 by D'Arcy J.M. Cain.

You may either choose to use the old mature interface provided by the `pg` module or otherwise the newer `pgdb` interface compliant with the DB-API 2.0[1] specification developed by the Python DB-SIG.

Here we describe only the older `pg` API. As long as PyGreSQL does not contain a description of the DB-API you should read about the API at http://www.python.org/topics/database/DatabaseAPI-2.0.html.

A tutorial-like introduction to the DB-API can be found at http://www2.linuxjournal.com/lj-issues/issue49/2605.html

6.1. The `pg` Module

The `pg` module defines three objects:

- `pgobject`, which handles the connection and all the requests to the database,
- `pglargeobject`, which handles all the accesses to PostgreSQL large objects, and
- `pgqueryobject` that handles query results.

If you want to see a simple example of the use of some of these functions, see http://www.druid.net/rides where you can find a link at the bottom to the actual Python code for the page.

6.1.1. Constants

Some constants are defined in the `pg` module dictionary. They are intended to be used as a parameters for methods calls. You should refer to the libpq description (Chapter 1) for more information about them. These constants are:

`INV_READ`
`INV_WRITE`

large objects access modes, used by `(pgobject.)locreate` and `(pglarge.)open`.

`SEEK_SET`
`SEEK_CUR`
`SEEK_END`

positional flags, used by `(pglarge.)seek`.

1. http://www.python.org/topics/database/DatabaseAPI-2.0.html

`version`
`__version__`

constants that give the current version

6.2. pg Module Functions

`pg` module defines only a few methods that allow to connect to a database and to define “default variables” that override the environment variables used by PostgreSQL.

These “default variables” were designed to allow you to handle general connection parameters without heavy code in your programs. You can prompt the user for a value, put it in the default variable, and forget it, without having to modify your environment. The support for default variables can be disabled by setting the `-DNO_DEF_VAR` option in the Python `Setup` file. Methods relative to this are specified by the tag [DV].

All variables are set to `None` at module initialization, specifying that standard environment variables should be used.

connect

Name

`connect` — open a connection to the database server

Synopsis

```
connect([dbname], [host], [port], [opt], [tty], [user], [passwd])
```

Parameters

dbname

Name of connected database (string/`None`).

host

Name of the server host (string/`None`).

port

Port used by the database server (integer/-1).

opt

Options for the server (string/`None`).

tty

File or tty for optional debug output from backend (string/None).

user

PostgreSQL user (string/None).

passwd

Password for user (string/None).

Return Type

pgobject

If successful, an object handling a database connection is returned.

Exceptions

TypeError

Bad argument type, or too many arguments.

SyntaxError

Duplicate argument definition.

pg.error

Some error occurred during pg connection definition.

(plus all exceptions relative to object allocation)

Description

This method opens a connection to a specified database on a given PostgreSQL server. You can use key words here, as described in the Python tutorial. The names of the key words are the name of the parameters given in the syntax line. For a precise description of the parameters, please refer to the PostgreSQL user manual.

Examples

```
import pg

con1 = pg.connect('testdb', 'myhost', 5432, None, None, 'bob', None)
con2 = pg.connect(dbname='testdb', host='localhost', user='bob')
```

get_defhost

Name

`get_defhost` — get default host name [DV]

Synopsis

```
get_defhost()
```

Parameters

none

Return Type

string or `None`

Default host specification

Exceptions

`SyntaxError`

Too many arguments.

Description

`get_defhost()` returns the current default host specification, or `None` if the environment variables should be used. Environment variables will not be looked up.

set_defhost

Name

`set_defhost` — set default host name [DV]

Synopsis

```
set_defhost(host)
```

Parameters

host

New default host (string/`None`).

Return Type

string or `None`

Previous default host specification.

Exceptions

`TypeError`

Bad argument type, or too many arguments.

Description

`set_defhost()` sets the default host value for new connections. If `None` is supplied as parameter, environment variables will be used in future connections. It returns the previous setting for default host.

get_defport

Name

`get_defport` — get default port [DV]

Synopsis

```
get_defport()
```

Parameters

none

Return Type

integer or `None`

Default port specification

Exceptions

`SyntaxError`

Too many arguments.

Description

`get_defport()` returns the current default port specification, or `None` if the environment variables should be used. Environment variables will not be looked up.

set_defport

Name

`set_defport` — set default port [DV]

Synopsis

```
set_defport(port)
```

Parameters

`port`

New default host (integer/-1).

Return Type

integer or `None`

Previous default port specification.

Exceptions

`TypeError`

Bad argument type, or too many arguments.

Description

`set_defport()` sets the default port value for new connections. If -1 is supplied as parameter, environment variables will be used in future connections. It returns the previous setting for default port.

get_defopt

Name

`get_defopt` — get default options specification [DV]

Synopsis

```
get_defopt()
```

Parameters

none

Return Type

string or `None`

Default options specification

Exceptions

`SyntaxError`

Too many arguments.

Description

`get_defopt()` returns the current default connection options specification, or `None` if the environment variables should be used. Environment variables will not be looked up.

set_defopt

Name

`set_defopt` — set default options specification [DV]

Synopsis

```
set_defopt(options)
```

Parameters

`options`

New default connection options (string/`None`).

Return Type

string or `None`

Previous default opt specification.

Exceptions

`TypeError`

Bad argument type, or too many arguments.

Description

`set_defopt()` sets the default connection options value for new connections. If `None` is supplied as parameter, environment variables will be used in future connections. It returns the previous setting for default options.

get_deftty

Name

`get_deftty` — get default connection debug terminal specification [DV]

Synopsis

```
get_deftty()
```

Parameters

none

Return Type

string or `None`

Default debug terminal specification

Exceptions

`SyntaxError`

Too many arguments.

Description

`get_deftty()` returns the current default debug terminal specification, or `None` if the environment variables should be used. Environment variables will not be looked up.

set_deftty

Name

`set_deftty` — set default connection debug terminal specification [DV]

Synopsis

```
set_deftty(terminal)
```

Parameters

`terminal`

New default debug terminal (string/`None`).

Return Type

string or `None`

Previous default debug terminal specification.

Exceptions

`TypeError`

Bad argument type, or too many arguments.

Description

`set_deftty()` sets the default terminal value for new connections. If `None` is supplied as parameter, environment variables will be used in future connections. It returns the previous setting for default terminal.

get_defbase

Name

`get_defbase` — get default database name specification [DV]

Synopsis

```
get_defbase()
```

Parameters

none

Return Type

string or `None`

Default debug database name specification

Exceptions

`SyntaxError`

Too many arguments.

Description

`get_defbase()` returns the current default database name specification, or `None` if the environment variables should be used. Environment variables will not be looked up.

set_defbase

Name

`set_defbase` — set default database name specification [DV]

Synopsis

```
set_defbase(database)
```

Parameters

`database`

New default database name (string/`None`).

Return Type

string or `None`

Previous default database name specification.

Exceptions

`TypeError`

Bad argument type, or too many arguments.

Description

`set_defbase()` sets the default database name for new connections. If `None` is supplied as parameter, environment variables will be used in future connections. It returns the previous setting for default database name.

6.3. Connection Object: `pgobject`

This object handles a connection to the PostgreSQL database. It embeds and hides all the parameters that define this connection, leaving just really significant parameters in function calls.

Some methods give direct access to the connection socket. They are specified by the tag [DA]. *Do not use them unless you really know what you are doing.* If you prefer disabling them, set the `-DNO_DIRECT` option in the Python `Setup` file.

Some other methods give access to large objects. if you want to forbid access to these from the module, set the `-DNO_LARGE` option in the Python `Setup` file. These methods are specified by the tag [LO].

Every `pgobject` defines a set of read-only attributes that describe the connection and its status. These attributes are:

host

  the host name of the server (string)

port

  the port of the server (integer)

db

  the selected database (string)

options

  the connection options (string)

tty

  the connection debug terminal (string)

user

  user name on the database system (string)

status

  the status of the connection (integer: 1 - OK, 0 - bad)

error

  the last warning/error message from the server (string)

query

Name

`query` — execute a SQL command

Synopsis

```
query(command)
```

Parameters

command

SQL command (string).

Return Type

`pgqueryobject` or `None`

Result values.

Exceptions

`TypeError`

Bad argument type, or too many arguments.

`ValueError`

Empty SQL query.

`pg.error`

Error during query processing, or invalid connection.

Description

`query()` method sends a SQL query to the database. If the query is an insert statement, the return value is the OID of the newly inserted row. If it is otherwise a query that does not return a result (i.e., is not a some kind of `SELECT` statement), it returns `None`. Otherwise, it returns a `pgqueryobject` that can be accessed via the `getresult()` or `dictresult()` methods or simply printed.

reset

Name

`reset` — reset the connection

Synopsis

```
reset()
```

Parameters

none

Return Type

none

Exceptions

`TypeError`

Too many (any) arguments.

Description

`reset()` method resets the current database.

close

Name

`close` — close the database connection

Synopsis

```
close()
```

Parameters

none

Return Type

none

Exceptions

`TypeError`

Too many (any) arguments.

Description

`close()` method closes the database connection. The connection will be closed in any case when the connection is deleted but this allows you to explicitly close it. It is mainly here to allow the DB-SIG API wrapper to implement a close function.

fileno

Name

`fileno` — return the socket used to connect to the database

Synopsis

```
fileno()
```

Parameters

none

Return Type

socket id

The underlying socket id used to connect to the database.

Exceptions

`TypeError`

Too many (any) arguments.

Description

`fileno()` method returns the underlying socket id used to connect to the database. This is useful for use in `select` calls, etc.

getnotify

Name

`getnotify` — get the last notify from the server

Synopsis

```
getnotify()
```

Parameters

none

Return Type

tuple, `None`

Last notify from server

Exceptions

`TypeError`

Too many (any) arguments.

`pg.error`

Invalid connection.

Description

`getnotify()` method tries to get a notify from the server (from the SQL statement `NOTIFY`). If the server returns no notify, the methods returns `None`. Otherwise, it returns a tuple (couple) `(relname, pid)`, where `relname` is the name of the notify and `pid` the process id of the connection that triggered the notify. Remember to do a listen query first otherwise `getnotify` will always return `None`.

inserttable

Name

`inserttable` — insert a list into a table

Synopsis

```
inserttable(table, values)
```

Parameters

`table`

The table name (string).

`values`

The list of rows values to insert (list).

Return Type

none

Exceptions

`TypeError`

Bad argument type or too many (any) arguments.

`pg.error`

Invalid connection.

Description

`inserttable()` method allows to quickly insert large blocks of data in a table: it inserts the whole values list into the given table. The list is a list of tuples/lists that define the values for each inserted row. The rows values may contain string, integer, long or double (real) values. *Be very careful:* this method does not type-check the fields according to the table definition; it just look whether or not it knows how to handle such types.

putline

Name

`putline` — write a line to the server socket [DA]

Synopsis

```
putline(line)
```

Parameters

`line`

Line to be written (string).

Return Type

none

Exceptions

`TypeError`

Bad argument type or too many (any) arguments.

`pg.error`

Invalid connection.

Description

`putline()` method allows to directly write a string to the server socket.

getline

Name

`getline` — get a line from server socket [DA]

Synopsis

```
getline()
```

Parameters

none

Return Type

string

The line read.

Exceptions

`TypeError`

Bad argument type or too many (any) arguments.

`pg.error`

Invalid connection.

Description

`getline()` method allows to directly read a string from the server socket.

endcopy

Name

`endcopy` — synchronize client and server [DA]

Synopsis

```
endcopy()
```

Parameters

none

Return Type

none

Exceptions

`TypeError`

Bad argument type or too many (any) arguments.

`pg.error`

Invalid connection.

Description

The use of direct access methods may desynchronize client and server. This method ensure that client and server will be synchronized.

locreate

Name

`locreate` — create a large object in the database [LO]

Synopsis

```
locreate(mode)
```

Parameters

`mode`

Large object create mode.

Return Type

`pglarge`

Object handling the PostgreSQL large object.

Exceptions

`TypeError`

Bad argument type or too many arguments.

`pg.error`

Invalid connection, or creation error.

Description

`locreate()` method creates a large object in the database. The mode can be defined by OR-ing the constants defined in the pg module (`INV_READ` and `INV_WRITE`).

getlo

Name

`getlo` — build a large object from given OID [LO]

Synopsis

```
getlo(oid)
```

Parameters

`oid`

OID of the existing large object (integer).

Return Type

`pglarge`

Object handling the PostgreSQL large object.

Exceptions

`TypeError`

Bad argument type or too many arguments.

`pg.error`

Invalid connection.

Description

`getlo()` method allows to reuse a formerly created large object through the `pglarge` interface, providing the user has its OID.

loimport

Name

`loimport` — import a file to a PostgreSQL large object [LO]

Synopsis

```
loimport(filename)
```

Parameters

`filename`

The name of the file to be imported (string).

Return Type

`pglarge`

Object handling the PostgreSQL large object.

Exceptions

`TypeError`

Bad argument type or too many arguments.

`pg.error`

Invalid connection, or error during file import.

Description

`loimport()` method allows to create large objects in a very simple way. You just give the name of a file containing the data to be use.

6.4. Database Wrapper Class: `DB`

`pg` module contains a class called `DB`. All `pgobject` methods are included in this class also. A number of additional `DB` class methods are described below. The preferred way to use this module is as follows (See description of the initialization method below.):

```
import pg

db = pg.DB(...)

for r in db.query(
    "SELECT foo,bar
       FROM foo_bar_table
      WHERE foo !~ bar"
    ).dictresult():

    print '%(foo)s %(bar)s' % r
```

The following describes the methods and variables of this class.

The `DB` class is initialized with the same arguments as the `pg.connect` method. It also initializes a few internal variables. The statement `db = DB()` will open the local database with the name of the user just like `pg.connect()` does.

pkey

Name

`pkey` — return the primary key of a table

Synopsis

```
pkey(table)
```

Parameters

`table`

name of table.

Return Type

string

Name of field which is the primary key of the table.

Description

`pkey()` method returns the primary key of a table. Note that this raises an exception if the table does not have a primary key.

get_databases

Name

`get_databases` — get list of databases in the system

Synopsis

```
get_databases()
```

Parameters

none

Return Type

list

List of databases in the system.

Description

Although you can do this with a simple select, it is added here for convenience

get_tables

Name

`get_tables` — get list of tables in connected database

Synopsis

```
get_tables()
```

Parameters

none

Return Type

list

List of tables in connected database.

Description

Although you can do this with a simple select, it is added here for convenience

get_attnames

Name

`get_attnames` — return the attribute names of a table

Synopsis

```
get_attnames(table)
```

Parameters

`table`

name of table.

Return Type

dictionary

The dictionary's keys are the attribute names, the values are the type names of the attributes.

Description

Given the name of a table, digs out the set of attribute names and types.

get

Name

`get` — get a tuple from a database table

Synopsis

```
get(table, arg, [keyname])
```

Parameters

`table`

Name of table.

`arg`

Either a dictionary or the value to be looked up.

[*`keyname`*]

Name of field to use as key (optional).

Return Type

dictionary

A dictionary mapping attribute names to row values.

Description

This method is the basic mechanism to get a single row. It assumes that the key specifies a unique row. If *`keyname`* is not specified then the primary key for the table is used. If *`arg`* is a dictionary then the value for the key is taken from it and it is modified to include the new values, replacing existing values where necessary. The OID is also put into the dictionary but in order to allow the caller to work with multiple tables, the attribute name is munged to make it unique. It consists of the string `oid_` followed by the name of the table.

insert

Name

`insert` — insert a tuple into a database table

Synopsis

```
insert(table, a)
```

Parameters

table

Name of table.

a

A dictionary of values.

Return Type

integer

The OID of the newly inserted row.

Description

This method inserts values into the table specified filling in the values from the dictionary. It then reloads the dictionary with the values from the database. This causes the dictionary to be updated with values that are modified by rules, triggers, etc.

Due to the way that this function works you will find inserts taking longer and longer as your table gets bigger. To overcome this problem simply add an index onto the OID of any table that you think may get large over time.

update

Name

`update` — update a database table

Synopsis

```
update(table, a)
```

Parameters

`table`

Name of table.

`a`

A dictionary of values.

Return Type

integer

The OID of the newly updated row.

Description

Similar to insert but updates an existing row. The update is based on the OID value as munged by get. The array returned is the one sent modified to reflect any changes caused by the update due to triggers, rules, defaults, etc.

clear

Name

`clear` — clear a database table

Synopsis

```
clear(table, [a])
```

Parameters

`table`

Name of table.

[*`a`*]

A dictionary of values.

Return Type

dictionary

A dictionary with an empty row.

Description

This method clears all the attributes to values determined by the types. Numeric types are set to 0, dates are set to `'today'` and everything else is set to the empty string. If the array argument is present, it is used as the array and any entries matching attribute names are cleared with everything else left unchanged.

delete

Name

`delete` — delete a row from a table

Synopsis

```
delete(table, [a])
```

Parameters

`table`

Name of table.

[*a*]

A dictionary of values.

Return Type

none

Description

This method deletes the row from a table. It deletes based on the OID as munged as described above.

6.5. Query Result Object: `pgqueryobject`

getresult

Name

`getresult` — get the values returned by the query

Synopsis

```
getresult()
```

Parameters

none

Return Type

list

List of tuples.

Exceptions

`SyntaxError`

Too many arguments.

`pg.error`

Invalid previous result.

Description

`getresult()` method returns the list of the values returned by the query. More information about this result may be accessed using `listfields`, `fieldname` and `fieldnum` methods.

dictresult

Name

`dictresult` — get the values returned by the query as a list of dictionaries

Synopsis

```
dictresult()
```

Parameters

none

Return Type

list

List of dictionaries.

Exceptions

`SyntaxError`

Too many arguments.

`pg.error`

Invalid previous result.

Description

`dictresult()` method returns the list of the values returned by the query with each tuple returned as a dictionary with the field names used as the dictionary index.

listfields

Name

`listfields` — list the fields names of the query result

Synopsis

```
listfields()
```

Parameters

none

Return Type

list

field names

Exceptions

`SyntaxError`

Too many arguments.

`pg.error`

Invalid query result, or invalid connection.

Description

`listfields()` method returns the list of field names defined for the query result. The fields are in the same order as the result values.

fieldname

Name

`fieldname` — get field name by number

Synopsis

```
fieldname(i)
```

Parameters

i

field number (integer).

Return Type

string

field name.

Exceptions

`TypeError`

Bad parameter type, or too many arguments.

`ValueError`

Invalid field number.

`pg.error`

Invalid query result, or invalid connection.

Description

`fieldname()` method allows to find a field name from its rank number. It can be useful for displaying a result. The fields are in the same order than the result values.

fieldnum

Name

`fieldnum` — get field number by name

Synopsis

```
fieldnum(name)
```

Parameters

`name`

field name (string).

Return Type

integer

field number (integer).

Exceptions

`TypeError`

Bad parameter type, or too many arguments.

`ValueError`

Unknown field name.

`pg.error`

Invalid query result, or invalid connection.

Description

`fieldnum()` method returns a field number from its name. It can be used to build a function that converts result list strings to their correct type, using a hardcoded table definition. The number returned is the field rank in the result values list.

ntuples

Name

`ntuples` — return the number of tuples in query object

Synopsis

```
ntuples()
```

Parameters

none

Return Type

integer

The number of tuples in query object.

Exceptions

`SyntaxError`

Too many arguments.

Description

`ntuples()` method returns the number of tuples found in a query.

6.6. Large Object: `pglarge`

This object handles all the request concerning a PostgreSQL large object. It embeds and hides all the "recurrent" variables (object OID and connection), exactly in the same way `pgobjects` do, thus only keeping significant parameters in function calls. It keeps a reference to the `pgobject` used for its creation, sending requests though with its parameters. Any modification but dereferencing the `pgobject` will thus affect the `pglarge` object. Dereferencing the initial `pgobject` is not a problem since Python will not deallocate it before the large object dereference it. All functions return a generic error message on call error, whatever the exact error was. The `error` attribute of the object allows to get the exact error message.

`pglarge` objects define a read-only set of attributes that allow to get some information about it. These attributes are:

`oid`

  the OID associated with the object

`pgcnx`

  the `pgobject` associated with the object

`error`

  the last warning/error message of the connection

> **Important:** In multithreaded environments, `error` may be modified by another thread using the same `pgobject`. Remember that these object are shared, not duplicated; you should provide some locking if you want to check for the error message in this situation. The OID attribute is very interesting because it allow you to reuse the OID later, creating the `pglarge` object with a `pgobject` `getlo()` method call.

See also Chapter 2 for more information about the PostgreSQL large object interface.

open

Name

`open` — open a large object

Synopsis

```
open(mode)
```

Parameters

`mode`

open mode definition (integer).

Return Type

none

Exceptions

`TypeError`

Bad parameter type, or too many arguments.

`IOError`

Already opened object, or open error.

`pg.error`

Invalid connection.

Description

`open()` method opens a large object for reading/writing, in the same way than the Unix `open()` function. The mode value can be obtained by OR-ing the constants defined in the pg module (`INV_READ`, `INV_WRITE`).

close

Name

`close` — close the large object

Synopsis

```
close()
```

Parameters

none

Return Type

none

Exceptions

`SyntaxError`

Too many arguments.

`IOError`

Object is not opened, or close error.

`pg.error`

Invalid connection.

Description

`close()` method closes previously opened large object, in the same way than the Unix `close()` function.

read

Name

`read` — read from the large object

Synopsis

```
read(size)
```

Parameters

`size`

Maximal size of the buffer to be read (integer).

Return Type

string

The read buffer.

Exceptions

`TypeError`

Bad parameter type, or too many arguments.

`IOError`

Object is not opened, or read error.

`pg.error`

Invalid connection or invalid object.

Description

`read()` method allows to read data from the large object, starting at current position.

write

Name

`write` — write to the large object

Synopsis

```
write(string)
```

Parameters

`string`

Buffer to be written (string).

Return Type

none

Exceptions

`TypeError`

Bad parameter type, or too many arguments.

`IOError`

Object is not opened, or write error.

`pg.error`

Invalid connection or invalid object.

Description

`write()` method allows to write data to the large object, starting at current position.

seek

Name

`seek` — change current position in the large object

Synopsis

```
seek(offset, whence)
```

Parameters

`offset`

Position offset (integer).

`whence`

Positional parameter (integer).

Return Type

integer

New current position in the object.

Exceptions

`TypeError`

Bad parameter type, or too many arguments.

`IOError`

Object is not opened, or seek error.

`pg.error`

Invalid connection or invalid object.

Description

`seek()` method allows to move the cursor position in the large object. The whence parameter can be obtained by OR-ing the constants defined in the `pg` module (`SEEK_SET`, `SEEK_CUR`, `SEEK_END`).

tell

Name

`tell` — return current position in the large object

Synopsis

```
tell()
```

Parameters

none

Return Type

integer

Current position in the object.

Exceptions

`SyntaxError`

Too many arguments.

`IOError`

Object is not opened, or seek error.

`pg.error`

Invalid connection or invalid object.

Description

`tell()` method allows to get the current position in the large object.

unlink

Name

`unlink` — delete the large object

Synopsis

```
unlink()
```

Parameters

none

Return Type

none

Exceptions

`SyntaxError`

Too many arguments.

`IOError`

Object is not closed, or unlink error.

`pg.error`

Invalid connection or invalid object.

Description

`unlink()` method unlinks (deletes) the large object.

size

Name

`size` — return the large object size

Synopsis

```
size()
```

Parameters

none

Return Type

integer

The large object size.

Exceptions

`SyntaxError`

Too many arguments.

`IOError`

Object is not opened, or seek/tell error.

`pg.error`

Invalid connection or invalid object.

Description

`size()` method allows to get the size of the large object. It was implemented because this function is very useful for a WWW-interfaced database. Currently, the large object needs to be opened first.

export

Name

`export` — save the large object to file

Synopsis

```
export(filename)
```

Parameters

`filename`

The file to be created.

Return Type

none

Exceptions

`TypeError`

Bad argument type, or too many arguments.

`IOError`

Object is not closed, or export error.

`pg.error`

Invalid connection or invalid object.

Description

`export()` method allows to dump the content of a large object in a very simple way. The exported file is created on the host of the program, not the server host.

II. Server Programming

This second part of the manual explains the PostgreSQL approach to extensibility and describe how users can extend PostgreSQL by adding user-defined types, operators, aggregates, and both query language and programming language functions. After a discussion of the PostgreSQL rule system, we discuss the trigger and SPI interfaces.

Chapter 7. Architecture

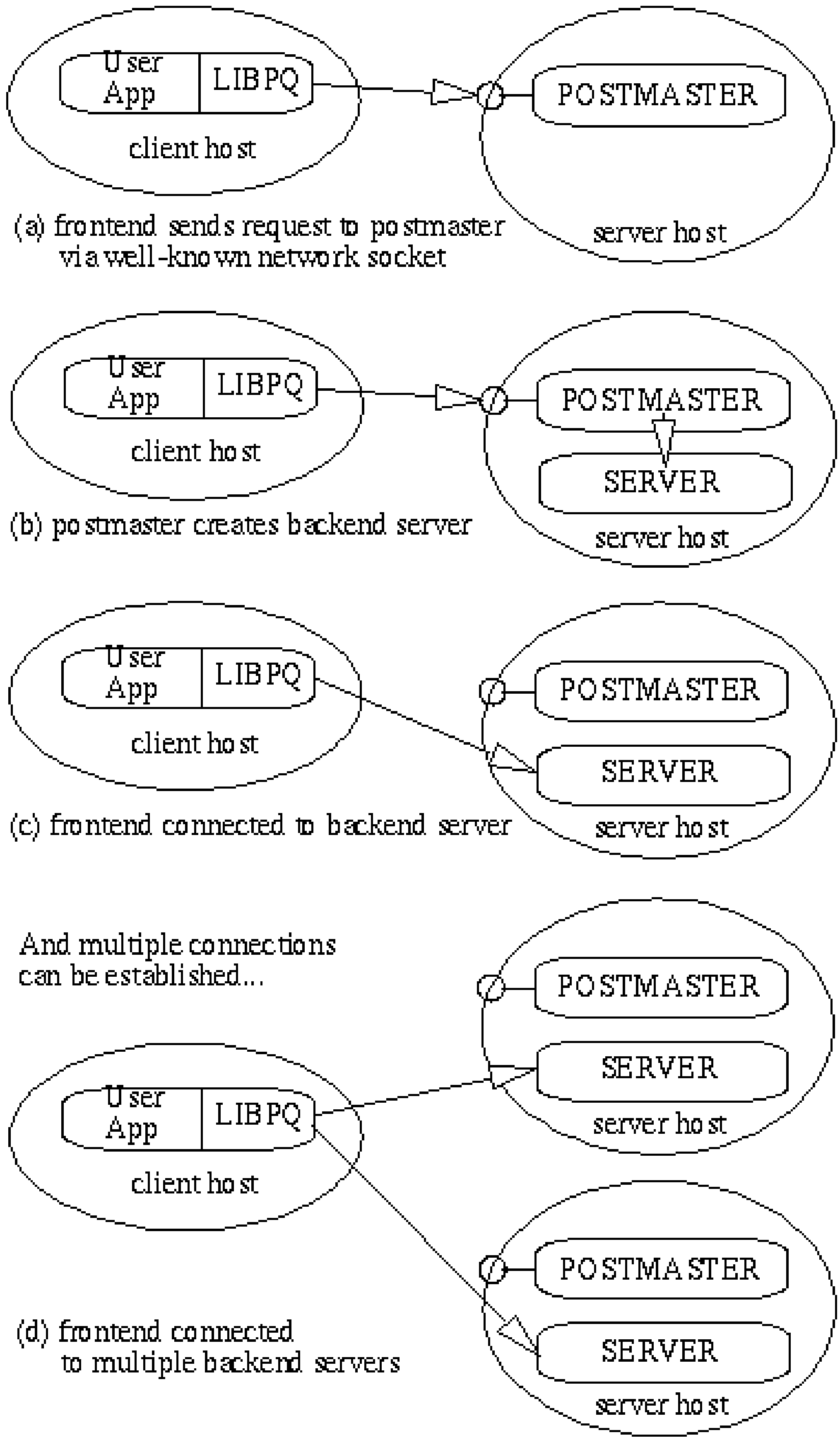
7.1. PostgreSQL Architectural Concepts

Before we begin, you should understand the basic PostgreSQL system architecture. Understanding how the parts of PostgreSQL interact will make the next chapter somewhat clearer. In database jargon, PostgreSQL uses a simple "process per-user" client/server model. A PostgreSQL session consists of the following cooperating Unix processes (programs):

- A supervisory daemon process (the postmaster),
- the user's frontend application (e.g., the psql program), and
- one or more backend database servers (the postgres process itself).

A single postmaster manages a given collection of databases on a single host. Such a collection of databases is called a cluster (of databases). A frontend application that wishes to access a given database within a cluster makes calls to an interface library (e.g., libpq) that is linked into the application. The library sends user requests over the network to the postmaster (Figure 7-1(a)), which in turn starts a new backend server process (Figure 7-1(b))

Figure 7-1. How a connection is established



and connects the frontend process to the new server (Figure 7-1(c)). From that point on, the frontend process and the backend server communicate without intervention by the postmaster. Hence, the postmaster is always running, waiting for connection requests, whereas frontend and backend processes come and go. The `libpq` library allows a single frontend to make multiple connections to backend processes. However, each backend process is a single-threaded process that can only execute one query at a time; so the communication over any one frontend-to-backend connection is single-threaded.

One implication of this architecture is that the postmaster and the backend always run on the same machine (the database server), while the frontend application may run anywhere. You should keep this in mind, because the files that can be accessed on a client machine may not be accessible (or may only be accessed using a different path name) on the database server machine.

You should also be aware that the postmaster and postgres servers run with the user ID of the PostgreSQL "superuser". Note that the PostgreSQL superuser does not have to be any particular user (e.g., a user named `postgres`), although many systems are installed that way. Furthermore, the PostgreSQL superuser should definitely not be the Unix superuser, `root`! It is safest if the PostgreSQL superuser is an ordinary, unprivileged user so far as the surrounding Unix system is concerned. In any case, all files relating to a database should belong to this Postgres superuser.

Chapter 8. Extending SQL: An Overview

In the sections that follow, we will discuss how you can extend the PostgreSQL SQL query language by adding:

- functions
- data types
- operators
- aggregates

8.1. How Extensibility Works

PostgreSQL is extensible because its operation is catalog-driven. If you are familiar with standard relational systems, you know that they store information about databases, tables, columns, etc., in what are commonly known as system catalogs. (Some systems call this the data dictionary). The catalogs appear to the user as tables like any other, but the DBMS stores its internal bookkeeping in them. One key difference between PostgreSQL and standard relational systems is that PostgreSQL stores much more information in its catalogs -- not only information about tables and columns, but also information about its types, functions, access methods, and so on. These tables can be modified by the user, and since PostgreSQL bases its internal operation on these tables, this means that PostgreSQL can be extended by users. By comparison, conventional database systems can only be extended by changing hardcoded procedures within the DBMS or by loading modules specially written by the DBMS vendor.

PostgreSQL is also unlike most other data managers in that the server can incorporate user-written code into itself through dynamic loading. That is, the user can specify an object code file (e.g., a shared library) that implements a new type or function and PostgreSQL will load it as required. Code written in SQL is even more trivial to add to the server. This ability to modify its operation "on the fly" makes PostgreSQL uniquely suited for rapid prototyping of new applications and storage structures.

8.2. The PostgreSQL Type System

The PostgreSQL type system can be broken down in several ways. Types are divided into base types and composite types. Base types are those, like `int4`, that are implemented in a language such as C. They generally correspond to what are often known as *abstract data types*; PostgreSQL can only operate on such types through methods provided by the user and only understands the behavior of such types to the extent that the user describes them. Composite types are created whenever the user creates a table.

PostgreSQL stores these types in only one way (within the file that stores all rows of a table) but the user can "look inside" at the attributes of these types from the query language and optimize their retrieval by (for example) defining indexes on the attributes. PostgreSQL base types are further divided into built-in types and user-defined types. Built-in types (like `int4`) are those that are compiled into the system. User-defined types are those created by the user in the manner to be described later.

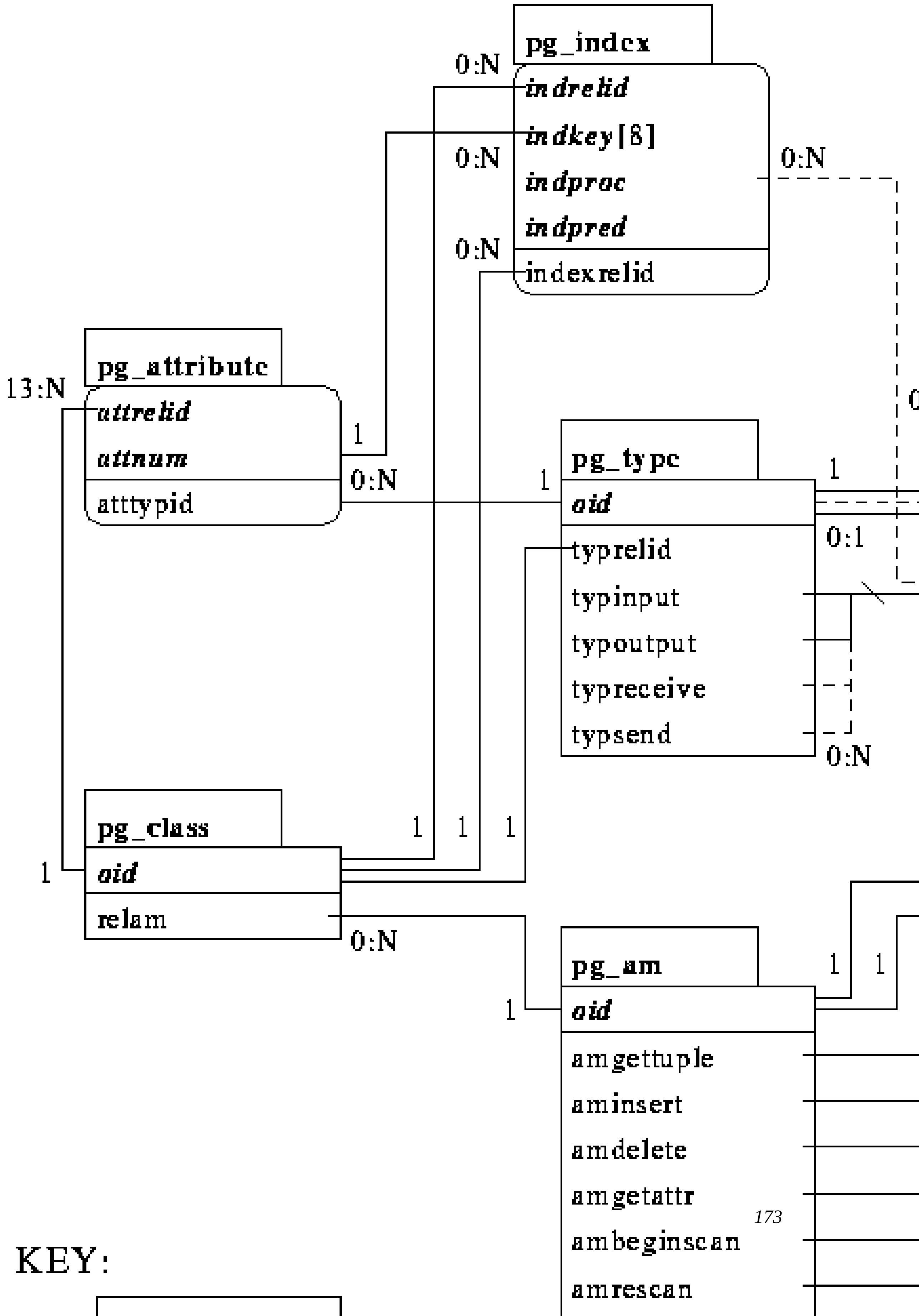
8.3. About the PostgreSQL System Catalogs

Having introduced the basic extensibility concepts, we can now take a look at how the catalogs are actually laid out. You can skip this section for now, but some later sections will be incomprehensible without the information given here, so mark this page for later reference. All system catalogs have names that begin with `pg_`. The following tables contain information that may be useful to the end user. (There are many other system catalogs, but there should rarely be a reason to query them directly.)

Table 8-1. PostgreSQL System Catalogs

Catalog Name	Description
`pg_database`	databases
`pg_class`	tables
`pg_attribute`	table columns
`pg_index`	indexes
`pg_proc`	procedures/functions
`pg_type`	data types (both base and complex)
`pg_operator`	operators
`pg_aggregate`	aggregate functions
`pg_am`	access methods
`pg_amop`	access method operators
`pg_amproc`	access method support functions
`pg_opclass`	access method operator classes

Figure 8-1. The major PostgreSQL system catalogs



The *Developer's Guide* gives a more detailed explanation of these catalogs and their columns. However, Figure 8-1 shows the major entities and their relationships in the system catalogs. (Columns that do not refer to other entities are not shown unless they are part of a primary key.) This diagram is more or less incomprehensible until you actually start looking at the contents of the catalogs and see how they relate to each other. For now, the main things to take away from this diagram are as follows:

- In several of the sections that follow, we will present various join queries on the system catalogs that display information we need to extend the system. Looking at this diagram should make some of these join queries (which are often three- or four-way joins) more understandable, because you will be able to see that the columns used in the queries form foreign keys in other tables.
- Many different features (tables, columns, functions, types, access methods, etc.) are tightly integrated in this schema. A simple create command may modify many of these catalogs.
- Types and procedures are central to the schema.

  Note: We use the words *procedure* and *function* more or less interchangeably.

  Nearly every catalog contains some reference to rows in one or both of these tables. For example, PostgreSQL frequently uses type signatures (e.g., of functions and operators) to identify unique rows of other catalogs.

- There are many columns and relationships that have obvious meanings, but there are many (particularly those that have to do with access methods) that do not.

Chapter 9. Extending SQL: Functions

9.1. Introduction

PostgreSQL provides four kinds of functions:

- query language functions (functions written in SQL)
- procedural language functions (functions written in, for example, PL/Tcl or PL/pgSQL)
- internal functions
- C language functions

Every kind of function can take a base type, a composite type, or some combination as arguments (parameters). In addition, every kind of function can return a base type or a composite type. It's easiest to define SQL functions, so we'll start with those. Examples in this section can also be found in `funcs.sql` and `funcs.c` in the tutorial directory.

Throughout this chapter, it can be useful to look at the reference page of the `CREATE FUNCTION` command to understand the examples better.

9.2. Query Language (SQL) Functions

SQL functions execute an arbitrary list of SQL statements, returning the result of the last query in the list, which must be a `SELECT`. In the simple (non-set) case, the first row of the last query's result will be returned. (Bear in mind that "the first row" of a multirow result is not well-defined unless you use `ORDER BY`.) If the last query happens to return no rows at all, NULL will be returned.

Alternatively, an SQL function may be declared to return a set, by specifying the function's return type as `SETOF` *`sometype`*. In this case all rows of the last query's result are returned. Further details appear below.

The body of an SQL function should be a list of one or more SQL statements separated by semicolons. Note that because the syntax of the `CREATE FUNCTION` command requires the body of the function to be enclosed in single quotes, single quote marks (`'`) used in the body of the function must be escaped, by writing two single quotes (`''`) or a backslash (`\'`) where each quote is desired.

Arguments to the SQL function may be referenced in the function body using the syntax `$`*`n`*: $1 refers to the first argument, $2 to the second, and so on. If an argument is of a composite type, then the "dot notation", e.g., `$1.emp`, may be used to access attributes of the argument.

9.2.1. Examples

To illustrate a simple SQL function, consider the following, which might be used to debit a bank account:

```
CREATE FUNCTION tp1 (integer, numeric) RETURNS integer AS '
    UPDATE bank
        SET balance = balance - $2
```

```
        WHERE accountno = $1;
    SELECT 1;
' LANGUAGE SQL;
```

A user could execute this function to debit account 17 by $100.00 as follows:

```
SELECT tp1(17, 100.0);
```

In practice one would probably like a more useful result from the function than a constant “1”, so a more likely definition is

```
CREATE FUNCTION tp1 (integer, numeric) RETURNS numeric AS '
    UPDATE bank
        SET balance = balance - $2
        WHERE accountno = $1;
    SELECT balance FROM bank WHERE accountno = $1;
' LANGUAGE SQL;
```

which adjusts the balance and returns the new balance.

Any collection of commands in the SQL language can be packaged together and defined as a function. The commands can include data modification (i.e., `INSERT`, `UPDATE`, and `DELETE`) as well as `SELECT` queries. However, the final command must be a `SELECT` that returns whatever is specified as the function’s return type. Alternatively, if you want to define a SQL function that performs actions but has no useful value to return, you can define it as returning `void`. In that case it must not end with a `SELECT`. For example:

```
CREATE FUNCTION clean_EMP () RETURNS void AS '
    DELETE FROM EMP
        WHERE EMP.salary <= 0;
' LANGUAGE SQL;

SELECT clean_EMP();

 clean_emp
-----------

(1 row)
```

9.2.2. SQL Functions on Base Types

The simplest possible SQL function has no arguments and simply returns a base type, such as `integer`:

```
CREATE FUNCTION one() RETURNS integer AS '
    SELECT 1 as RESULT;
' LANGUAGE SQL;

SELECT one();

 one
```

```
-----
   1
```

Notice that we defined a column alias within the function body for the result of the function (with the name `RESULT`), but this column alias is not visible outside the function. Hence, the result is labeled `one` instead of `RESULT`.

It is almost as easy to define SQL functions that take base types as arguments. In the example below, notice how we refer to the arguments within the function as `$1` and `$2`:

```
CREATE FUNCTION add_em(integer, integer) RETURNS integer AS '
    SELECT $1 + $2;
' LANGUAGE SQL;

SELECT add_em(1, 2) AS answer;

 answer
--------
      3
```

9.2.3. SQL Functions on Composite Types

When specifying functions with arguments of composite types, we must not only specify which argument we want (as we did above with `$1` and `$2`) but also the attributes of that argument. For example, suppose that `EMP` is a table containing employee data, and therefore also the name of the composite type of each row of the table. Here is a function `double_salary` that computes what your salary would be if it were doubled:

```
CREATE FUNCTION double_salary(EMP) RETURNS integer AS '
    SELECT $1.salary * 2 AS salary;
' LANGUAGE SQL;

SELECT name, double_salary(EMP) AS dream
    FROM EMP
    WHERE EMP.cubicle ~= point '(2,1)';

 name | dream
------+-------
 Sam  |  2400
```

Notice the use of the syntax `$1.salary` to select one field of the argument row value. Also notice how the calling `SELECT` command uses a table name to denote the entire current row of that table as a composite value.

It is also possible to build a function that returns a composite type. This is an example of a function that returns a single `EMP` row:

```
CREATE FUNCTION new_emp() RETURNS EMP AS '
    SELECT text ''None'' AS name,
        1000 AS salary,
        25 AS age,
        point ''(2,2)'' AS cubicle;
' LANGUAGE SQL;
```

In this case we have specified each of the attributes with a constant value, but any computation or expression could have been substituted for these constants. Note two important things about defining the function:

- The target list order must be exactly the same as that in which the columns appear in the table associated with the composite type. (Naming the columns, as we did above, is irrelevant to the system.)
- You must typecast the expressions to match the definition of the composite type, or you will get errors like this:

```
ERROR:  function declared to return emp returns varchar instead of text at column 1
```

A function that returns a row (composite type) can be used as a table function, as described below. It can also be called in the context of an SQL expression, but only when you extract a single attribute out of the row or pass the entire row into another function that accepts the same composite type. For example,

```
SELECT (new_emp()).name;

 name
------
 None
```

We need the extra parentheses to keep the parser from getting confused:

```
SELECT new_emp().name;
ERROR:  parser: parse error at or near "."
```

Another option is to use functional notation for extracting an attribute. The simple way to explain this is that we can use the notations `attribute(table)` and `table.attribute` interchangeably:

```
SELECT name(new_emp());

 name
------
 None

--
-- this is the same as:
--  SELECT EMP.name AS youngster FROM EMP WHERE EMP.age < 30
--
SELECT name(EMP) AS youngster
    FROM EMP
```

```
    WHERE age(EMP) < 30;

 youngster
-----------
 Sam
```

Another way to use a function returning a row result is to declare a second function accepting a row type parameter, and pass the function result to it:

```
CREATE FUNCTION getname(emp) RETURNS text AS
'SELECT $1.name;'
LANGUAGE SQL;

SELECT getname(new_emp());
 getname
---------
 None
(1 row)
```

9.2.4. SQL Table Functions

A table function is one that may be used in the `FROM` clause of a query. All SQL language functions may be used in this manner, but it is particularly useful for functions returning composite types. If the function is defined to return a base type, the table function produces a one-column table. If the function is defined to return a composite type, the table function produces a column for each column of the composite type.

Here is an example:

```
CREATE TABLE foo (fooid int, foosubid int, fooname text);
INSERT INTO foo VALUES(1,1,'Joe');
INSERT INTO foo VALUES(1,2,'Ed');
INSERT INTO foo VALUES(2,1,'Mary');

CREATE FUNCTION getfoo(int) RETURNS foo AS '
    SELECT * FROM foo WHERE fooid = $1;
' LANGUAGE SQL;

SELECT *, upper(fooname) FROM getfoo(1) AS t1;

 fooid | foosubid | fooname | upper
-------+----------+---------+-------
     1 |        1 | Joe     | JOE
(2 rows)
```

As the example shows, we can work with the columns of the function's result just the same as if they were columns of a regular table.

Note that we only got one row out of the function. This is because we did not say `SETOF`.

9.2.5. SQL Functions Returning Sets

When an SQL function is declared as returning `SETOF` *`sometype`*, the function's final `SELECT` query is executed to completion, and each row it outputs is returned as an element of the set.

This feature is normally used by calling the function as a table function. In this case each row returned by the function becomes a row of the table seen by the query. For example, assume that table `foo` has the same contents as above, and we say:

```
CREATE FUNCTION getfoo(int) RETURNS setof foo AS '
    SELECT * FROM foo WHERE fooid = $1;
' LANGUAGE SQL;

SELECT * FROM getfoo(1) AS t1;

 fooid | foosubid | fooname
-------+----------+---------
     1 |        1 | Joe
     1 |        2 | Ed
(2 rows)
```

Currently, functions returning sets may also be called in the target list of a `SELECT` query. For each row that the `SELECT` generates by itself, the function returning set is invoked, and an output row is generated for each element of the function's result set. Note, however, that this capability is deprecated and may be removed in future releases. The following is an example function returning a set from the target list:

```
CREATE FUNCTION listchildren(text) RETURNS SETOF text AS
'SELECT name FROM nodes WHERE parent = $1'
LANGUAGE SQL;

SELECT * FROM nodes;
   name    | parent
-----------+--------
 Top       |
 Child1    | Top
 Child2    | Top
 Child3    | Top
 SubChild1 | Child1
 SubChild2 | Child1
(6 rows)

SELECT listchildren('Top');
 listchildren
--------------
 Child1
 Child2
 Child3
(3 rows)

SELECT name, listchildren(name) FROM nodes;
  name  | listchildren
--------+--------------
```

```
 Top    | Child1
 Top    | Child2
 Top    | Child3
 Child1 | SubChild1
 Child1 | SubChild2
(5 rows)
```

In the last `SELECT`, notice that no output row appears for `Child2`, `Child3`, etc. This happens because `listchildren` returns an empty set for those inputs, so no output rows are generated.

9.3. Procedural Language Functions

Procedural languages aren't built into the PostgreSQL server; they are offered by loadable modules. Please refer to the documentation of the procedural language in question for details about the syntax and how the function body is interpreted for each language.

There are currently four procedural languages available in the standard PostgreSQL distribution: PL/pgSQL, PL/Tcl, PL/Perl, and PL/Python. Other languages can be defined by users. Refer to Chapter 18 for more information. The basics of developing a new procedural language are covered in Section 9.8.

9.4. Internal Functions

Internal functions are functions written in C that have been statically linked into the PostgreSQL server. The "body" of the function definition specifies the C-language name of the function, which need not be the same as the name being declared for SQL use. (For reasons of backwards compatibility, an empty body is accepted as meaning that the C-language function name is the same as the SQL name.)

Normally, all internal functions present in the backend are declared during the initialization of the database cluster (`initdb`), but a user could use `CREATE FUNCTION` to create additional alias names for an internal function. Internal functions are declared in `CREATE FUNCTION` with language name `internal`. For instance, to create an alias for the `sqrt` function:

```
CREATE FUNCTION square_root(double precision) RETURNS double precision
    AS ’dsqrt’
    LANGUAGE INTERNAL
    WITH (isStrict);
```

(Most internal functions expect to be declared "strict".)

> **Note:** Not all "predefined" functions are "internal" in the above sense. Some predefined functions are written in SQL.

9.5. C Language Functions

User-defined functions can be written in C (or a language that can be made compatible with C, such as C++). Such functions are compiled into dynamically loadable objects (also called shared libraries) and are loaded by the server on demand. The dynamic loading feature is what distinguishes "C language" functions from "internal" functions --- the actual coding conventions are essentially the same for both. (Hence, the standard internal function library is a rich source of coding examples for user-defined C functions.)

Two different calling conventions are currently used for C functions. The newer "version 1" calling convention is indicated by writing a `PG_FUNCTION_INFO_V1()` macro call for the function, as illustrated below. Lack of such a macro indicates an old-style ("version 0") function. The language name specified in `CREATE FUNCTION` is `C` in either case. Old-style functions are now deprecated because of portability problems and lack of functionality, but they are still supported for compatibility reasons.

9.5.1. Dynamic Loading

The first time a user-defined function in a particular loadable object file is called in a backend session, the dynamic loader loads that object file into memory so that the function can be called. The `CREATE FUNCTION` for a user-defined C function must therefore specify two pieces of information for the function: the name of the loadable object file, and the C name (link symbol) of the specific function to call within that object file. If the C name is not explicitly specified then it is assumed to be the same as the SQL function name.

The following algorithm is used to locate the shared object file based on the name given in the `CREATE FUNCTION` command:

1. If the name is an absolute path, the given file is loaded.
2. If the name starts with the string `$libdir`, that part is replaced by the PostgreSQL package library directory name, which is determined at build time.
3. If the name does not contain a directory part, the file is searched for in the path specified by the configuration variable `dynamic_library_path`.
4. Otherwise (the file was not found in the path, or it contains a non-absolute directory part), the dynamic loader will try to take the name as given, which will most likely fail. (It is unreliable to depend on the current working directory.)

If this sequence does not work, the platform-specific shared library file name extension (often `.so`) is appended to the given name and this sequence is tried again. If that fails as well, the load will fail.

> **Note:** The user ID the PostgreSQL server runs as must be able to traverse the path to the file you intend to load. Making the file or a higher-level directory not readable and/or not executable by the postgres user is a common mistake.

In any case, the file name that is given in the `CREATE FUNCTION` command is recorded literally in the system catalogs, so if the file needs to be loaded again the same procedure is applied.

> **Note:** PostgreSQL will not compile a C function automatically. The object file must be compiled before it is referenced in a `CREATE FUNCTION` command. See Section 9.5.8 for additional information.

> **Note:** After it is used for the first time, a dynamically loaded object file is retained in memory. Future calls in the same session to the function(s) in that file will only incur the small overhead of a symbol table lookup. If you need to force a reload of an object file, for example after recompiling it, use the `LOAD` command or begin a fresh session.

It is recommended to locate shared libraries either relative to `$libdir` or through the dynamic library path. This simplifies version upgrades if the new installation is at a different location. The actual directory that `$libdir` stands for can be found out with the command `pg_config --pkglibdir`.

> **Note:** Before PostgreSQL release 7.2, only exact absolute paths to object files could be specified in `CREATE FUNCTION`. This approach is now deprecated since it makes the function definition unnecessarily unportable. It's best to specify just the shared library name with no path nor extension, and let the search mechanism provide that information instead.

9.5.2. Base Types in C-Language Functions

Table 9-1 gives the C type required for parameters in the C functions that will be loaded into PostgreSQL. The "Defined In" column gives the header file that needs to be included to get the type definition. (The actual definition may be in a different file that is included by the listed file. It is recommended that users stick to the defined interface.) Note that you should always include `postgres.h` first in any source file, because it declares a number of things that you will need anyway.

Table 9-1. Equivalent C Types for Built-In PostgreSQL Types

SQL Type	C Type	Defined In
`abstime`	`AbsoluteTime`	`utils/nabstime.h`
`boolean`	`bool`	`postgres.h` (maybe compiler built-in)
`box`	`BOX*`	`utils/geo_decls.h`
`bytea`	`bytea*`	`postgres.h`
`"char"`	`char`	(compiler built-in)
`character`	`BpChar*`	`postgres.h`
`cid`	`CommandId`	`postgres.h`
`date`	`DateADT`	`utils/date.h`
`smallint` (`int2`)	`int2` or `int16`	`postgres.h`
`int2vector`	`int2vector*`	`postgres.h`
`integer` (`int4`)	`int4` or `int32`	`postgres.h`
`real` (`float4`)	`float4*`	`postgres.h`
`double precision` (`float8`)	`float8*`	`postgres.h`

SQL Type	C Type	Defined In
interval	Interval*	utils/timestamp.h
lseg	LSEG*	utils/geo_decls.h
name	Name	postgres.h
oid	Oid	postgres.h
oidvector	oidvector*	postgres.h
path	PATH*	utils/geo_decls.h
point	POINT*	utils/geo_decls.h
regproc	regproc	postgres.h
reltime	RelativeTime	utils/nabstime.h
text	text*	postgres.h
tid	ItemPointer	storage/itemptr.h
time	TimeADT	utils/date.h
time with time zone	TimeTzADT	utils/date.h
timestamp	Timestamp*	utils/timestamp.h
tinterval	TimeInterval	utils/nabstime.h
varchar	VarChar*	postgres.h
xid	TransactionId	postgres.h

Internally, PostgreSQL regards a base type as a "blob of memory". The user-defined functions that you define over a type in turn define the way that PostgreSQL can operate on it. That is, PostgreSQL will only store and retrieve the data from disk and use your user-defined functions to input, process, and output the data. Base types can have one of three internal formats:

- pass by value, fixed-length
- pass by reference, fixed-length
- pass by reference, variable-length

By-value types can only be 1, 2 or 4 bytes in length (also 8 bytes, if `sizeof(Datum)` is 8 on your machine). You should be careful to define your types such that they will be the same size (in bytes) on all architectures. For example, the `long` type is dangerous because it is 4 bytes on some machines and 8 bytes on others, whereas `int` type is 4 bytes on most Unix machines. A reasonable implementation of the `int4` type on Unix machines might be:

```
/* 4-byte integer, passed by value */
typedef int int4;
```

PostgreSQL automatically figures things out so that the integer types really have the size they advertise.

On the other hand, fixed-length types of any size may be passed by-reference. For example, here is a sample implementation of a PostgreSQL type:

```
/* 16-byte structure, passed by reference */
```

```
typedef struct
{
    double  x, y;
} Point;
```

Only pointers to such types can be used when passing them in and out of PostgreSQL functions. To return a value of such a type, allocate the right amount of memory with `palloc()`, fill in the allocated memory, and return a pointer to it. (Alternatively, you can return an input value of the same type by returning its pointer. *Never* modify the contents of a pass-by-reference input value, however.)

Finally, all variable-length types must also be passed by reference. All variable-length types must begin with a length field of exactly 4 bytes, and all data to be stored within that type must be located in the memory immediately following that length field. The length field is the total length of the structure (i.e., it includes the size of the length field itself). We can define the text type as follows:

```
typedef struct {
    int4 length;
    char data[1];
} text;
```

Obviously, the data field declared here is not long enough to hold all possible strings. Since it's impossible to declare a variable-size structure in C, we rely on the knowledge that the C compiler won't range-check array subscripts. We just allocate the necessary amount of space and then access the array as if it were declared the right length. (If this isn't a familiar trick to you, you may wish to spend some time with an introductory C programming textbook before delving deeper into PostgreSQL server programming.) When manipulating variable-length types, we must be careful to allocate the correct amount of memory and set the length field correctly. For example, if we wanted to store 40 bytes in a text structure, we might use a code fragment like this:

```
#include "postgres.h"
...
char buffer[40]; /* our source data */
...
text *destination = (text *) palloc(VARHDRSZ + 40);
destination->length = VARHDRSZ + 40;
memcpy(destination->data, buffer, 40);
...
```

`VARHDRSZ` is the same as `sizeof(int4)`, but it's considered good style to use the macro `VARHDRSZ` to refer to the size of the overhead for a variable-length type.

Now that we've gone over all of the possible structures for base types, we can show some examples of real functions.

9.5.3. Version-0 Calling Conventions for C-Language Functions

We present the "old style" calling convention first --- although this approach is now deprecated, it's easier to get a handle on initially. In the version-0 method, the arguments and result of the C function are just declared in normal C style, but being careful to use the C representation of each SQL data type as shown above.

Here are some examples:

```
#include "postgres.h"
#include <string.h>

/* By Value */

int
add_one(int arg)
{
    return arg + 1;
}

/* By Reference, Fixed Length */

float8 *
add_one_float8(float8 *arg)
{
    float8    *result = (float8 *) palloc(sizeof(float8));

    *result = *arg + 1.0;

    return result;
}

Point *
makepoint(Point *pointx, Point *pointy)
{
    Point     *new_point = (Point *) palloc(sizeof(Point));

    new_point->x = pointx->x;
    new_point->y = pointy->y;

    return new_point;
}

/* By Reference, Variable Length */

text *
copytext(text *t)
{
    /*
     * VARSIZE is the total size of the struct in bytes.
     */
    text *new_t = (text *) palloc(VARSIZE(t));
    VARATT_SIZEP(new_t) = VARSIZE(t);
    /*
     * VARDATA is a pointer to the data region of the struct.
     */
    memcpy((void *) VARDATA(new_t), /* destination */
```

```
                (void *) VARDATA(t),      /* source */
                VARSIZE(t)-VARHDRSZ);     /* how many bytes */
        return new_t;
    }

    text *
    concat_text(text *arg1, text *arg2)
    {
        int32 new_text_size = VARSIZE(arg1) + VARSIZE(arg2) - VARHDRSZ;
        text *new_text = (text *) palloc(new_text_size);

        VARATT_SIZEP(new_text) = new_text_size;
        memcpy(VARDATA(new_text), VARDATA(arg1), VARSIZE(arg1)-VARHDRSZ);
        memcpy(VARDATA(new_text) + (VARSIZE(arg1)-VARHDRSZ),
               VARDATA(arg2), VARSIZE(arg2)-VARHDRSZ);
        return new_text;
    }
```

Supposing that the above code has been prepared in file `funcs.c` and compiled into a shared object, we could define the functions to PostgreSQL with commands like this:

```
CREATE FUNCTION add_one(int4) RETURNS int4
     AS 'PGROOT/tutorial/funcs' LANGUAGE C
     WITH (isStrict);

-- note overloading of SQL function name add_one()
CREATE FUNCTION add_one(float8) RETURNS float8
     AS 'PGROOT/tutorial/funcs',
        'add_one_float8'
     LANGUAGE C WITH (isStrict);

CREATE FUNCTION makepoint(point, point) RETURNS point
     AS 'PGROOT/tutorial/funcs' LANGUAGE C
     WITH (isStrict);

CREATE FUNCTION copytext(text) RETURNS text
     AS 'PGROOT/tutorial/funcs' LANGUAGE C
     WITH (isStrict);

CREATE FUNCTION concat_text(text, text) RETURNS text
     AS 'PGROOT/tutorial/funcs' LANGUAGE C
     WITH (isStrict);
```

Here *`PGROOT`* stands for the full path to the PostgreSQL source tree. (Better style would be to use just `'funcs'` in the `AS` clause, after having added *`PGROOT`*`/tutorial` to the search path. In any case, we may omit the system-specific extension for a shared library, commonly `.so` or `.sl`.)

Notice that we have specified the functions as "strict", meaning that the system should automatically assume a NULL result if any input value is NULL. By doing this, we avoid having to check for NULL inputs in the function code. Without this, we'd have to check for null values explicitly, for example by checking for a null pointer for each pass-by-reference argument. (For pass-by-value arguments, we don't even have a way to check!)

Although this calling convention is simple to use, it is not very portable; on some architectures there are problems with passing smaller-than-int data types this way. Also, there is no simple way to return a NULL result, nor to cope with NULL arguments in any way other than making the function strict. The version-1 convention, presented next, overcomes these objections.

9.5.4. Version-1 Calling Conventions for C-Language Functions

The version-1 calling convention relies on macros to suppress most of the complexity of passing arguments and results. The C declaration of a version-1 function is always

```
Datum funcname(PG_FUNCTION_ARGS)
```

In addition, the macro call

```
PG_FUNCTION_INFO_V1(funcname);
```

must appear in the same source file (conventionally it's written just before the function itself). This macro call is not needed for `internal`-language functions, since PostgreSQL currently assumes all internal functions are version-1. However, it is *required* for dynamically-loaded functions.

In a version-1 function, each actual argument is fetched using a `PG_GETARG_xxx()` macro that corresponds to the argument's data type, and the result is returned using a `PG_RETURN_xxx()` macro for the return type.

Here we show the same functions as above, coded in version-1 style:

```
#include "postgres.h"
#include <string.h>
#include "fmgr.h"

/* By Value */

PG_FUNCTION_INFO_V1(add_one);

Datum
add_one(PG_FUNCTION_ARGS)
{
    int32   arg = PG_GETARG_INT32(0);

    PG_RETURN_INT32(arg + 1);
}

/* By Reference, Fixed Length */

PG_FUNCTION_INFO_V1(add_one_float8);

Datum
add_one_float8(PG_FUNCTION_ARGS)
{
    /* The macros for FLOAT8 hide its pass-by-reference nature */
```

```
    float8   arg = PG_GETARG_FLOAT8(0);

    PG_RETURN_FLOAT8(arg + 1.0);
}

PG_FUNCTION_INFO_V1(makepoint);

Datum
makepoint(PG_FUNCTION_ARGS)
{
    /* Here, the pass-by-reference nature of Point is not hidden */
    Point     *pointx = PG_GETARG_POINT_P(0);
    Point     *pointy = PG_GETARG_POINT_P(1);
    Point     *new_point = (Point *) palloc(sizeof(Point));

    new_point->x = pointx->x;
    new_point->y = pointy->y;

    PG_RETURN_POINT_P(new_point);
}

/* By Reference, Variable Length */

PG_FUNCTION_INFO_V1(copytext);

Datum
copytext(PG_FUNCTION_ARGS)
{
    text     *t = PG_GETARG_TEXT_P(0);
    /*
     * VARSIZE is the total size of the struct in bytes.
     */
    text     *new_t = (text *) palloc(VARSIZE(t));
    VARATT_SIZEP(new_t) = VARSIZE(t);
    /*
     * VARDATA is a pointer to the data region of the struct.
     */
    memcpy((void *) VARDATA(new_t), /* destination */
           (void *) VARDATA(t),     /* source */
           VARSIZE(t)-VARHDRSZ);    /* how many bytes */
    PG_RETURN_TEXT_P(new_t);
}

PG_FUNCTION_INFO_V1(concat_text);

Datum
concat_text(PG_FUNCTION_ARGS)
{
    text  *arg1 = PG_GETARG_TEXT_P(0);
    text  *arg2 = PG_GETARG_TEXT_P(1);
    int32 new_text_size = VARSIZE(arg1) + VARSIZE(arg2) - VARHDRSZ;
    text *new_text = (text *) palloc(new_text_size);
```

```
    VARATT_SIZEP(new_text) = new_text_size;
    memcpy(VARDATA(new_text), VARDATA(arg1), VARSIZE(arg1)-VARHDRSZ);
    memcpy(VARDATA(new_text) + (VARSIZE(arg1)-VARHDRSZ),
           VARDATA(arg2), VARSIZE(arg2)-VARHDRSZ);
    PG_RETURN_TEXT_P(new_text);
}
```

The `CREATE FUNCTION` commands are the same as for the version-0 equivalents.

At first glance, the version-1 coding conventions may appear to be just pointless obscurantism. However, they do offer a number of improvements, because the macros can hide unnecessary detail. An example is that in coding `add_one_float8`, we no longer need to be aware that `float8` is a pass-by-reference type. Another example is that the `GETARG` macros for variable-length types hide the need to deal with fetching "toasted" (compressed or out-of-line) values. The old-style `copytext` and `concat_text` functions shown above are actually wrong in the presence of toasted values, because they don't call `pg_detoast_datum()` on their inputs. (The handler for old-style dynamically-loaded functions currently takes care of this detail, but it does so less efficiently than is possible for a version-1 function.)

One big improvement in version-1 functions is better handling of NULL inputs and results. The macro `PG_ARGISNULL(`*`n`*`)` allows a function to test whether each input is NULL (of course, doing this is only necessary in functions not declared "strict"). As with the `PG_GETARG_`*`xxx`*`()` macros, the input arguments are counted beginning at zero. Note that one should refrain from executing `PG_GETARG_`*`xxx`*`()` until one has verified that the argument isn't NULL. To return a NULL result, execute `PG_RETURN_NULL()`; this works in both strict and nonstrict functions.

Other options provided in the new-style interface are two variants of the `PG_GETARG_`*`xxx`*`()` macros. The first of these, `PG_GETARG_`*`xxx`*`_COPY()` guarantees to return a copy of the specified parameter which is safe for writing into. (The normal macros will sometimes return a pointer to a value that is physically stored in a table, and so must not be written to. Using the `PG_GETARG_`*`xxx`*`_COPY()` macros guarantees a writable result.)

The second variant consists of the `PG_GETARG_`*`xxx`*`_SLICE()` macros which take three parameters. The first is the number of the parameter (as above). The second and third are the offset and length of the segment to be returned. Offsets are counted from zero, and a negative length requests that the remainder of the value be returned. These routines provide more efficient access to parts of large values in the case where they have storage type "external". (The storage type of a column can be specified using `ALTER TABLE` *`tablename`* `ALTER COLUMN` *`colname`* `SET STORAGE` *`storagetype`*. Storage type is one of `plain`, `external`, `extended`, or `main`.)

The version-1 function call conventions make it possible to return "set" results and implement trigger functions and procedural-language call handlers. Version-1 code is also more portable than version-0, because it does not break ANSI C restrictions on function call protocol. For more details see `src/backend/utils/fmgr/README` in the source distribution.

9.5.5. Composite Types in C-Language Functions

Composite types do not have a fixed layout like C structures. Instances of a composite type may contain null fields. In addition, composite types that are part of an inheritance hierarchy may have different fields than other members of the same inheritance hierarchy. Therefore, PostgreSQL provides a procedural interface for accessing fields of composite types from C. As PostgreSQL processes a set of rows, each row will be passed into your function as an opaque structure of type `TUPLE`. Suppose we want to write a function to answer the query

```
SELECT name, c_overpaid(emp, 1500) AS overpaid
FROM emp
WHERE name = 'Bill' OR name = 'Sam';
```

In the query above, we can define `c_overpaid` as:

```
#include "postgres.h"
#include "executor/executor.h"  /* for GetAttributeByName() */

bool
c_overpaid(TupleTableSlot *t, /* the current row of EMP */
           int32 limit)
{
    bool isnull;
    int32 salary;

    salary = DatumGetInt32(GetAttributeByName(t, "salary", &isnull));
    if (isnull)
        return (false);
    return salary > limit;
}

/* In version-1 coding, the above would look like this: */

PG_FUNCTION_INFO_V1(c_overpaid);

Datum
c_overpaid(PG_FUNCTION_ARGS)
{
    TupleTableSlot  *t = (TupleTableSlot *) PG_GETARG_POINTER(0);
    int32            limit = PG_GETARG_INT32(1);
    bool isnull;
    int32 salary;

    salary = DatumGetInt32(GetAttributeByName(t, "salary", &isnull));
    if (isnull)
        PG_RETURN_BOOL(false);
    /* Alternatively, we might prefer to do PG_RETURN_NULL() for null salary */

    PG_RETURN_BOOL(salary > limit);
}
```

`GetAttributeByName` is the PostgreSQL system function that returns attributes out of the current row. It has three arguments: the argument of type `TupleTableSlot*` passed into the function, the name of the desired attribute, and a return parameter that tells whether the attribute is null. `GetAttributeByName` returns a `Datum` value that you can convert to the proper data type by using the appropriate `DatumGetXXX()` macro.

The following command lets PostgreSQL know about the `c_overpaid` function:

```
CREATE FUNCTION c_overpaid(emp, int4)
RETURNS bool
AS 'PGROOT/tutorial/funcs'
LANGUAGE C;
```

9.5.6. Table Function API

The Table Function API assists in the creation of user-defined C language table functions (Section 9.7). Table functions are functions that produce a set of rows, made up of either base (scalar) data types, or composite (multi-column) data types. The API is split into two main components: support for returning composite data types, and support for returning multiple rows (set returning functions or SRFs).

The Table Function API relies on macros and functions to suppress most of the complexity of building composite data types and returning multiple results. A table function must follow the version-1 calling convention described above. In addition, the source file must include:

```
#include "funcapi.h"
```

9.5.6.1. Returning Rows (Composite Types)

The Table Function API support for returning composite data types (or rows) starts with the `AttInMetadata` structure. This structure holds arrays of individual attribute information needed to create a row from raw C strings. It also saves a pointer to the `TupleDesc`. The information carried here is derived from the `TupleDesc`, but it is stored here to avoid redundant CPU cycles on each call to a table function. In the case of a function returning a set, the `AttInMetadata` structure should be computed once during the first call and saved for re-use in later calls.

```
typedef struct AttInMetadata
{
    /* full TupleDesc */
    TupleDesc       tupdesc;

    /* array of attribute type input function finfo */
    FmgrInfo       *attinfuncs;

    /* array of attribute type typelem */
    Oid            *attelems;

    /* array of attribute typmod */
    int32        *atttypmods;
} AttInMetadata;
```

To assist you in populating this structure, several functions and a macro are available. Use

```
TupleDesc RelationNameGetTupleDesc(const char *relname)
```

to get a `TupleDesc` based on a specified relation, or

```
TupleDesc TypeGetTupleDesc(Oid typeoid, List *colaliases)
```

to get a `TupleDesc` based on a type OID. This can be used to get a `TupleDesc` for a base (scalar) or composite (relation) type. Then

```
AttInMetadata *TupleDescGetAttInMetadata(TupleDesc tupdesc)
```

will return a pointer to an `AttInMetadata`, initialized based on the given `TupleDesc`. `AttInMetadata` can be used in conjunction with C strings to produce a properly formed tuple. The metadata is stored here to avoid redundant work across multiple calls.

To return a tuple you must create a tuple slot based on the `TupleDesc`. You can use

```
TupleTableSlot *TupleDescGetSlot(TupleDesc tupdesc)
```

to initialize this tuple slot, or obtain one through other (user provided) means. The tuple slot is needed to create a `Datum` for return by the function. The same slot can (and should) be re-used on each call.

After constructing an `AttInMetadata` structure,

```
HeapTuple BuildTupleFromCStrings(AttInMetadata *attinmeta, char **values)
```

can be used to build a `HeapTuple` given user data in C string form. "values" is an array of C strings, one for each attribute of the return tuple. Each C string should be in the form expected by the input function of the attribute data type. In order to return a null value for one of the attributes, the corresponding pointer in the *`values`* array should be set to `NULL`. This function will need to be called again for each tuple you return.

Building a tuple via `TupleDescGetAttInMetadata` and `BuildTupleFromCStrings` is only convenient if your function naturally computes the values to be returned as text strings. If your code naturally computes the values as a set of Datums, you should instead use the underlying `heap_formtuple` routine to convert the `Datum`s directly into a tuple. You will still need the `TupleDesc` and a `TupleTableSlot`, but not `AttInMetadata`.

Once you have built a tuple to return from your function, the tuple must be converted into a `Datum`. Use

```
TupleGetDatum(TupleTableSlot *slot, HeapTuple tuple)
```

to get a `Datum` given a tuple and a slot. This `Datum` can be returned directly if you intend to return just a single row, or it can be used as the current return value in a set-returning function.

An example appears below.

9.5.6.2. Returning Sets

A set-returning function (SRF) is normally called once for each item it returns. The SRF must therefore save enough state to remember what it was doing and return the next item on each call. The Table Function API provides the `FuncCallContext` structure to help control this process. `fcinfo->flinfo->fn_extra` is used to hold a pointer to `FuncCallContext` across calls.

```
typedef struct
{
    /*
     * Number of times we've been called before.
     *
     * call_cntr is initialized to 0 for you by SRF_FIRSTCALL_INIT(), and
     * incremented for you every time SRF_RETURN_NEXT() is called.
     */
    uint32 call_cntr;

    /*
     * OPTIONAL maximum number of calls
     *
     * max_calls is here for convenience ONLY and setting it is OPTIONAL.
     * If not set, you must provide alternative means to know when the
     * function is done.
     */
    uint32 max_calls;

    /*
     * OPTIONAL pointer to result slot
     *
     * slot is for use when returning tuples (i.e. composite data types)
     * and is not needed when returning base (i.e. scalar) data types.
     */
    TupleTableSlot *slot;

    /*
     * OPTIONAL pointer to misc user provided context info
     *
     * user_fctx is for use as a pointer to your own struct to retain
     * arbitrary context information between calls for your function.
     */
    void *user_fctx;

    /*
     * OPTIONAL pointer to struct containing arrays of attribute type input
     * metainfo
     *
     * attinmeta is for use when returning tuples (i.e. composite data types)
     * and is not needed when returning base (i.e. scalar) data types. It
     * is ONLY needed if you intend to use BuildTupleFromCStrings() to create
     * the return tuple.
     */
    AttInMetadata *attinmeta;
```

```
    /*
     * memory context used for structures which must live for multiple calls
     *
     * multi_call_memory_ctx is set by SRF_FIRSTCALL_INIT() for you, and used
     * by SRF_RETURN_DONE() for cleanup. It is the most appropriate memory
     * context for any memory that is to be re-used across multiple calls
     * of the SRF.
     */
    MemoryContext multi_call_memory_ctx;
} FuncCallContext;
```

An SRF uses several functions and macros that automatically manipulate the `FuncCallContext` structure (and expect to find it via `fn_extra`). Use

```
SRF_IS_FIRSTCALL()
```

to determine if your function is being called for the first or a subsequent time. On the first call (only) use

```
SRF_FIRSTCALL_INIT()
```

to initialize the `FuncCallContext`. On every function call, including the first, use

```
SRF_PERCALL_SETUP()
```

to properly set up for using the `FuncCallContext` and clearing any previously returned data left over from the previous pass.

If your function has data to return, use

```
SRF_RETURN_NEXT(funcctx, result)
```

to return it to the caller. (The `result` must be a `Datum`, either a single value or a tuple prepared as described earlier.) Finally, when your function is finished returning data, use

```
SRF_RETURN_DONE(funcctx)
```

to clean up and end the SRF.

The memory context that is current when the SRF is called is a transient context that will be cleared between calls. This means that you do not need to `pfree` everything you `palloc`; it will go away anyway. However, if you want to allocate any data structures to live across calls, you need to put them somewhere else. The memory context referenced by `multi_call_memory_ctx` is a suitable location for any data that needs to survive until the SRF is finished running. In most cases, this means that you should switch into `multi_call_memory_ctx` while doing the first-call setup.

A complete pseudo-code example looks like the following:

```
Datum
my_Set_Returning_Function(PG_FUNCTION_ARGS)
{
    FuncCallContext  *funcctx;
    Datum             result;
    MemoryContext     oldcontext;
    [user defined declarations]
```

```
    if (SRF_IS_FIRSTCALL())
    {
        funcctx = SRF_FIRSTCALL_INIT();
        oldcontext = MemoryContextSwitchTo(funcctx->multi_call_memory_ctx);
        /* one-time setup code appears here: */
        [user defined code]
        [if returning composite]
            [build TupleDesc, and perhaps AttInMetadata]
            [obtain slot]
            funcctx->slot = slot;
        [endif returning composite]
        [user defined code]
        MemoryContextSwitchTo(oldcontext);
    }

    /* each-time setup code appears here: */
    [user defined code]
    funcctx = SRF_PERCALL_SETUP();
    [user defined code]

    /* this is just one way we might test whether we are done: */
    if (funcctx->call_cntr < funcctx->max_calls)
    {
        /* here we want to return another item: */
        [user defined code]
        [obtain result Datum]
        SRF_RETURN_NEXT(funcctx, result);
    }
    else
    {
        /* here we are done returning items, and just need to clean up: */
        [user defined code]
        SRF_RETURN_DONE(funcctx);
    }
}
```

A complete example of a simple SRF returning a composite type looks like:

```
PG_FUNCTION_INFO_V1(testpassbyval);
Datum
testpassbyval(PG_FUNCTION_ARGS)
{
    FuncCallContext     *funcctx;
    int                  call_cntr;
    int                  max_calls;
    TupleDesc            tupdesc;
    TupleTableSlot       *slot;
    AttInMetadata       *attinmeta;

     /* stuff done only on the first call of the function */
     if (SRF_IS_FIRSTCALL())
     {
```

```
        MemoryContext oldcontext;

        /* create a function context for cross-call persistence */
        funcctx = SRF_FIRSTCALL_INIT();

        /* switch to memory context appropriate for multiple function calls */
        oldcontext = MemoryContextSwitchTo(funcctx->multi_call_memory_ctx);

        /* total number of tuples to be returned */
        funcctx->max_calls = PG_GETARG_UINT32(0);

        /*
         * Build a tuple description for a __testpassbyval tuple
         */
        tupdesc = RelationNameGetTupleDesc("__testpassbyval");

        /* allocate a slot for a tuple with this tupdesc */
        slot = TupleDescGetSlot(tupdesc);

        /* assign slot to function context */
        funcctx->slot = slot;

        /*
         * Generate attribute metadata needed later to produce tuples from raw
         * C strings
         */
        attinmeta = TupleDescGetAttInMetadata(tupdesc);
        funcctx->attinmeta = attinmeta;

        MemoryContextSwitchTo(oldcontext);
    }

    /* stuff done on every call of the function */
    funcctx = SRF_PERCALL_SETUP();

    call_cntr = funcctx->call_cntr;
    max_calls = funcctx->max_calls;
    slot = funcctx->slot;
    attinmeta = funcctx->attinmeta;

    if (call_cntr < max_calls)    /* do when there is more left to send */
    {
        char       **values;
        HeapTuple    tuple;
        Datum        result;

        /*
         * Prepare a values array for storage in our slot.
         * This should be an array of C strings which will
         * be processed later by the appropriate "in" functions.
         */
        values = (char **) palloc(3 * sizeof(char *));
        values[0] = (char *) palloc(16 * sizeof(char));
```

```
            values[1] = (char *) palloc(16 * sizeof(char));
            values[2] = (char *) palloc(16 * sizeof(char));

            snprintf(values[0], 16, "%d", 1 * PG_GETARG_INT32(1));
            snprintf(values[1], 16, "%d", 2 * PG_GETARG_INT32(1));
            snprintf(values[2], 16, "%d", 3 * PG_GETARG_INT32(1));

            /* build a tuple */
            tuple = BuildTupleFromCStrings(attinmeta, values);

            /* make the tuple into a datum */
            result = TupleGetDatum(slot, tuple);

            /* Clean up (this is not actually necessary) */
            pfree(values[0]);
            pfree(values[1]);
            pfree(values[2]);
            pfree(values);

             SRF_RETURN_NEXT(funcctx, result);
        }
        else    /* do when there is no more left */
        {
             SRF_RETURN_DONE(funcctx);
        }
    }
```

with supporting SQL code of

```
CREATE TYPE __testpassbyval AS (f1 int4, f2 int4, f3 int4);

CREATE OR REPLACE FUNCTION testpassbyval(int4, int4) RETURNS setof __testpassbyval
  AS 'MODULE_PATHNAME','testpassbyval' LANGUAGE 'c' IMMUTABLE STRICT;
```

See `contrib/tablefunc` for more examples of table functions.

9.5.7. Writing Code

We now turn to the more difficult task of writing programming language functions. Be warned: this section of the manual will not make you a programmer. You must have a good understanding of C (including the use of pointers) before trying to write C functions for use with PostgreSQL. While it may be possible to load functions written in languages other than C into PostgreSQL, this is often difficult (when it is possible at all) because other languages, such as FORTRAN and Pascal often do not follow the same *calling convention* as C. That is, other languages do not pass argument and return values between functions in the same way. For this reason, we will assume that your programming language functions are written in C.

The basic rules for building C functions are as follows:

- Use `pg_config --includedir-server` to find out where the PostgreSQL server header files are installed on your system (or the system that your users will be running on). This option is new with PostgreSQL 7.2. For PostgreSQL 7.1 you should use the option `--includedir`. (`pg_config` will exit with a non-zero status if it encounters an unknown option.) For releases prior to 7.1 you will have to guess, but since that was before the current calling conventions were introduced, it is unlikely that you want to support those releases.
- When allocating memory, use the PostgreSQL routines `palloc` and `pfree` instead of the corresponding C library routines `malloc` and `free`. The memory allocated by `palloc` will be freed automatically at the end of each transaction, preventing memory leaks.
- Always zero the bytes of your structures using `memset` or `bzero`. Several routines (such as the hash access method, hash join and the sort algorithm) compute functions of the raw bits contained in your structure. Even if you initialize all fields of your structure, there may be several bytes of alignment padding (holes in the structure) that may contain garbage values.
- Most of the internal PostgreSQL types are declared in `postgres.h`, while the function manager interfaces (`PG_FUNCTION_ARGS`, etc.) are in `fmgr.h`, so you will need to include at least these two files. For portability reasons it's best to include `postgres.h` *first*, before any other system or user header files. Including `postgres.h` will also include `elog.h` and `palloc.h` for you.
- Symbol names defined within object files must not conflict with each other or with symbols defined in the PostgreSQL server executable. You will have to rename your functions or variables if you get error messages to this effect.
- Compiling and linking your object code so that it can be dynamically loaded into PostgreSQL always requires special flags. See Section 9.5.8 for a detailed explanation of how to do it for your particular operating system.

9.5.8. Compiling and Linking Dynamically-Loaded Functions

Before you are able to use your PostgreSQL extension functions written in C, they must be compiled and linked in a special way to produce a file that can be dynamically loaded by the server. To be precise, a *shared library* needs to be created.

For more information you should read the documentation of your operating system, in particular the manual pages for the C compiler, `cc`, and the link editor, `ld`. In addition, the PostgreSQL source code contains several working examples in the `contrib` directory. If you rely on these examples you will make your modules dependent on the availability of the PostgreSQL source code, however.

Creating shared libraries is generally analogous to linking executables: first the source files are compiled into object files, then the object files are linked together. The object files need to be created as *position-independent code* (PIC), which conceptually means that they can be placed at an arbitrary location in memory when they are loaded by the executable. (Object files intended for executables are usually not compiled that way.) The command to link a shared library contains special flags to distinguish it from linking an executable. --- At least this is the theory. On some systems the practice is much uglier.

In the following examples we assume that your source code is in a file `foo.c` and we will create a shared library `foo.so`. The intermediate object file will be called `foo.o` unless otherwise noted. A shared library can contain more than one object file, but we only use one here.

BSD/OS

The compiler flag to create PIC is `-fpic`. The linker flag to create shared libraries is `-shared`.

```
gcc -fpic -c foo.c
ld -shared -o foo.so foo.o
```

This is applicable as of version 4.0 of BSD/OS.

FreeBSD

The compiler flag to create PIC is `-fpic`. To create shared libraries the compiler flag is `-shared`.

```
gcc -fpic -c foo.c
gcc -shared -o foo.so foo.o
```

This is applicable as of version 3.0 of FreeBSD.

HP-UX

The compiler flag of the system compiler to create PIC is `+z`. When using GCC it's `-fpic`. The linker flag for shared libraries is `-b`. So

```
cc +z -c foo.c
```

or

```
gcc -fpic -c foo.c
```

and then

```
ld -b -o foo.sl foo.o
```

HP-UX uses the extension `.sl` for shared libraries, unlike most other systems.

IRIX

PIC is the default, no special compiler options are necessary. The linker option to produce shared libraries is `-shared`.

```
cc -c foo.c
ld -shared -o foo.so foo.o
```

Linux

The compiler flag to create PIC is `-fpic`. On some platforms in some situations `-fPIC` must be used if `-fpic` does not work. Refer to the GCC manual for more information. The compiler flag to create a shared library is `-shared`. A complete example looks like this:

```
cc -fpic -c foo.c
cc -shared -o foo.so foo.o
```

MacOS X

Here is a sample. It assumes the developer tools are installed.

```
cc -c foo.c
cc -bundle -flat_namespace -undefined suppress -o foo.so foo.o
```

NetBSD

The compiler flag to create PIC is `-fpic`. For ELF systems, the compiler with the flag `-shared` is used to link shared libraries. On the older non-ELF systems, `ld -Bshareable` is used.

```
gcc -fpic -c foo.c
gcc -shared -o foo.so foo.o
```

OpenBSD

The compiler flag to create PIC is `-fpic`. `ld -Bshareable` is used to link shared libraries.

```
gcc -fpic -c foo.c
ld -Bshareable -o foo.so foo.o
```

Solaris

The compiler flag to create PIC is `-KPIC` with the Sun compiler and `-fpic` with GCC. To link shared libraries, the compiler option is `-G` with either compiler or alternatively `-shared` with GCC.

```
cc -KPIC -c foo.c
cc -G -o foo.so foo.o
```

or

```
gcc -fpic -c foo.c
gcc -G -o foo.so foo.o
```

Tru64 UNIX

PIC is the default, so the compilation command is the usual one. `ld` with special options is used to do the linking:

```
cc -c foo.c
ld -shared -expect_unresolved '*' -o foo.so foo.o
```

The same procedure is used with GCC instead of the system compiler; no special options are required.

UnixWare

The compiler flag to create PIC is `-K PIC` with the SCO compiler and `-fpic` with GCC. To link shared libraries, the compiler option is `-G` with the SCO compiler and `-shared` with GCC.

```
cc -K PIC -c foo.c
cc -G -o foo.so foo.o
```

or

```
gcc -fpic -c foo.c
gcc -shared -o foo.so foo.o
```

Tip: If you want to package your extension modules for wide distribution you should consider using GNU Libtool[1] for building shared libraries. It encapsulates the platform differences into a general and powerful interface. Serious packaging also requires considerations about library versioning, symbol resolution methods, and other issues.

The resulting shared library file can then be loaded into PostgreSQL. When specifying the file name to the `CREATE FUNCTION` command, one must give it the name of the shared library file, not the intermediate object file. Note that the system's standard shared-library extension (usually `.so` or `.sl`) can be omitted from the `CREATE FUNCTION` command, and normally should be omitted for best portability.

Refer back to Section 9.5.1 about where the server expects to find the shared library files.

9.6. Function Overloading

More than one function may be defined with the same SQL name, so long as the arguments they take are different. In other words, function names can be *overloaded*. When a query is executed, the server will determine which function to call from the data types and the number of the provided arguments. Overloading can also be used to simulate functions with a variable number of arguments, up to a finite maximum number.

A function may also have the same name as an attribute. In the case that there is an ambiguity between a function on a complex type and an attribute of the complex type, the attribute will always be used.

When creating a family of overloaded functions, one should be careful not to create ambiguities. For instance, given the functions

```
CREATE FUNCTION test(int, real) RETURNS ...
CREATE FUNCTION test(smallint, double precision) RETURNS ...
```

it is not immediately clear which function would be called with some trivial input like `test(1, 1.5)`. The currently implemented resolution rules are described in the *User's Guide*, but it is unwise to design a system that subtly relies on this behavior.

When overloading C language functions, there is an additional constraint: The C name of each function in the family of overloaded functions must be different from the C names of all other functions, either internal or dynamically loaded. If this rule is violated, the behavior is not portable. You might get a run-time linker error, or one of the functions will get called (usually the internal one). The alternative form of the `AS` clause for the SQL `CREATE FUNCTION` command decouples the SQL function name from the function name in the C source code. E.g.,

```
CREATE FUNCTION test(int) RETURNS int
    AS 'filename', 'test_1arg'
    LANGUAGE C;
CREATE FUNCTION test(int, int) RETURNS int
    AS 'filename', 'test_2arg'
    LANGUAGE C;
```

The names of the C functions here reflect one of many possible conventions.

1. http://www.gnu.org/software/libtool/

Prior to PostgreSQL 7.0, this alternative syntax did not exist. There is a trick to get around the problem, by defining a set of C functions with different names and then define a set of identically-named SQL function wrappers that take the appropriate argument types and call the matching C function.

9.7. Table Functions

Table functions are functions that produce a set of rows, made up of either base (scalar) data types, or composite (multi-column) data types. They are used like a table, view, or subselect in the `FROM` clause of a query. Columns returned by table functions may be included in `SELECT`, `JOIN`, or `WHERE` clauses in the same manner as a table, view, or subselect column.

If a table function returns a base data type, the single result column is named for the function. If the function returns a composite type, the result columns get the same names as the individual attributes of the type.

A table function may be aliased in the `FROM` clause, but it also may be left unaliased. If a function is used in the FROM clause with no alias, the function name is used as the relation name.

Table functions work wherever tables do in `SELECT` statements. For example

```
CREATE TABLE foo (fooid int, foosubid int, fooname text);

CREATE FUNCTION getfoo(int) RETURNS setof foo AS '
    SELECT * FROM foo WHERE fooid = $1;
' LANGUAGE SQL;

SELECT * FROM getfoo(1) AS t1;

SELECT * FROM foo
WHERE foosubid in (select foosubid from getfoo(foo.fooid) z
                   where z.fooid = foo.fooid);

CREATE VIEW vw_getfoo AS SELECT * FROM getfoo(1);
SELECT * FROM vw_getfoo;
```

are all valid statements.

In some cases it is useful to define table functions that can return different column sets depending on how they are invoked. To support this, the table function can be declared as returning the pseudo-type `record`. When such a function is used in a query, the expected row structure must be specified in the query itself, so that the system can know how to parse and plan the query. Consider this example:

```
SELECT *
FROM dblink('dbname=template1', 'select proname, prosrc from pg_proc')
  AS t1(proname name, prosrc text)
WHERE proname LIKE 'bytea%';
```

The `dblink` function executes a remote query (see `contrib/dblink`). It is declared to return `record` since it might be used for any kind of query. The actual column set must be specified in the calling query so that the parser knows, for example, what `*` should expand to.

9.8. Procedural Language Handlers

All calls to functions that are written in a language other than the current "version 1" interface for compiled languages (this includes functions in user-defined procedural languages, functions written in SQL, and functions using the version 0 compiled language interface), go through a *call handler* function for the specific language. It is the responsibility of the call handler to execute the function in a meaningful way, such as by interpreting the supplied source text. This section describes how a language call handler can be written. This is not a common task, in fact, it has only been done a handful of times in the history of PostgreSQL, but the topic naturally belongs in this chapter, and the material might give some insight into the extensible nature of the PostgreSQL system.

The call handler for a procedural language is a "normal" function, which must be written in a compiled language such as C and registered with PostgreSQL as taking no arguments and returning the `language_handler` type. This special pseudo-type identifies the handler as a call handler and prevents it from being called directly in queries.

> **Note:** In PostgreSQL 7.1 and later, call handlers must adhere to the "version 1" function manager interface, not the old-style interface.

The call handler is called in the same way as any other function: It receives a pointer to a `FunctionCallInfoData struct` containing argument values and information about the called function, and it is expected to return a `Datum` result (and possibly set the `isnull` field of the `FunctionCallInfoData` structure, if it wishes to return an SQL NULL result). The difference between a call handler and an ordinary callee function is that the `flinfo->fn_oid` field of the `FunctionCallInfoData` structure will contain the OID of the actual function to be called, not of the call handler itself. The call handler must use this field to determine which function to execute. Also, the passed argument list has been set up according to the declaration of the target function, not of the call handler.

It's up to the call handler to fetch the `pg_proc` entry and to analyze the argument and return types of the called procedure. The AS clause from the `CREATE FUNCTION` of the procedure will be found in the `prosrc` attribute of the `pg_proc` table entry. This may be the source text in the procedural language itself (like for PL/Tcl), a path name to a file, or anything else that tells the call handler what to do in detail.

Often, the same function is called many times per SQL statement. A call handler can avoid repeated lookups of information about the called function by using the `flinfo->fn_extra` field. This will initially be NULL, but can be set by the call handler to point at information about the PL function. On subsequent calls, if `flinfo->fn_extra` is already non-NULL then it can be used and the information lookup step skipped. The call handler must be careful that `flinfo->fn_extra` is made to point at memory that will live at least until the end of the current query, since an `FmgrInfo` data structure could be kept that long. One way to do this is to allocate the extra data in the memory context specified by `flinfo->fn_mcxt`; such data will normally have the same lifespan as the `FmgrInfo` itself. But the handler could also choose to use a longer-lived context so that it can cache function definition information across queries.

When a PL function is invoked as a trigger, no explicit arguments are passed, but the `FunctionCallInfoData`'s `context` field points at a `TriggerData` node, rather than being NULL as it is in a plain function call. A language handler should provide mechanisms for PL functions to get at the trigger information.

This is a template for a PL handler written in C:

```
#include "postgres.h"
#include "executor/spi.h"
#include "commands/trigger.h"
#include "utils/elog.h"
#include "fmgr.h"
#include "access/heapam.h"
#include "utils/syscache.h"
#include "catalog/pg_proc.h"
#include "catalog/pg_type.h"

PG_FUNCTION_INFO_V1(plsample_call_handler);

Datum
plsample_call_handler(PG_FUNCTION_ARGS)
{
    Datum          retval;

    if (CALLED_AS_TRIGGER(fcinfo))
    {
        /*
         * Called as a trigger procedure
         */
        TriggerData    *trigdata = (TriggerData *) fcinfo->context;

        retval = ...
    }
    else {
        /*
         * Called as a function
         */

        retval = ...
    }

    return retval;
}
```

Only a few thousand lines of code have to be added instead of the dots to complete the call handler. See Section 9.5 for information on how to compile it into a loadable module.

The following commands then register the sample procedural language:

```
CREATE FUNCTION plsample_call_handler () RETURNS language_handler
    AS '/usr/local/pgsql/lib/plsample'
    LANGUAGE C;
CREATE LANGUAGE plsample
    HANDLER plsample_call_handler;
```

Chapter 10. Extending SQL: Types

As previously mentioned, there are two kinds of types in PostgreSQL: base types (defined in a programming language) and composite types. This chapter describes how to define new base types.

The examples in this section can be found in `complex.sql` and `complex.c` in the tutorial directory. Composite examples are in `funcs.sql`.

A user-defined type must always have input and output functions. These functions determine how the type appears in strings (for input by the user and output to the user) and how the type is organized in memory. The input function takes a null-terminated character string as its input and returns the internal (in memory) representation of the type. The output function takes the internal representation of the type and returns a null-terminated character string.

Suppose we want to define a complex type which represents complex numbers. Naturally, we would choose to represent a complex in memory as the following C structure:

```
typedef struct Complex {
    double      x;
    double      y;
} Complex;
```

and a string of the form `(x,y)` as the external string representation.

The functions are usually not hard to write, especially the output function. However, there are a number of points to remember:

- When defining your external (string) representation, remember that you must eventually write a complete and robust parser for that representation as your input function!

  For instance:

  ```
  Complex *
  complex_in(char *str)
  {
      double x, y;
      Complex *result;
      if (sscanf(str, " ( %lf , %lf )", &x, &y) != 2) {
          elog(ERROR, "complex_in: error in parsing %s", str);
          return NULL;
      }
      result = (Complex *)palloc(sizeof(Complex));
      result->x = x;
      result->y = y;
      return (result);
  }
  ```

  The output function can simply be:

  ```
  char *
  complex_out(Complex *complex)
  {
      char *result;
  ```

```
    if (complex == NULL)
        return(NULL);
    result = (char *) palloc(60);
    sprintf(result, "(%g,%g)", complex->x, complex->y);
    return(result);
}
```

- You should try to make the input and output functions inverses of each other. If you do not, you will have severe problems when you need to dump your data into a file and then read it back in (say, into someone else's database on another computer). This is a particularly common problem when floating-point numbers are involved.

To define the `complex` type, we need to create the two user-defined functions `complex_in` and `complex_out` before creating the type:

```
CREATE FUNCTION complex_in(cstring)
    RETURNS complex
    AS 'PGROOT/tutorial/complex'
    LANGUAGE C;

CREATE FUNCTION complex_out(complex)
    RETURNS cstring
    AS 'PGROOT/tutorial/complex'
    LANGUAGE C;
```

Finally, we can declare the data type:

```
CREATE TYPE complex (
    internallength = 16,
    input = complex_in,
    output = complex_out
);
```

Notice that the declarations of the input and output functions must reference the not-yet-defined type. This is allowed, but will draw warning messages that may be ignored.

As discussed earlier, PostgreSQL fully supports arrays of base types. Additionally, PostgreSQL supports arrays of user-defined types as well. When you define a type, PostgreSQL automatically provides support for arrays of that type. For historical reasons, the array type has the same name as the user-defined type with the underscore character _ prepended.

Composite types do not need any function defined on them, since the system already understands what they look like inside.

If the values of your data type might exceed a few hundred bytes in size (in internal form), you should be careful to mark them TOAST-able. To do this, the internal representation must follow the standard layout for variable-length data: the first four bytes must be an `int32` containing the total length in bytes of the datum (including itself). Then, all your functions that accept values of the type must be careful to call `pg_detoast_datum()` on the supplied values --- after checking that the value is not NULL, if your function is not strict. Finally, select the appropriate storage option when giving the `CREATE TYPE` command.

Chapter 11. Extending SQL: Operators

11.1. Introduction

PostgreSQL supports left unary, right unary, and binary operators. Operators can be overloaded; that is, the same operator name can be used for different operators that have different numbers and types of operands. If there is an ambiguous situation and the system cannot determine the correct operator to use, it will return an error. You may have to type-cast the left and/or right operands to help it understand which operator you meant to use.

Every operator is "syntactic sugar" for a call to an underlying function that does the real work; so you must first create the underlying function before you can create the operator. However, an operator is *not merely* syntactic sugar, because it carries additional information that helps the query planner optimize queries that use the operator. Much of this chapter will be devoted to explaining that additional information.

11.2. Example

Here is an example of creating an operator for adding two complex numbers. We assume we've already created the definition of type `complex` (see Chapter 10). First we need a function that does the work, then we can define the operator:

```
CREATE FUNCTION complex_add(complex, complex)
    RETURNS complex
    AS 'PGROOT/tutorial/complex'
    LANGUAGE C;

CREATE OPERATOR + (
    leftarg = complex,
    rightarg = complex,
    procedure = complex_add,
    commutator = +
);
```

Now we can do:

```
SELECT (a + b) AS c FROM test_complex;

        c
-----------------
 (5.2,6.05)
 (133.42,144.95)
```

We've shown how to create a binary operator here. To create unary operators, just omit one of `leftarg` (for left unary) or `rightarg` (for right unary). The `procedure` clause and the argument clauses are the only required items in `CREATE OPERATOR`. The `commutator` clause shown in the example is an optional hint to the query optimizer. Further details about `commutator` and other optimizer hints appear below.

11.3. Operator Optimization Information

Author: Written by Tom Lane.

A PostgreSQL operator definition can include several optional clauses that tell the system useful things about how the operator behaves. These clauses should be provided whenever appropriate, because they can make for considerable speedups in execution of queries that use the operator. But if you provide them, you must be sure that they are right! Incorrect use of an optimization clause can result in backend crashes, subtly wrong output, or other Bad Things. You can always leave out an optimization clause if you are not sure about it; the only consequence is that queries might run slower than they need to.

Additional optimization clauses might be added in future versions of PostgreSQL. The ones described here are all the ones that release 7.3.2 understands.

11.3.1. COMMUTATOR

The `COMMUTATOR` clause, if provided, names an operator that is the commutator of the operator being defined. We say that operator A is the commutator of operator B if (x A y) equals (y B x) for all possible input values x, y. Notice that B is also the commutator of A. For example, operators < and > for a particular data type are usually each others' commutators, and operator `+` is usually commutative with itself. But operator `-` is usually not commutative with anything.

The left operand type of a commuted operator is the same as the right operand type of its commutator, and vice versa. So the name of the commutator operator is all that PostgreSQL needs to be given to look up the commutator, and that's all that needs to be provided in the `COMMUTATOR` clause.

When you are defining a self-commutative operator, you just do it. When you are defining a pair of commutative operators, things are a little trickier: how can the first one to be defined refer to the other one, which you haven't defined yet? There are two solutions to this problem:

- One way is to omit the `COMMUTATOR` clause in the first operator that you define, and then provide one in the second operator's definition. Since PostgreSQL knows that commutative operators come in pairs, when it sees the second definition it will automatically go back and fill in the missing `COMMUTATOR` clause in the first definition.
- The other, more straightforward way is just to include `COMMUTATOR` clauses in both definitions. When PostgreSQL processes the first definition and realizes that `COMMUTATOR` refers to a non-existent operator, the system will make a dummy entry for that operator in the system catalog. This dummy entry will have valid data only for the operator name, left and right operand types, and result type, since that's all that PostgreSQL can deduce at this point. The first operator's catalog entry will link to this dummy entry. Later, when you define the second operator, the system updates the dummy entry with the additional information from the second definition. If you try to use the dummy operator before it's been filled in, you'll just get an error message. (Note: This procedure did not work reliably in PostgreSQL versions before 6.5, but it is now the recommended way to do things.)

11.3.2. NEGATOR

The `NEGATOR` clause, if provided, names an operator that is the negator of the operator being defined. We say that operator A is the negator of operator B if both return Boolean results and (x A y) equals NOT (x B y) for all possible inputs x, y. Notice that B is also the negator of A. For example, < and >= are a negator pair for most data types. An operator can never validly be its own negator.

Unlike commutators, a pair of unary operators could validly be marked as each others' negators; that would mean (A x) equals NOT (B x) for all x, or the equivalent for right unary operators.

An operator's negator must have the same left and/or right operand types as the operator itself, so just as with `COMMUTATOR`, only the operator name need be given in the `NEGATOR` clause.

Providing a negator is very helpful to the query optimizer since it allows expressions like `NOT (x = y)` to be simplified into x <> y. This comes up more often than you might think, because `NOT` operations can be inserted as a consequence of other rearrangements.

Pairs of negator operators can be defined using the same methods explained above for commutator pairs.

11.3.3. RESTRICT

The `RESTRICT` clause, if provided, names a restriction selectivity estimation function for the operator (note that this is a function name, not an operator name). `RESTRICT` clauses only make sense for binary operators that return `boolean`. The idea behind a restriction selectivity estimator is to guess what fraction of the rows in a table will satisfy a `WHERE`-clause condition of the form

```
column OP constant
```

for the current operator and a particular constant value. This assists the optimizer by giving it some idea of how many rows will be eliminated by `WHERE` clauses that have this form. (What happens if the constant is on the left, you may be wondering? Well, that's one of the things that `COMMUTATOR` is for...)

Writing new restriction selectivity estimation functions is far beyond the scope of this chapter, but fortunately you can usually just use one of the system's standard estimators for many of your own operators. These are the standard restriction estimators:

`eqsel` for =
`neqsel` for <>
`scalarltsel` for < or <=
`scalargtsel` for > or >=

It might seem a little odd that these are the categories, but they make sense if you think about it. = will typically accept only a small fraction of the rows in a table; <> will typically reject only a small fraction. < will accept a fraction that depends on where the given constant falls in the range of values for that table column (which, it just so happens, is information collected by `ANALYZE` and made available to the selectivity estimator). <= will accept a slightly larger fraction than < for the same comparison constant, but they're close enough to not be worth distinguishing, especially since we're not likely to do better than a rough guess anyhow. Similar remarks apply to > and >=.

You can frequently get away with using either `eqsel` or `neqsel` for operators that have very high or very low selectivity, even if they aren't really equality or inequality. For example, the approximate-equality geometric operators use `eqsel` on the assumption that they'll usually only match a small fraction of the entries in a table.

You can use `scalarltsel` and `scalargtsel` for comparisons on data types that have some sensible means of being converted into numeric scalars for range comparisons. If possible, add the data type to those understood by the routine `convert_to_scalar()` in `src/backend/utils/adt/selfuncs.c`. (Eventually, this routine should be replaced by per-data-type functions identified through a column of the `pg_type` system catalog; but that hasn't happened yet.) If you do not do this, things will still work, but the optimizer's estimates won't be as good as they could be.

There are additional selectivity functions designed for geometric operators in `src/backend/utils/adt/geo_selfuncs.c`: `areasel`, `positionsel`, and `contsel`. At this writing these are just stubs, but you may want to use them (or even better, improve them) anyway.

11.3.4. JOIN

The `JOIN` clause, if provided, names a join selectivity estimation function for the operator (note that this is a function name, not an operator name). `JOIN` clauses only make sense for binary operators that return `boolean`. The idea behind a join selectivity estimator is to guess what fraction of the rows in a pair of tables will satisfy a `WHERE`-clause condition of the form

```
table1.column1 OP table2.column2
```

for the current operator. As with the `RESTRICT` clause, this helps the optimizer very substantially by letting it figure out which of several possible join sequences is likely to take the least work.

As before, this chapter will make no attempt to explain how to write a join selectivity estimator function, but will just suggest that you use one of the standard estimators if one is applicable:

`eqjoinsel` for =
`neqjoinsel` for <>
`scalarltjoinsel` for < or <=
`scalargtjoinsel` for > or >=
`areajoinsel` for 2D area-based comparisons
`positionjoinsel` for 2D position-based comparisons
`contjoinsel` for 2D containment-based comparisons

11.3.5. HASHES

The `HASHES` clause, if present, tells the system that it is permissible to use the hash join method for a join based on this operator. `HASHES` only makes sense for binary operators that return `boolean`, and in practice the operator had better be equality for some data type.

The assumption underlying hash join is that the join operator can only return true for pairs of left and right values that hash to the same hash code. If two values get put in different hash buckets, the join will never compare them at all, implicitly assuming that the result of the join operator must be false. So it never makes sense to specify `HASHES` for operators that do not represent equality.

In fact, logical equality is not good enough either; the operator had better represent pure bitwise equality, because the hash function will be computed on the memory representation of the values regardless of what the bits mean. For example, equality of time intervals is not bitwise equality; the interval equality operator considers two time intervals equal if they have the same duration, whether or not their endpoints are identical. What this means is that a join using = between interval fields would yield different results if implemented as a hash join than if implemented another way, because a large fraction of the pairs that should match will hash to different values and will never be compared by the hash join. But if the optimizer chose to use a different kind of join, all the pairs that the equality operator says are equal will be found. We don't want that kind of inconsistency, so we don't mark interval equality as hashable.

There are also machine-dependent ways in which a hash join might fail to do the right thing. For example, if your data type is a structure in which there may be uninteresting pad bits, it's unsafe to mark the equality operator `HASHES`. (Unless, perhaps, you write your other operators to ensure that the unused bits are always zero.) Another example is that the floating-point data types are unsafe for hash joins. On machines that meet the IEEE floating-point standard, minus zero and plus zero are different values (different bit patterns) but they are defined to compare equal. So, if the equality operator on floating-point data types were marked `HASHES`, a minus zero and a plus zero would probably not be matched up by a hash join, but they would be matched up by any other join process.

The bottom line is that you should probably only use `HASHES` for equality operators that are (or could be) implemented by `memcmp()`.

11.3.6. `MERGES` (`SORT1`, `SORT2`, `LTCMP`, `GTCMP`)

The `MERGES` clause, if present, tells the system that it is permissible to use the merge join method for a join based on this operator. `MERGES` only makes sense for binary operators that return `boolean`, and in practice the operator must represent equality for some data type or pair of data types.

Merge join is based on the idea of sorting the left- and right-hand tables into order and then scanning them in parallel. So, both data types must be capable of being fully ordered, and the join operator must be one that can only succeed for pairs of values that fall at the "same place" in the sort order. In practice this means that the join operator must behave like equality. But unlike hash join, where the left and right data types had better be the same (or at least bitwise equivalent), it is possible to merge-join two distinct data types so long as they are logically compatible. For example, the `int2`-versus-`int4` equality operator is merge-joinable. We only need sorting operators that will bring both data types into a logically compatible sequence.

Execution of a merge join requires that the system be able to identify four operators related to the merge-join equality operator: less-than comparison for the left input data type, less-than comparison for the right input data type, less-than comparison between the two data types, and greater-than comparison between the two data types. (These are actually four distinct operators if the merge-joinable operator has two different input data types; but when the input types are the same the three less-than operators are all the same operator.) It is possible to specify these operators individually by name, as the `SORT1`, `SORT2`, `LTCMP`, and `GTCMP` options respectively. The system will fill in the default names <, <, <, > respectively if any of these are omitted when `MERGES` is specified. Also, `MERGES` will be assumed to be implied if any of these four operator options appear, so it is possible to specify just some of them and let the system fill in the rest.

The input data types of the four comparison operators can be deduced from the input types of the merge-joinable operator, so just as with `COMMUTATOR`, only the operator names need be given in these clauses. Unless you are using peculiar choices of operator names, it's sufficient to write `MERGES` and let the system fill in the details. (As with `COMMUTATOR` and `NEGATOR`, the system is able to make dummy operator entries if you happen to define the equality operator before the other ones.)

There are additional restrictions on operators that you mark merge-joinable. These restrictions are not currently checked by `CREATE OPERATOR`, but errors may occur when the operator is used if any are not true:

- A merge-joinable equality operator must have a merge-joinable commutator (itself if the two data types are the same, or a related equality operator if they are different).
- If there is a merge-joinable operator relating any two data types A and B, and another merge-joinable operator relating B to any third data type C, then A and C must also have a merge-joinable operator; in other words, having a merge-joinable operator must be transitive.
- Bizarre results will ensue at runtime if the four comparison operators you name do not sort the data values compatibly.

> **Note:** In PostgreSQL versions before 7.3, the `MERGES` shorthand was not available: to make a merge-joinable operator one had to write both `SORT1` and `SORT2` explicitly. Also, the `LTCMP` and `GTCMP` options did not exist; the names of those operators were hardwired as $<$ and $>$ respectively.

Chapter 12. Extending SQL: Aggregates

Aggregate functions in PostgreSQL are expressed as *state values* and *state transition functions*. That is, an aggregate can be defined in terms of state that is modified whenever an input item is processed. To define a new aggregate function, one selects a data type for the state value, an initial value for the state, and a state transition function. The state transition function is just an ordinary function that could also be used outside the context of the aggregate. A *final function* can also be specified, in case the desired output of the aggregate is different from the data that needs to be kept in the running state value.

Thus, in addition to the input and result data types seen by a user of the aggregate, there is an internal state-value data type that may be different from both the input and result types.

If we define an aggregate that does not use a final function, we have an aggregate that computes a running function of the column values from each row. `Sum` is an example of this kind of aggregate. `Sum` starts at zero and always adds the current row's value to its running total. For example, if we want to make a `sum` aggregate to work on a data type for complex numbers, we only need the addition function for that data type. The aggregate definition is:

```
CREATE AGGREGATE complex_sum (
    sfunc = complex_add,
    basetype = complex,
    stype = complex,
    initcond = '(0,0)'
);

SELECT complex_sum(a) FROM test_complex;

 complex_sum
-------------
 (34,53.9)
```

(In practice, we'd just name the aggregate `sum`, and rely on PostgreSQL to figure out which kind of sum to apply to a column of type `complex`.)

The above definition of `sum` will return zero (the initial state condition) if there are no non-null input values. Perhaps we want to return NULL in that case instead --- the SQL standard expects `sum` to behave that way. We can do this simply by omitting the `initcond` phrase, so that the initial state condition is NULL. Ordinarily this would mean that the `sfunc` would need to check for a NULL state-condition input, but for `sum` and some other simple aggregates like `max` and `min`, it's sufficient to insert the first non-null input value into the state variable and then start applying the transition function at the second non-null input value. PostgreSQL will do that automatically if the initial condition is NULL and the transition function is marked "strict" (i.e., not to be called for NULL inputs).

Another bit of default behavior for a "strict" transition function is that the previous state value is retained unchanged whenever a NULL input value is encountered. Thus, null values are ignored. If you need some other behavior for NULL inputs, just define your transition function as non-strict, and code it to test for NULL inputs and do whatever is needed.

`Avg` (average) is a more complex example of an aggregate. It requires two pieces of running state: the sum of the inputs and the count of the number of inputs. The final result is obtained by dividing these quantities. Average is typically implemented by using a two-element array as the transition state value. For example, the built-in implementation of `avg(float8)` looks like:

```
CREATE AGGREGATE avg (
    sfunc = float8_accum,
    basetype = float8,
    stype = float8[],
    finalfunc = float8_avg,
    initcond = '{0,0}'
);
```

For further details see the description of the `CREATE AGGREGATE` command in the *Reference Manual*.

Chapter 13. The Rule System

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13.1. Introduction

Production rule systems are conceptually simple, but there are many subtle points involved in actually using them. Some of these points and the theoretical foundations of the PostgreSQL rule system can be found in *On Rules, Procedures, Caching and Views in Database Systems*.

Some other database systems define active database rules. These are usually stored procedures and triggers and are implemented in PostgreSQL as functions and triggers.

The query rewrite rule system (the *rule system* from now on) is totally different from stored procedures and triggers. It modifies queries to take rules into consideration, and then passes the modified query to the query planner for planning and execution. It is very powerful, and can be used for many things such as query language procedures, views, and versions. The power of this rule system is discussed in *A Unified Framework for Version Modeling Using Production Rules in a Database System* as well as *On Rules, Procedures, Caching and Views in Database Systems*.

13.2. What is a Query Tree?

To understand how the rule system works it is necessary to know when it is invoked and what its input and results are.

The rule system is located between the query parser and the planner. It takes the output of the parser, one query tree, and the rewrite rules from the `pg_rewrite` catalog, which are query trees too with some extra information, and creates zero or many query trees as result. So its input and output are always things the parser itself could have produced and thus, anything it sees is basically representable as an SQL statement.

Now what is a query tree? It is an internal representation of an SQL statement where the single parts that built it are stored separately. These query trees are visible when starting the PostgreSQL backend with debug level 4 and typing queries into the interactive backend interface. The rule actions in the `pg_rewrite` system catalog are also stored as query trees. They are not formatted like the debug output, but they contain exactly the same information.

Reading a query tree requires some experience and it was a hard time when I started to work on the rule system. I can remember that I was standing at the coffee machine and I saw the cup in a target list, water and coffee powder in a range table and all the buttons in a qualification expression. Since SQL representations of query trees are sufficient to understand the rule system, this document will not teach how to read them. It might help to learn it and the naming conventions are required in the later following descriptions.

13.2.1. The Parts of a Query tree

When reading the SQL representations of the query trees in this document it is necessary to be able to identify the parts the statement is broken into when it is in the query tree structure. The parts of a query tree are

the command type

> This is a simple value telling which command (SELECT, INSERT, UPDATE, DELETE) produced the parse tree.

the range table

> The range table is a list of relations that are used in the query. In a SELECT statement these are the relations given after the FROM keyword.
>
> Every range table entry identifies a table or view and tells by which name it is called in the other parts of the query. In the query tree the range table entries are referenced by index rather than by name, so here it doesn't matter if there are duplicate names as it would in an SQL statement. This can happen after the range tables of rules have been merged in. The examples in this document will not have this situation.

the result relation

> This is an index into the range table that identifies the relation where the results of the query go.
>
> SELECT queries normally don't have a result relation. The special case of a SELECT INTO is mostly identical to a CREATE TABLE, INSERT ... SELECT sequence and is not discussed separately here.
>
> On INSERT, UPDATE and DELETE queries the result relation is the table (or view!) where the changes take effect.

the target list

> The target list is a list of expressions that define the result of the query. In the case of a SELECT, the expressions are what builds the final output of the query. They are the expressions between the SELECT and the FROM keywords. (* is just an abbreviation for all the attribute names of a relation. It is expanded by the parser into the individual attributes, so the rule system never sees it.)
>
> DELETE queries don't need a target list because they don't produce any result. In fact the planner will add a special CTID entry to the empty target list. But this is after the rule system and will be discussed later. For the rule system the target list is empty.
>
> In INSERT queries the target list describes the new rows that should go into the result relation. It is the expressions in the VALUES clause or the ones from the SELECT clause in INSERT ... SELECT. The first step of the rewrite process adds target list entries for any columns that were not assigned to by the original query and have defaults. Any remaining columns (with neither a given value nor a default) will be filled in by the planner with a constant NULL expression.
>
> In UPDATE queries, the target list describes the new rows that should replace the old ones. In the rule system, it contains just the expressions from the SET attribute = expression part of the query. The planner will handle missing columns by inserting expressions that copy the values from the old row into the new one. And it will add the special CTID entry just as for DELETE too.
>
> Every entry in the target list contains an expression that can be a constant value, a variable pointing to an attribute of one of the relations in the range table, a parameter, or an expression tree made of function calls, constants, variables, operators etc.

the qualification

The query's qualification is an expression much like one of those contained in the target list entries. The result value of this expression is a Boolean that tells if the operation (INSERT, UPDATE, DELETE or SELECT) for the final result row should be executed or not. It is the WHERE clause of an SQL statement.

the join tree

The query's join tree shows the structure of the FROM clause. For a simple query like SELECT FROM a, b, c the join tree is just a list of the FROM items, because we are allowed to join them in any order. But when JOIN expressions --- particularly outer joins --- are used, we have to join in the order shown by the joins. The join tree shows the structure of the JOIN expressions. The restrictions associated with particular JOIN clauses (from ON or USING expressions) are stored as qualification expressions attached to those join tree nodes. It turns out to be convenient to store the top-level WHERE expression as a qualification attached to the top-level join tree item, too. So really the join tree represents both the FROM and WHERE clauses of a SELECT.

the others

The other parts of the query tree like the ORDER BY clause aren't of interest here. The rule system substitutes entries there while applying rules, but that doesn't have much to do with the fundamentals of the rule system.

13.3. Views and the Rule System

13.3.1. Implementation of Views in PostgreSQL

Views in PostgreSQL are implemented using the rule system. In fact there is essentially no difference between

```
CREATE VIEW myview AS SELECT * FROM mytab;
```

compared against the two commands

```
CREATE TABLE myview (same attribute list as for mytab);
CREATE RULE "_RETURN" AS ON SELECT TO myview DO INSTEAD
    SELECT * FROM mytab;
```

because this is exactly what the CREATE VIEW command does internally. This has some side effects. One of them is that the information about a view in the PostgreSQL system catalogs is exactly the same as it is for a table. So for the query parser, there is absolutely no difference between a table and a view. They are the same thing - relations. That is the important one for now.

13.3.2. How SELECT Rules Work

Rules ON SELECT are applied to all queries as the last step, even if the command given is an INSERT, UPDATE or DELETE. And they have different semantics from the others in that they modify the parse tree in place instead of creating a new one. So SELECT rules are described first.

Currently, there can be only one action in an ON SELECT rule, and it must be an unconditional SELECT action that is INSTEAD. This restriction was required to make rules safe enough to open them for ordinary users and it restricts rules ON SELECT to real view rules.

The examples for this document are two join views that do some calculations and some more views using them in turn. One of the two first views is customized later by adding rules for INSERT, UPDATE and DELETE operations so that the final result will be a view that behaves like a real table with some magic functionality. It is not such a simple example to start from and this makes things harder to get into. But it's better to have one example that covers all the points discussed step by step rather than having many different ones that might mix up in mind.

The database needed to play with the examples is named `al_bundy`. You'll see soon why this is the database name. And it needs the procedural language PL/pgSQL installed, because we need a little min() function returning the lower of 2 integer values. We create that as

```
CREATE FUNCTION min(integer, integer) RETURNS integer AS '
    BEGIN
        IF $1 < $2 THEN
            RETURN $1;
        END IF;
        RETURN $2;
    END;
' LANGUAGE plpgsql;
```

The real tables we need in the first two rule system descriptions are these:

```
CREATE TABLE shoe_data (
    shoename   char(10),      -- primary key
    sh_avail   integer,       -- available # of pairs
    slcolor    char(10),      -- preferred shoelace color
    slminlen   float,         -- miminum shoelace length
    slmaxlen   float,         -- maximum shoelace length
    slunit     char(8)        -- length unit
);

CREATE TABLE shoelace_data (
    sl_name    char(10),      -- primary key
    sl_avail   integer,       -- available # of pairs
    sl_color   char(10),      -- shoelace color
    sl_len     float,         -- shoelace length
    sl_unit    char(8)        -- length unit
);

CREATE TABLE unit (
    un_name    char(8),       -- the primary key
    un_fact    float          -- factor to transform to cm
```

```
);
```

I think most of us wear shoes and can realize that this is really useful data. Well there are shoes out in the world that don't require shoelaces, but this doesn't make Al's life easier and so we ignore it.

The views are created as

```
CREATE VIEW shoe AS
    SELECT sh.shoename,
           sh.sh_avail,
           sh.slcolor,
           sh.slminlen,
           sh.slminlen * un.un_fact AS slminlen_cm,
           sh.slmaxlen,
           sh.slmaxlen * un.un_fact AS slmaxlen_cm,
           sh.slunit
      FROM shoe_data sh, unit un
     WHERE sh.slunit = un.un_name;

CREATE VIEW shoelace AS
    SELECT s.sl_name,
           s.sl_avail,
           s.sl_color,
           s.sl_len,
           s.sl_unit,
           s.sl_len * u.un_fact AS sl_len_cm
      FROM shoelace_data s, unit u
     WHERE s.sl_unit = u.un_name;

CREATE VIEW shoe_ready AS
    SELECT rsh.shoename,
           rsh.sh_avail,
           rsl.sl_name,
           rsl.sl_avail,
           min(rsh.sh_avail, rsl.sl_avail) AS total_avail
      FROM shoe rsh, shoelace rsl
     WHERE rsl.sl_color = rsh.slcolor
       AND rsl.sl_len_cm >= rsh.slminlen_cm
       AND rsl.sl_len_cm <= rsh.slmaxlen_cm;
```

The CREATE VIEW command for the `shoelace` view (which is the simplest one we have) will create a relation shoelace and an entry in `pg_rewrite` that tells that there is a rewrite rule that must be applied whenever the relation shoelace is referenced in a query's range table. The rule has no rule qualification (discussed later, with the non SELECT rules, since SELECT rules currently cannot have them) and it is INSTEAD. Note that rule qualifications are not the same as query qualifications! The rule's action has a query qualification.

The rule's action is one query tree that is a copy of the SELECT statement in the view creation command.

> **Note:** The two extra range table entries for NEW and OLD (named *NEW* and *CURRENT* for historical reasons in the printed query tree) you can see in the `pg_rewrite` entry aren't of interest for SELECT rules.

Now we populate `unit`, `shoe_data` and `shoelace_data` and Al types the first SELECT in his life:

```
al_bundy=> INSERT INTO unit VALUES ('cm', 1.0);
al_bundy=> INSERT INTO unit VALUES ('m', 100.0);
al_bundy=> INSERT INTO unit VALUES ('inch', 2.54);
al_bundy=>
al_bundy=> INSERT INTO shoe_data VALUES
al_bundy->     ('sh1', 2, 'black', 70.0, 90.0, 'cm');
al_bundy=> INSERT INTO shoe_data VALUES
al_bundy->     ('sh2', 0, 'black', 30.0, 40.0, 'inch');
al_bundy=> INSERT INTO shoe_data VALUES
al_bundy->     ('sh3', 4, 'brown', 50.0, 65.0, 'cm');
al_bundy=> INSERT INTO shoe_data VALUES
al_bundy->     ('sh4', 3, 'brown', 40.0, 50.0, 'inch');
al_bundy=>
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl1', 5, 'black', 80.0, 'cm');
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl2', 6, 'black', 100.0, 'cm');
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl3', 0, 'black', 35.0 , 'inch');
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl4', 8, 'black', 40.0 , 'inch');
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl5', 4, 'brown', 1.0 , 'm');
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl6', 0, 'brown', 0.9 , 'm');
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl7', 7, 'brown', 60 , 'cm');
al_bundy=> INSERT INTO shoelace_data VALUES
al_bundy->     ('sl8', 1, 'brown', 40 , 'inch');
al_bundy=>
al_bundy=> SELECT * FROM shoelace;
sl_name   |sl_avail|sl_color  |sl_len|sl_unit |sl_len_cm
----------+--------+----------+------+--------+---------
sl1       |       5|black     |    80|cm      |       80
sl2       |       6|black     |   100|cm      |      100
sl7       |       7|brown     |    60|cm      |       60
sl3       |       0|black     |    35|inch    |     88.9
sl4       |       8|black     |    40|inch    |    101.6
sl8       |       1|brown     |    40|inch    |    101.6
sl5       |       4|brown     |     1|m       |      100
sl6       |       0|brown     |   0.9|m       |       90
(8 rows)
```

It's the simplest SELECT Al can do on our views, so we take this to explain the basics of view rules. The `SELECT * FROM shoelace` was interpreted by the parser and produced the parse tree

```
SELECT shoelace.sl_name, shoelace.sl_avail,
       shoelace.sl_color, shoelace.sl_len,
       shoelace.sl_unit, shoelace.sl_len_cm
  FROM shoelace shoelace;
```

and this is given to the rule system. The rule system walks through the range table and checks if there are rules in `pg_rewrite` for any relation. When processing the range table entry for `shoelace` (the only one up to now) it finds the `_RETURN` rule with the parse tree

```
SELECT s.sl_name, s.sl_avail,
       s.sl_color, s.sl_len, s.sl_unit,
       float8mul(s.sl_len, u.un_fact) AS sl_len_cm
  FROM shoelace *OLD*, shoelace *NEW*,
       shoelace_data s, unit u
 WHERE bpchareq(s.sl_unit, u.un_name);
```

Note that the parser changed the calculation and qualification into calls to the appropriate functions. But in fact this changes nothing.

To expand the view, the rewriter simply creates a subselect range-table entry containing the rule's action parse tree, and substitutes this range table entry for the original one that referenced the view. The resulting rewritten parse tree is almost the same as if Al had typed

```
SELECT shoelace.sl_name, shoelace.sl_avail,
       shoelace.sl_color, shoelace.sl_len,
       shoelace.sl_unit, shoelace.sl_len_cm
  FROM (SELECT s.sl_name,
               s.sl_avail,
               s.sl_color,
               s.sl_len,
               s.sl_unit,
               s.sl_len * u.un_fact AS sl_len_cm
          FROM shoelace_data s, unit u
         WHERE s.sl_unit = u.un_name) shoelace;
```

There is one difference however: the sub-query's range table has two extra entries shoelace *OLD*, shoelace *NEW*. These entries don't participate directly in the query, since they aren't referenced by the sub-query's join tree or target list. The rewriter uses them to store the access permission check info that was originally present in the range-table entry that referenced the view. In this way, the executor will still check that the user has proper permissions to access the view, even though there's no direct use of the view in the rewritten query.

That was the first rule applied. The rule system will continue checking the remaining range-table entries in the top query (in this example there are no more), and it will recursively check the range-table entries in the added sub-query to see if any of them reference views. (But it won't expand *OLD* or *NEW* --- otherwise we'd have infinite recursion!) In this example, there are no rewrite rules for shoelace_data or unit, so rewriting is complete and the above is the final result given to the planner.

Now we face Al with the problem that the Blues Brothers appear in his shop and want to buy some new shoes, and as the Blues Brothers are, they want to wear the same shoes. And they want to wear them immediately, so they need shoelaces too.

Al needs to know for which shoes currently in the store he has the matching shoelaces (color and size) and where the total number of exactly matching pairs is greater or equal to two. We teach him what to do and he asks his database:

```
al_bundy=> SELECT * FROM shoe_ready WHERE total_avail >= 2;
shoename  |sh_avail|sl_name   |sl_avail|total_avail
```

```
----------+--------+----------+--------+-----------
sh1       |       2|sl1       |       5|          2
sh3       |       4|sl7       |       7|          4
(2 rows)
```

Al is a shoe guru and so he knows that only shoes of type sh1 would fit (shoelace sl7 is brown and shoes that need brown shoelaces aren't shoes the Blues Brothers would ever wear).

The output of the parser this time is the parse tree

```
SELECT shoe_ready.shoename, shoe_ready.sh_avail,
       shoe_ready.sl_name, shoe_ready.sl_avail,
       shoe_ready.total_avail
  FROM shoe_ready shoe_ready
 WHERE int4ge(shoe_ready.total_avail, 2);
```

The first rule applied will be the one for the `shoe_ready` view and it results in the parse tree

```
SELECT shoe_ready.shoename, shoe_ready.sh_avail,
       shoe_ready.sl_name, shoe_ready.sl_avail,
       shoe_ready.total_avail
  FROM (SELECT rsh.shoename,
               rsh.sh_avail,
               rsl.sl_name,
               rsl.sl_avail,
               min(rsh.sh_avail, rsl.sl_avail) AS total_avail
          FROM shoe rsh, shoelace rsl
         WHERE rsl.sl_color = rsh.slcolor
           AND rsl.sl_len_cm >= rsh.slminlen_cm
           AND rsl.sl_len_cm <= rsh.slmaxlen_cm) shoe_ready
 WHERE int4ge(shoe_ready.total_avail, 2);
```

Similarly, the rules for `shoe` and `shoelace` are substituted into the range table of the sub-query, leading to a three-level final query tree:

```
SELECT shoe_ready.shoename, shoe_ready.sh_avail,
       shoe_ready.sl_name, shoe_ready.sl_avail,
       shoe_ready.total_avail
  FROM (SELECT rsh.shoename,
               rsh.sh_avail,
               rsl.sl_name,
               rsl.sl_avail,
               min(rsh.sh_avail, rsl.sl_avail) AS total_avail
          FROM (SELECT sh.shoename,
                       sh.sh_avail,
                       sh.slcolor,
                       sh.slminlen,
                       sh.slminlen * un.un_fact AS slminlen_cm,
                       sh.slmaxlen,
                       sh.slmaxlen * un.un_fact AS slmaxlen_cm,
                       sh.slunit
                  FROM shoe_data sh, unit un
                 WHERE sh.slunit = un.un_name) rsh,
               (SELECT s.sl_name,
```

```
                          s.sl_avail,
                          s.sl_color,
                          s.sl_len,
                          s.sl_unit,
                          s.sl_len * u.un_fact AS sl_len_cm
                     FROM shoelace_data s, unit u
                    WHERE s.sl_unit = u.un_name) rsl
            WHERE rsl.sl_color = rsh.slcolor
              AND rsl.sl_len_cm >= rsh.slminlen_cm
              AND rsl.sl_len_cm <= rsh.slmaxlen_cm) shoe_ready
    WHERE int4ge(shoe_ready.total_avail, 2);
```

It turns out that the planner will collapse this tree into a two-level query tree: the bottommost selects will be “pulled up” into the middle select since there’s no need to process them separately. But the middle select will remain separate from the top, because it contains aggregate functions. If we pulled those up it would change the behavior of the topmost select, which we don’t want. However, collapsing the query tree is an optimization that the rewrite system doesn’t have to concern itself with.

> **Note:** There is currently no recursion stopping mechanism for view rules in the rule system (only for the other kinds of rules). This doesn’t hurt much, because the only way to push this into an endless loop (blowing up the backend until it reaches the memory limit) is to create tables and then setup the view rules by hand with CREATE RULE in such a way, that one selects from the other that selects from the one. This could never happen if CREATE VIEW is used because for the first CREATE VIEW, the second relation does not exist and thus the first view cannot select from the second.

13.3.3. View Rules in Non-SELECT Statements

Two details of the parse tree aren’t touched in the description of view rules above. These are the command type and the result relation. In fact, view rules don’t need this information.

There are only a few differences between a parse tree for a SELECT and one for any other command. Obviously they have another command type and this time the result relation points to the range table entry where the result should go. Everything else is absolutely the same. So having two tables t1 and t2 with attributes a and b, the parse trees for the two statements

```
SELECT t2.b FROM t1, t2 WHERE t1.a = t2.a;

UPDATE t1 SET b = t2.b WHERE t1.a = t2.a;
```

are nearly identical.

- The range tables contain entries for the tables t1 and t2.
- The target lists contain one variable that points to attribute b of the range table entry for table t2.
- The qualification expressions compare the attributes a of both ranges for equality.
- The join trees show a simple join between t1 and t2.

The consequence is, that both parse trees result in similar execution plans. They are both joins over the two tables. For the UPDATE the missing columns from t1 are added to the target list by the planner and the final parse tree will read as

```
UPDATE t1 SET a = t1.a, b = t2.b WHERE t1.a = t2.a;
```

and thus the executor run over the join will produce exactly the same result set as a

```
SELECT t1.a, t2.b FROM t1, t2 WHERE t1.a = t2.a;
```

will do. But there is a little problem in UPDATE. The executor does not care what the results from the join it is doing are meant for. It just produces a result set of rows. The difference that one is a SELECT command and the other is an UPDATE is handled in the caller of the executor. The caller still knows (looking at the parse tree) that this is an UPDATE, and he knows that this result should go into table t1. But which of the rows that are there has to be replaced by the new row?

To resolve this problem, another entry is added to the target list in UPDATE (and also in DELETE) statements: the current tuple ID (CTID). This is a system attribute containing the file block number and position in the block for the row. Knowing the table, the CTID can be used to retrieve the original t1 row to be updated. After adding the CTID to the target list, the query actually looks like

```
SELECT t1.a, t2.b, t1.ctid FROM t1, t2 WHERE t1.a = t2.a;
```

Now another detail of PostgreSQL enters the stage. At this moment, table rows aren't overwritten and this is why ABORT TRANSACTION is fast. In an UPDATE, the new result row is inserted into the table (after stripping CTID) and in the tuple header of the row that CTID pointed to the `cmax` and `xmax` entries are set to the current command counter and current transaction ID. Thus the old row is hidden and after the transaction committed the vacuum cleaner can really move it out.

Knowing all that, we can simply apply view rules in absolutely the same way to any command. There is no difference.

13.3.4. The Power of Views in PostgreSQL

The above demonstrates how the rule system incorporates view definitions into the original parse tree. In the second example a simple SELECT from one view created a final parse tree that is a join of 4 tables (unit is used twice with different names).

13.3.4.1. Benefits

The benefit of implementing views with the rule system is, that the planner has all the information about which tables have to be scanned plus the relationships between these tables plus the restrictive qualifications from the views plus the qualifications from the original query in one single parse tree. And this is still the situation when the original query is already a join over views. Now the planner has to decide which is the best path to execute the query. The more information the planner has, the better this decision can be. And the rule system as implemented in PostgreSQL ensures, that this is all information available about the query up to now.

13.3.5. What about updating a view?

What happens if a view is named as the target relation for an INSERT, UPDATE, or DELETE? After doing the substitutions described above, we will have a query tree in which the result relation points at a subquery range table entry. This will not work, so the rewriter throws an error if it sees it has produced such a thing.

To change this we can define rules that modify the behavior of non-SELECT queries. This is the topic of the next section.

13.4. Rules on INSERT, UPDATE and DELETE

13.4.1. Differences from View Rules

Rules that are defined ON INSERT, UPDATE and DELETE are totally different from the view rules described in the previous section. First, their CREATE RULE command allows more:

- They can have no action.
- They can have multiple actions.
- The keyword INSTEAD is optional.
- The pseudo relations NEW and OLD become useful.
- They can have rule qualifications.

Second, they don't modify the parse tree in place. Instead they create zero or many new parse trees and can throw away the original one.

13.4.2. How These Rules Work

Keep the syntax

```
CREATE RULE rule_name AS ON event
    TO object [WHERE rule_qualification]
    DO [INSTEAD] [action | (actions) | NOTHING];
```

in mind. In the following, *update rules* means rules that are defined ON INSERT, UPDATE or DELETE.

Update rules get applied by the rule system when the result relation and the command type of a parse tree are equal to the object and event given in the CREATE RULE command. For update rules, the rule system creates a list of parse trees. Initially the parse tree list is empty. There can be zero (NOTHING keyword), one or multiple actions. To simplify, we look at a rule with one action. This rule can have a qualification or not and it can be INSTEAD or not.

What is a rule qualification? It is a restriction that tells when the actions of the rule should be done and when not. This qualification can only reference the NEW and/or OLD pseudo relations which are basically the relation given as object (but with a special meaning).

So we have four cases that produce the following parse trees for a one-action rule.

- No qualification and not INSTEAD:
  - The parse tree from the rule action where the original parse tree's qualification has been added.
- No qualification but INSTEAD:
  - The parse tree from the rule action where the original parse tree's qualification has been added.
- Qualification given and not INSTEAD:
  - The parse tree from the rule action where the rule qualification and the original parse tree's qualification have been added.
- Qualification given and INSTEAD:
  - The parse tree from the rule action where the rule qualification and the original parse tree's qualification have been added.
  - The original parse tree where the negated rule qualification has been added.

Finally, if the rule is not INSTEAD, the unchanged original parse tree is added to the list. Since only qualified INSTEAD rules already add the original parse tree, we end up with either one or two output parse trees for a rule with one action.

For ON INSERT rules, the original query (if not suppressed by INSTEAD) is done before any actions added by rules. This allows the actions to see the inserted row(s). But for ON UPDATE and ON DELETE rules, the original query is done after the actions added by rules. This ensures that the actions can see the to-be-updated or to-be-deleted rows; otherwise, the actions might do nothing because they find no rows matching their qualifications.

The parse trees generated from rule actions are thrown into the rewrite system again and maybe more rules get applied resulting in more or less parse trees. So the parse trees in the rule actions must have either another command type or another result relation. Otherwise this recursive process will end up in a loop. There is a compiled-in recursion limit of currently 100 iterations. If after 100 iterations there are still update rules to apply the rule system assumes a loop over multiple rule definitions and reports an error.

The parse trees found in the actions of the `pg_rewrite` system catalog are only templates. Since they can reference the range-table entries for NEW and OLD, some substitutions have to be made before they can be used. For any reference to NEW, the target list of the original query is searched for a corresponding entry. If found, that entry's expression replaces the reference. Otherwise NEW means the same as OLD (for an UPDATE) or is replaced by NULL (for an INSERT). Any reference to OLD is replaced by a reference to the range-table entry which is the result relation.

After we are done applying update rules, we apply view rules to the produced parse tree(s). Views cannot insert new update actions so there is no need to apply update rules to the output of view rewriting.

13.4.2.1. A First Rule Step by Step

We want to trace changes to the sl_avail column in the `shoelace_data` relation. So we setup a log table and a rule that conditionally writes a log entry when an UPDATE is performed on `shoelace_data`.

```
CREATE TABLE shoelace_log (
    sl_name    char(10),      -- shoelace changed
```

```
        sl_avail    integer,        -- new available value
        log_who     text,           -- who did it
        log_when    timestamp       -- when
    );

    CREATE RULE log_shoelace AS ON UPDATE TO shoelace_data
        WHERE NEW.sl_avail != OLD.sl_avail
        DO INSERT INTO shoelace_log VALUES (
                                        NEW.sl_name,
                                        NEW.sl_avail,
                                        current_user,
                                        current_timestamp
                                    );
```

Now Al does

```
al_bundy=> UPDATE shoelace_data SET sl_avail = 6
al_bundy->     WHERE sl_name = 'sl7';
```

and we look at the log table.

```
al_bundy=> SELECT * FROM shoelace_log;
sl_name   |sl_avail|log_who|log_when
----------+--------+-------+--------------------------------
sl7       |       6|Al     |Tue Oct 20 16:14:45 1998 MET DST
(1 row)
```

That's what we expected. What happened in the background is the following. The parser created the parse tree (this time the parts of the original parse tree are highlighted because the base of operations is the rule action for update rules).

```
  UPDATE shoelace_data SET sl_avail = 6
FROM shoelace_data shoelace_data
WHERE bpchareq(shoelace_data.sl_name, 'sl7');
```

There is a rule `log_shoelace` that is ON UPDATE with the rule qualification expression

```
int4ne(NEW.sl_avail, OLD.sl_avail)
```

and one action

```
INSERT INTO shoelace_log VALUES(
       *NEW*.sl_name, *NEW*.sl_avail,
       current_user, current_timestamp)
  FROM shoelace_data *NEW*, shoelace_data *OLD*;
```

This is a little strange-looking since you can't normally write INSERT ... VALUES ... FROM. The FROM clause here is just to indicate that there are range-table entries in the parse tree for *NEW* and *OLD*. These are needed so that they can be referenced by variables in the INSERT command's query tree.

The rule is a qualified non-INSTEAD rule, so the rule system has to return two parse trees: the modified rule action and the original parse tree. In the first step the range table of the original query is incorporated into the rule's action parse tree. This results in

```
INSERT INTO shoelace_log VALUES(
       *NEW*.sl_name, *NEW*.sl_avail,
       current_user, current_timestamp)
  FROM shoelace_data *NEW*, shoelace_data *OLD*,
       shoelace_data shoelace_data;
```

In step 2 the rule qualification is added to it, so the result set is restricted to rows where sl_avail changes.

```
INSERT INTO shoelace_log VALUES(
       *NEW*.sl_name, *NEW*.sl_avail,
       current_user, current_timestamp)
  FROM shoelace_data *NEW*, shoelace_data *OLD*,
       shoelace_data shoelace_data
 WHERE int4ne(*NEW*.sl_avail, *OLD*.sl_avail);
```

This is even stranger-looking, since INSERT ... VALUES doesn't have a WHERE clause either, but the planner and executor will have no difficulty with it. They need to support this same functionality anyway for INSERT ... SELECT.

In step 3 the original parse tree's qualification is added, restricting the result set further to only the rows touched by the original parse tree.

```
INSERT INTO shoelace_log VALUES(
       *NEW*.sl_name, *NEW*.sl_avail,
       current_user, current_timestamp)
  FROM shoelace_data *NEW*, shoelace_data *OLD*,
       shoelace_data shoelace_data
 WHERE int4ne(*NEW*.sl_avail, *OLD*.sl_avail)
   AND bpchareq(shoelace_data.sl_name, 'sl7');
```

Step 4 replaces NEW references by the target list entries from the original parse tree or by the matching variable references from the result relation.

```
INSERT INTO shoelace_log VALUES(
       shoelace_data.sl_name, 6,
       current_user, current_timestamp)
  FROM shoelace_data *NEW*, shoelace_data *OLD*,
       shoelace_data shoelace_data
 WHERE int4ne(6, *OLD*.sl_avail)
   AND bpchareq(shoelace_data.sl_name, 'sl7');
```

Step 5 changes OLD references into result relation references.

```
INSERT INTO shoelace_log VALUES(
       shoelace_data.sl_name, 6,
       current_user, current_timestamp)
  FROM shoelace_data *NEW*, shoelace_data *OLD*,
       shoelace_data shoelace_data
 WHERE int4ne(6, shoelace_data.sl_avail)
   AND bpchareq(shoelace_data.sl_name, 'sl7');
```

That’s it. Since the rule is not INSTEAD, we also output the original parse tree. In short, the output from the rule system is a list of two parse trees that are the same as the statements:

```
INSERT INTO shoelace_log VALUES(
       shoelace_data.sl_name, 6,
       current_user, current_timestamp)
  FROM shoelace_data
 WHERE 6 != shoelace_data.sl_avail
   AND shoelace_data.sl_name = ’sl7’;

UPDATE shoelace_data SET sl_avail = 6
 WHERE sl_name = ’sl7’;
```

These are executed in this order and that is exactly what the rule defines. The substitutions and the qualifications added ensure that if the original query would be, say,

```
UPDATE shoelace_data SET sl_color = ’green’
 WHERE sl_name = ’sl7’;
```

no log entry would get written. This time the original parse tree does not contain a target list entry for sl_avail, so NEW.sl_avail will get replaced by shoelace_data.sl_avail resulting in the extra query

```
INSERT INTO shoelace_log VALUES(
       shoelace_data.sl_name, shoelace_data.sl_avail,
       current_user, current_timestamp)
  FROM shoelace_data
 WHERE shoelace_data.sl_avail != shoelace_data.sl_avail
   AND shoelace_data.sl_name = ’sl7’;
```

and that qualification will never be true. It will also work if the original query modifies multiple rows. So if Al would issue the command

```
UPDATE shoelace_data SET sl_avail = 0
 WHERE sl_color = ’black’;
```

four rows in fact get updated (sl1, sl2, sl3 and sl4). But sl3 already has sl_avail = 0. This time, the original parse trees qualification is different and that results in the extra parse tree

```
INSERT INTO shoelace_log SELECT
       shoelace_data.sl_name, 0,
       current_user, current_timestamp
  FROM shoelace_data
 WHERE 0 != shoelace_data.sl_avail
   AND shoelace_data.sl_color = ’black’;
```

This parse tree will surely insert three new log entries. And that’s absolutely correct.

Here we can see why it is important that the original parse tree is executed last. If the UPDATE would have been executed first, all the rows are already set to zero, so the logging INSERT would not find any row where 0 != shoelace_data.sl_avail.

13.4.3. Cooperation with Views

A simple way to protect view relations from the mentioned possibility that someone can try to INSERT, UPDATE and DELETE on them is to let those parse trees get thrown away. We create the rules

```
CREATE RULE shoe_ins_protect AS ON INSERT TO shoe
    DO INSTEAD NOTHING;
CREATE RULE shoe_upd_protect AS ON UPDATE TO shoe
    DO INSTEAD NOTHING;
CREATE RULE shoe_del_protect AS ON DELETE TO shoe
    DO INSTEAD NOTHING;
```

If Al now tries to do any of these operations on the view relation `shoe`, the rule system will apply the rules. Since the rules have no actions and are INSTEAD, the resulting list of parse trees will be empty and the whole query will become nothing because there is nothing left to be optimized or executed after the rule system is done with it.

A more sophisticated way to use the rule system is to create rules that rewrite the parse tree into one that does the right operation on the real tables. To do that on the `shoelace` view, we create the following rules:

```
CREATE RULE shoelace_ins AS ON INSERT TO shoelace
    DO INSTEAD
    INSERT INTO shoelace_data VALUES (
           NEW.sl_name,
           NEW.sl_avail,
           NEW.sl_color,
           NEW.sl_len,
           NEW.sl_unit);

CREATE RULE shoelace_upd AS ON UPDATE TO shoelace
    DO INSTEAD
    UPDATE shoelace_data SET
           sl_name = NEW.sl_name,
           sl_avail = NEW.sl_avail,
           sl_color = NEW.sl_color,
           sl_len = NEW.sl_len,
           sl_unit = NEW.sl_unit
     WHERE sl_name = OLD.sl_name;

CREATE RULE shoelace_del AS ON DELETE TO shoelace
    DO INSTEAD
    DELETE FROM shoelace_data
     WHERE sl_name = OLD.sl_name;
```

Now there is a pack of shoelaces arriving in Al's shop and it has a big part list. Al is not that good in calculating and so we don't want him to manually update the shoelace view. Instead we setup two little tables, one where he can insert the items from the part list and one with a special trick. The create commands for these are:

```
CREATE TABLE shoelace_arrive (
    arr_name    char(10),
    arr_quant   integer
```

```
);

CREATE TABLE shoelace_ok (
    ok_name     char(10),
    ok_quant    integer
);

CREATE RULE shoelace_ok_ins AS ON INSERT TO shoelace_ok
    DO INSTEAD
    UPDATE shoelace SET
           sl_avail = sl_avail + NEW.ok_quant
     WHERE sl_name = NEW.ok_name;
```

Now Al can sit down and do whatever until

```
al_bundy=> SELECT * FROM shoelace_arrive;
arr_name  |arr_quant
----------+---------
sl3       |       10
sl6       |       20
sl8       |       20
(3 rows)
```

is exactly what's on the part list. We take a quick look at the current data,

```
al_bundy=> SELECT * FROM shoelace;
sl_name   |sl_avail|sl_color  |sl_len|sl_unit |sl_len_cm
----------+--------+----------+------+--------+---------
sl1       |       5|black     |    80|cm      |       80
sl2       |       6|black     |   100|cm      |      100
sl7       |       6|brown     |    60|cm      |       60
sl3       |       0|black     |    35|inch    |     88.9
sl4       |       8|black     |    40|inch    |    101.6
sl8       |       1|brown     |    40|inch    |    101.6
sl5       |       4|brown     |     1|m       |      100
sl6       |       0|brown     |   0.9|m       |       90
(8 rows)
```

move the arrived shoelaces in

```
al_bundy=> INSERT INTO shoelace_ok SELECT * FROM shoelace_arrive;
```

and check the results

```
al_bundy=> SELECT * FROM shoelace ORDER BY sl_name;
sl_name   |sl_avail|sl_color  |sl_len|sl_unit |sl_len_cm
----------+--------+----------+------+--------+---------
sl1       |       5|black     |    80|cm      |       80
sl2       |       6|black     |   100|cm      |      100
sl7       |       6|brown     |    60|cm      |       60
sl4       |       8|black     |    40|inch    |    101.6
sl3       |      10|black     |    35|inch    |     88.9
sl8       |      21|brown     |    40|inch    |    101.6
sl5       |       4|brown     |     1|m       |      100
```

```
sl6       |      20|brown     |   0.9|m       |       90
(8 rows)

al_bundy=> SELECT * FROM shoelace_log;
sl_name   |sl_avail|log_who|log_when
----------+--------+-------+--------------------------------
sl7       |       6|Al     |Tue Oct 20 19:14:45 1998 MET DST
sl3       |      10|Al     |Tue Oct 20 19:25:16 1998 MET DST
sl6       |      20|Al     |Tue Oct 20 19:25:16 1998 MET DST
sl8       |      21|Al     |Tue Oct 20 19:25:16 1998 MET DST
(4 rows)
```

It's a long way from the one INSERT ... SELECT to these results. And its description will be the last in this document (but not the last example :-). First there was the parser's output

```
INSERT INTO shoelace_ok SELECT
       shoelace_arrive.arr_name, shoelace_arrive.arr_quant
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok;
```

Now the first rule `shoelace_ok_ins` is applied and turns it into

```
UPDATE shoelace SET
       sl_avail = int4pl(shoelace.sl_avail, shoelace_arrive.arr_quant)
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok *OLD*, shoelace_ok *NEW*,
       shoelace shoelace
 WHERE bpchareq(shoelace.sl_name, showlace_arrive.arr_name);
```

and throws away the original INSERT on `shoelace_ok`. This rewritten query is passed to the rule system again and the second applied rule `shoelace_upd` produced

```
UPDATE shoelace_data SET
       sl_name = shoelace.sl_name,
       sl_avail = int4pl(shoelace.sl_avail, shoelace_arrive.arr_quant),
       sl_color = shoelace.sl_color,
       sl_len = shoelace.sl_len,
       sl_unit = shoelace.sl_unit
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok *OLD*, shoelace_ok *NEW*,
       shoelace shoelace, shoelace *OLD*,
       shoelace *NEW*, shoelace_data showlace_data
 WHERE bpchareq(shoelace.sl_name, showlace_arrive.arr_name)
   AND bpchareq(shoelace_data.sl_name, shoelace.sl_name);
```

Again it's an INSTEAD rule and the previous parse tree is trashed. Note that this query still uses the view `shoelace`. But the rule system isn't finished with this loop so it continues and applies the `_RETURN` rule on it and we get

```
UPDATE shoelace_data SET
       sl_name = s.sl_name,
       sl_avail = int4pl(s.sl_avail, shoelace_arrive.arr_quant),
       sl_color = s.sl_color,
       sl_len = s.sl_len,
```

```
       sl_unit = s.sl_unit
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok *OLD*, shoelace_ok *NEW*,
       shoelace shoelace, shoelace *OLD*,
       shoelace *NEW*, shoelace_data showlace_data,
       shoelace *OLD*, shoelace *NEW*,
       shoelace_data s, unit u
 WHERE bpchareq(s.sl_name, showlace_arrive.arr_name)
   AND bpchareq(shoelace_data.sl_name, s.sl_name);
```

Again an update rule has been applied and so the wheel turns on and we are in rewrite round 3. This time rule `log_shoelace` gets applied, producing the extra parse tree

```
INSERT INTO shoelace_log SELECT
       s.sl_name,
       int4pl(s.sl_avail, shoelace_arrive.arr_quant),
       current_user,
       current_timestamp
  FROM shoelace_arrive shoelace_arrive, shoelace_ok shoelace_ok,
       shoelace_ok *OLD*, shoelace_ok *NEW*,
       shoelace shoelace, shoelace *OLD*,
       shoelace *NEW*, shoelace_data showlace_data,
       shoelace *OLD*, shoelace *NEW*,
       shoelace_data s, unit u,
       shoelace_data *OLD*, shoelace_data *NEW*
       shoelace_log shoelace_log
 WHERE bpchareq(s.sl_name,  showlace_arrive.arr_name)
   AND bpchareq(shoelace_data.sl_name, s.sl_name);
   AND int4ne(int4pl(s.sl_avail, shoelace_arrive.arr_quant), s.sl_avail);
```

After that the rule system runs out of rules and returns the generated parse trees. So we end up with two final parse trees that are equal to the SQL statements

```
INSERT INTO shoelace_log SELECT
       s.sl_name,
       s.sl_avail + shoelace_arrive.arr_quant,
       current_user,
       current_timestamp
  FROM shoelace_arrive shoelace_arrive, shoelace_data shoelace_data,
       shoelace_data s
 WHERE s.sl_name = shoelace_arrive.arr_name
   AND shoelace_data.sl_name = s.sl_name
   AND s.sl_avail + shoelace_arrive.arr_quant != s.sl_avail;

UPDATE shoelace_data SET
       sl_avail = shoelace_data.sl_avail + shoelace_arrive.arr_quant
  FROM shoelace_arrive shoelace_arrive,
       shoelace_data shoelace_data,
       shoelace_data s
 WHERE s.sl_name = shoelace_arrive.sl_name
   AND shoelace_data.sl_name = s.sl_name;
```

The result is that data coming from one relation inserted into another, changed into updates on a third, changed into updating a fourth plus logging that final update in a fifth gets reduced into two queries.

There is a little detail that's a bit ugly. Looking at the two queries turns out, that the `shoelace_data` relation appears twice in the range table where it could definitely be reduced to one. The planner does not handle it and so the execution plan for the rule systems output of the INSERT will be

```
Nested Loop
  ->  Merge Join
        ->  Seq Scan
              ->  Sort
                    ->  Seq Scan on s
        ->  Seq Scan
              ->  Sort
                    ->  Seq Scan on shoelace_arrive
  ->  Seq Scan on shoelace_data
```

while omitting the extra range table entry would result in a

```
Merge Join
  ->  Seq Scan
        ->  Sort
              ->  Seq Scan on s
  ->  Seq Scan
        ->  Sort
              ->  Seq Scan on shoelace_arrive
```

that totally produces the same entries in the log relation. Thus, the rule system caused one extra scan on the `shoelace_data` relation that is absolutely not necessary. And the same obsolete scan is done once more in the UPDATE. But it was a really hard job to make that all possible at all.

A final demonstration of the PostgreSQL rule system and its power. There is a cute blonde that sells shoelaces. And what Al could never realize, she's not only cute, she's smart too - a little too smart. Thus, it happens from time to time that Al orders shoelaces that are absolutely not sellable. This time he ordered 1000 pairs of magenta shoelaces and since another kind is currently not available but he committed to buy some, he also prepared his database for pink ones.

```
al_bundy=> INSERT INTO shoelace VALUES
al_bundy->     ('sl9', 0, 'pink', 35.0, 'inch', 0.0);
al_bundy=> INSERT INTO shoelace VALUES
al_bundy->     ('sl10', 1000, 'magenta', 40.0, 'inch', 0.0);
```

Since this happens often, we must lookup for shoelace entries, that fit for absolutely no shoe sometimes. We could do that in a complicated statement every time, or we can setup a view for it. The view for this is

```
CREATE VIEW shoelace_obsolete AS
    SELECT * FROM shoelace WHERE NOT EXISTS
        (SELECT shoename FROM shoe WHERE slcolor = sl_color);
```

Its output is

```
al_bundy=> SELECT * FROM shoelace_obsolete;
sl_name   |sl_avail|sl_color  |sl_len|sl_unit |sl_len_cm
----------+--------+----------+------+--------+---------
```

```
sl9       |       0|pink      |    35|inch    |     88.9
sl10      |    1000|magenta   |    40|inch    |    101.6
```

For the 1000 magenta shoelaces we must debit Al before we can throw 'em away, but that's another problem. The pink entry we delete. To make it a little harder for PostgreSQL, we don't delete it directly. Instead we create one more view

```
CREATE VIEW shoelace_candelete AS
    SELECT * FROM shoelace_obsolete WHERE sl_avail = 0;
```

and do it this way:

```
DELETE FROM shoelace WHERE EXISTS
    (SELECT * FROM shoelace_candelete
             WHERE sl_name = shoelace.sl_name);
```

Voilà:

```
al_bundy=> SELECT * FROM shoelace;
sl_name   |sl_avail|sl_color  |sl_len|sl_unit |sl_len_cm
----------+--------+----------+------+--------+---------
sl1       |       5|black     |    80|cm      |       80
sl2       |       6|black     |   100|cm      |      100
sl7       |       6|brown     |    60|cm      |       60
sl4       |       8|black     |    40|inch    |    101.6
sl3       |      10|black     |    35|inch    |     88.9
sl8       |      21|brown     |    40|inch    |    101.6
sl10      |    1000|magenta   |    40|inch    |    101.6
sl5       |       4|brown     |     1|m       |      100
sl6       |      20|brown     |   0.9|m       |       90
(9 rows)
```

A DELETE on a view, with a subselect qualification that in total uses 4 nesting/joined views, where one of them itself has a subselect qualification containing a view and where calculated view columns are used, gets rewritten into one single parse tree that deletes the requested data from a real table.

I think there are only a few situations out in the real world, where such a construct is necessary. But it makes me feel comfortable that it works.

The truth is: Doing this I found one more bug while writing this document. But after fixing that I was a little amazed that it works at all.

13.5. Rules and Permissions

Due to rewriting of queries by the PostgreSQL rule system, other tables/views than those used in the original query get accessed. Using update rules, this can include write access to tables.

Rewrite rules don't have a separate owner. The owner of a relation (table or view) is automatically the owner of the rewrite rules that are defined for it. The PostgreSQL rule system changes the behavior of the default access control system. Relations that are used due to rules get checked against the permissions of the rule owner, not the user invoking the rule. This means, that a user does only need the required permissions for the tables/views he names in his queries.

For example: A user has a list of phone numbers where some of them are private, the others are of interest for the secretary of the office. He can construct the following:

```
CREATE TABLE phone_data (person text, phone text, private bool);
CREATE VIEW phone_number AS
    SELECT person, phone FROM phone_data WHERE NOT private;
GRANT SELECT ON phone_number TO secretary;
```

Nobody except him (and the database superusers) can access the phone_data table. But due to the GRANT, the secretary can SELECT from the phone_number view. The rule system will rewrite the SELECT from phone_number into a SELECT from phone_data and add the qualification that only entries where private is false are wanted. Since the user is the owner of phone_number, the read access to phone_data is now checked against his permissions and the query is considered granted. The check for accessing phone_number is also performed, but this is done against the invoking user, so nobody but the user and the secretary can use it.

The permissions are checked rule by rule. So the secretary is for now the only one who can see the public phone numbers. But the secretary can setup another view and grant access to that to public. Then, anyone can see the phone_number data through the secretaries view. What the secretary cannot do is to create a view that directly accesses phone_data (actually he can, but it will not work since every access aborts the transaction during the permission checks). And as soon as the user will notice, that the secretary opened his phone_number view, he can REVOKE his access. Immediately any access to the secretaries view will fail.

Someone might think that this rule by rule checking is a security hole, but in fact it isn't. If this would not work, the secretary could setup a table with the same columns as phone_number and copy the data to there once per day. Then it's his own data and he can grant access to everyone he wants. A GRANT means "I trust you". If someone you trust does the thing above, it's time to think it over and then REVOKE.

This mechanism does also work for update rules. In the examples of the previous section, the owner of the tables in Al's database could GRANT SELECT, INSERT, UPDATE and DELETE on the shoelace view to al. But only SELECT on shoelace_log. The rule action to write log entries will still be executed successfully. And Al could see the log entries. But he cannot create fake entries, nor could he manipulate or remove existing ones.

> **Warning:** GRANT ALL currently includes RULE permission. This means the granted user could drop the rule, do the changes and reinstall it. I think this should get changed quickly.

13.6. Rules and Command Status

The PostgreSQL server returns a command status string, such as `INSERT 149592 1`, for each query it receives. This is simple enough when there are no rules involved, but what happens when the query is rewritten by rules?

As of PostgreSQL 7.3, rules affect the command status as follows:

1. If there is no unconditional INSTEAD rule for the query, then the originally given query will be executed, and its command status will be returned as usual. (But note that if there were any conditional INSTEAD rules, the negation of their qualifications will have been added to the original query. This may reduce the number of rows it processes, and if so the reported status will be affected.)
2. If there is any unconditional INSTEAD rule for the query, then the original query will not be executed at all. In this case, the server will return the command status for the last query that was inserted by an INSTEAD rule (conditional or unconditional) and is of the same type (INSERT, UPDATE, or DELETE) as the original query. If no query meeting those requirements is added by any rule, then the returned command status shows the original query type and zeroes for the tuple-count and OID fields.

The programmer can ensure that any desired INSTEAD rule is the one that sets the command status in the second case, by giving it the alphabetically last rule name among the active rules, so that it fires last.

13.7. Rules versus Triggers

Many things that can be done using triggers can also be implemented using the PostgreSQL rule system. What currently cannot be implemented by rules are some kinds of constraints. It is possible, to place a qualified rule that rewrites a query to NOTHING if the value of a column does not appear in another table. But then the data is silently thrown away and that’s not a good idea. If checks for valid values are required, and in the case of an invalid value an error message should be generated, it must be done by a trigger for now.

On the other hand a trigger that is fired on INSERT on a view can do the same as a rule, put the data somewhere else and suppress the insert in the view. But it cannot do the same thing on UPDATE or DELETE, because there is no real data in the view relation that could be scanned and thus the trigger would never get called. Only a rule will help.

For the things that can be implemented by both, it depends on the usage of the database, which is the best. A trigger is fired for any row affected once. A rule manipulates the parse tree or generates an additional one. So if many rows are affected in one statement, a rule issuing one extra query would usually do a better job than a trigger that is called for any single row and must execute his operations this many times.

For example: There are two tables

```
CREATE TABLE computer (
    hostname        text,    -- indexed
    manufacturer    text     -- indexed
);

CREATE TABLE software (
    software        text,    -- indexed
    hostname        text     -- indexed
);
```

Both tables have many thousands of rows and the index on `hostname` is unique. The `hostname` column contains the full qualified domain name of the computer. The rule/trigger should constraint delete rows from software that reference the deleted host. Since the trigger is called for each individual row deleted from computer, it can use the statement

```
DELETE FROM software WHERE hostname = $1;
```

in a prepared and saved plan and pass the `hostname` in the parameter. The rule would be written as

```
CREATE RULE computer_del AS ON DELETE TO computer
    DO DELETE FROM software WHERE hostname = OLD.hostname;
```

Now we look at different types of deletes. In the case of a

```
DELETE FROM computer WHERE hostname = 'mypc.local.net';
```

the table computer is scanned by index (fast) and the query issued by the trigger would also be an index scan (fast too). The extra query from the rule would be a

```
DELETE FROM software WHERE computer.hostname = 'mypc.local.net'
                       AND software.hostname = computer.hostname;
```

Since there are appropriate indexes setup, the planner will create a plan of

```
Nestloop
  ->  Index Scan using comp_hostidx on computer
  ->  Index Scan using soft_hostidx on software
```

So there would be not that much difference in speed between the trigger and the rule implementation. With the next delete we want to get rid of all the 2000 computers where the `hostname` starts with 'old'. There are two possible queries to do that. One is

```
DELETE FROM computer WHERE hostname >= 'old'
                       AND hostname <  'ole'
```

Where the plan for the rule query will be a

```
Hash Join
  ->  Seq Scan on software
  ->  Hash
    ->  Index Scan using comp_hostidx on computer
```

The other possible query is a

```
DELETE FROM computer WHERE hostname ~ '^old';
```

with the execution plan

```
Nestloop
  ->  Index Scan using comp_hostidx on computer
  ->  Index Scan using soft_hostidx on software
```

This shows, that the planner does not realize that the qualification for the `hostname` on computer could also be used for an index scan on software when there are multiple qualification expressions combined with AND, what he does in the regexp version of the query. The trigger will get invoked once for any of the 2000 old computers that have to be deleted and that will result in one index scan over computer and 2000 index scans for the software. The rule implementation will do it with two queries over indexes. And it depends on the overall size of the software table if the rule will still be faster in the sequential scan situation. 2000 query executions over the SPI manager take some time, even if all the index blocks to look them up will soon appear in the cache.

The last query we look at is a

```
DELETE FROM computer WHERE manufacurer = 'bim';
```

Again this could result in many rows to be deleted from computer. So the trigger will again fire many queries into the executor. But the rule plan will again be the nested loop over two index scans. Only using another index on computer:

```
Nestloop
  ->  Index Scan using comp_manufidx on computer
  ->  Index Scan using soft_hostidx on software
```

resulting from the rules query

```
DELETE FROM software WHERE computer.manufacurer = 'bim'
                       AND software.hostname = computer.hostname;
```

In any of these cases, the extra queries from the rule system will be more or less independent from the number of affected rows in a query.

Another situation is cases on UPDATE where it depends on the change of an attribute if an action should be performed or not. In PostgreSQL version 6.4, the attribute specification for rule events is disabled (it will have its comeback latest in 6.5, maybe earlier - stay tuned). So for now the only way to create a rule as in the shoelace_log example is to do it with a rule qualification. That results in an extra query that is performed always, even if the attribute of interest cannot change at all because it does not appear in the target list of the initial query. When this is enabled again, it will be one more advantage of rules over triggers. Optimization of a trigger must fail by definition in this case, because the fact that its actions will only be done when a specific attribute is updated is hidden in its functionality. The definition of a trigger only allows to specify it on row level, so whenever a row is touched, the trigger must be called to make its decision. The rule system will know it by looking up the target list and will suppress the additional query completely if the attribute isn't touched. So the rule, qualified or not, will only do its scans if there ever could be something to do.

Rules will only be significantly slower than triggers if their actions result in large and bad qualified joins, a situation where the planner fails. They are a big hammer. Using a big hammer without caution can cause big damage. But used with the right touch, they can hit any nail on the head.

Chapter 14. Interfacing Extensions To Indexes

14.1. Introduction

The procedures described thus far let you define new types, new functions, and new operators. However, we cannot yet define a secondary index (such as a B-tree, R-tree, or hash access method) over a new type, nor associate operators of a new type with secondary indexes. To do these things, we must define an *operator class* for the new data type. We will describe operator classes in the context of a running example: a new operator class for the B-tree access method that stores and sorts complex numbers in ascending absolute value order.

> **Note:** Prior to PostgreSQL release 7.3, it was necessary to make manual additions to `pg_amop`, `pg_amproc`, and `pg_opclass` in order to create a user-defined operator class. That approach is now deprecated in favor of using `CREATE OPERATOR CLASS`, which is a much simpler and less error-prone way of creating the necessary catalog entries.

14.2. Access Methods and Operator Classes

The `pg_am` table contains one row for every index access method. Support for access to regular tables is built into PostgreSQL, but all index access methods are described in `pg_am`. It is possible to add a new index access method by defining the required interface routines and then creating a row in `pg_am` --- but that is far beyond the scope of this chapter.

The routines for an index access method do not directly know anything about the data types the access method will operate on. Instead, an *operator class* identifies the set of operations that the access method needs to be able to use to work with a particular data type. Operator classes are so called because one thing they specify is the set of WHERE-clause operators that can be used with an index (ie, can be converted into an index scan qualification). An operator class may also specify some *support procedures* that are needed by the internal operations of the index access method, but do not directly correspond to any WHERE-clause operator that can be used with the index.

It is possible to define multiple operator classes for the same input data type and index access method. By doing this, multiple sets of indexing semantics can be defined for a single data type. For example, a B-tree index requires a sort ordering to be defined for each data type it works on. It might be useful for a complex-number data type to have one B-tree operator class that sorts the data by complex absolute value, another that sorts by real part, and so on. Typically one of the operator classes will be deemed most commonly useful and will be marked as the default operator class for that data type and index access method.

The same operator class name can be used for several different access methods (for example, both B-tree and hash access methods have operator classes named `oid_ops`), but each such class is an independent entity and must be defined separately.

14.3. Access Method Strategies

The operators associated with an operator class are identified by “strategy numbers”, which serve to identify the semantics of each operator within the context of its operator class. For example, B-trees impose a strict ordering on keys, lesser to greater, and so operators like “less than” and “greater than or equal to” are interesting with respect to a B-tree. Because PostgreSQL allows the user to define operators, PostgreSQL cannot look at the name of an operator (e.g., < or >=) and tell what kind of comparison it is. Instead, the index access method defines a set of “strategies”, which can be thought of as generalized operators. Each operator class shows which actual operator corresponds to each strategy for a particular data type and interpretation of the index semantics.

B-tree indexes define 5 strategies, as shown in Table 14-1.

Table 14-1. B-tree Strategies

Operation	Strategy Number
less than	1
less than or equal	2
equal	3
greater than or equal	4
greater than	5

Hash indexes express only bitwise similarity, and so they define only 1 strategy, as shown in Table 14-2.

Table 14-2. Hash Strategies

Operation	Strategy Number
equal	1

R-tree indexes express rectangle-containment relationships. They define 8 strategies, as shown in Table 14-3.

Table 14-3. R-tree Strategies

Operation	Strategy Number
left of	1
left of or overlapping	2
overlapping	3
right of or overlapping	4
right of	5
same	6
contains	7
contained by	8

GiST indexes are even more flexible: they do not have a fixed set of strategies at all. Instead, the “consistency” support routine of a particular GiST operator class interprets the strategy numbers however it likes.

By the way, the `amorderstrategy` column in `pg_am` tells whether the access method supports ordered scan. Zero means it doesn't; if it does, `amorderstrategy` is the strategy number that corresponds to the ordering operator. For example, B-tree has `amorderstrategy` = 1, which is its "less than" strategy number.

In short, an operator class must specify a set of operators that express each of these semantic ideas for the operator class's data type.

14.4. Access Method Support Routines

Strategies aren't usually enough information for the system to figure out how to use an index. In practice, the access methods require additional support routines in order to work. For example, the B-tree access method must be able to compare two keys and determine whether one is greater than, equal to, or less than the other. Similarly, the R-tree access method must be able to compute intersections, unions, and sizes of rectangles. These operations do not correspond to operators used in qualifications in SQL queries; they are administrative routines used by the access methods, internally.

Just as with operators, the operator class identifies which specific functions should play each of these roles for a given data type and semantic interpretation. The index access method specifies the set of functions it needs, and the operator class identifies the correct functions to use by assigning "support function numbers" to them.

B-trees require a single support function, as shown in Table 14-4.

Table 14-4. B-tree Support Functions

Function	Support Number
Compare two keys and return an integer less than zero, zero, or greater than zero, indicating whether the first key is less than, equal to, or greater than the second.	1

Hash indexes likewise require one support function, as shown in Table 14-5.

Table 14-5. Hash Support Functions

Function	Support Number
Compute the hash value for a key	1

R-tree indexes require three support functions, as shown in Table 14-6.

Table 14-6. R-tree Support Functions

Function	Support Number
union	1
intersection	2

Function	Support Number
size	3

GiST indexes require seven support functions, as shown in Table 14-7.

Table 14-7. GiST Support Functions

Function	Support Number
consistent	1
union	2
compress	3
decompress	4
penalty	5
picksplit	6
equal	7

14.5. Creating the Operators and Support Routines

Now that we have seen the ideas, here is the promised example of creating a new operator class. First, we need a set of operators. The procedure for defining operators was discussed in Chapter 11. For the `complex_abs_ops` operator class on B-trees, the operators we require are:

- absolute-value less-than (strategy 1)
- absolute-value less-than-or-equal (strategy 2)
- absolute-value equal (strategy 3)
- absolute-value greater-than-or-equal (strategy 4)
- absolute-value greater-than (strategy 5)

Suppose the code that implements these functions is stored in the file *PGROOT*`/src/tutorial/complex.c`, which we have compiled into *PGROOT*`/src/tutorial/complex.so`. Part of the C code looks like this:

```
#define Mag(c) ((c)->x*(c)->x + (c)->y*(c)->y)

         bool
         complex_abs_eq(Complex *a, Complex *b)
         {
             double amag = Mag(a), bmag = Mag(b);
             return (amag==bmag);
         }
```

(Note that we will only show the equality operator in this text. The other four operators are very similar. Refer to `complex.c` or `complex.source` for the details.)

We make the function known to PostgreSQL like this:

```
CREATE FUNCTION complex_abs_eq(complex, complex) RETURNS boolean
    AS 'PGROOT/src/tutorial/complex'
    LANGUAGE C;
```

There are some important things that are happening here:

- First, note that operators for less-than, less-than-or-equal, equal, greater-than-or-equal, and greater-than for `complex` are being defined. We can only have one operator named, say, = and taking type `complex` for both operands. In this case we don't have any other operator = for `complex`, but if we were building a practical data type we'd probably want = to be the ordinary equality operation for complex numbers. In that case, we'd need to use some other operator name for `complex_abs_eq`.
- Second, although PostgreSQL can cope with operators having the same name as long as they have different input data types, C can only cope with one global routine having a given name, period. So we shouldn't name the C function something simple like `abs_eq`. Usually it's a good practice to include the data type name in the C function name, so as not to conflict with functions for other data types.
- Third, we could have made the PostgreSQL name of the function `abs_eq`, relying on PostgreSQL to distinguish it by input data types from any other PostgreSQL function of the same name. To keep the example simple, we make the function have the same names at the C level and PostgreSQL level.
- Finally, note that these operator functions return Boolean values. In practice, all operators defined as index access method strategies must return type `boolean`, since they must appear at the top level of a `WHERE` clause to be used with an index. (On the other hand, support functions return whatever the particular access method expects -- in the case of the comparison function for B-trees, a signed integer.)

Now we are ready to define the operators:

```
CREATE OPERATOR = (
     leftarg = complex, rightarg = complex,
     procedure = complex_abs_eq,
     restrict = eqsel, join = eqjoinsel
         );
```

The important things here are the procedure names (which are the C functions defined above) and the restriction and join selectivity functions. You should just use the selectivity functions used in the example (see `complex.source`). Note that there are different such functions for the less-than, equal, and greater-than cases. These must be supplied or the optimizer will be unable to make effective use of the index.

The next step is the registration of the comparison "support routine" required by B-trees. The C code that implements this is in the same file that contains the operator procedures:

```
CREATE FUNCTION complex_abs_cmp(complex, complex)
    RETURNS integer
    AS 'PGROOT/src/tutorial/complex'
    LANGUAGE C;
```

14.6. Creating the Operator Class

Now that we have the required operators and support routine, we can finally create the operator class:

```
CREATE OPERATOR CLASS complex_abs_ops
    DEFAULT FOR TYPE complex USING btree AS
        OPERATOR        1       < ,
        OPERATOR        2       <= ,
        OPERATOR        3       = ,
        OPERATOR        4       >= ,
        OPERATOR        5       > ,
        FUNCTION        1       complex_abs_cmp(complex, complex);
```

And we're done! (Whew.) It should now be possible to create and use B-tree indexes on `complex` columns.

We could have written the operator entries more verbosely, as in

```
        OPERATOR        1       < (complex, complex) ,
```

but there is no need to do so when the operators take the same data type we are defining the operator class for.

The above example assumes that you want to make this new operator class the default B-tree operator class for the `complex` data type. If you don't, just leave out the word `DEFAULT`.

14.7. Special Features of Operator Classes

There are two special features of operator classes that we have not discussed yet, mainly because they are not very useful with the default B-tree index access method.

Normally, declaring an operator as a member of an operator class means that the index access method can retrieve exactly the set of rows that satisfy a WHERE condition using the operator. For example,

```
SELECT * FROM table WHERE integer_column < 4;
```

can be satisfied exactly by a B-tree index on the integer column. But there are cases where an index is useful as an inexact guide to the matching rows. For example, if an R-tree index stores only bounding boxes for objects, then it cannot exactly satisfy a WHERE condition that tests overlap between nonrectangular objects such as polygons. Yet we could use the index to find objects whose bounding box overlaps the bounding box of the target object, and then do the exact overlap test only on the objects found by the index. If this scenario applies, the index is said to be "lossy" for the operator, and we add `RECHECK` to the `OPERATOR` clause in the `CREATE OPERATOR CLASS` command. `RECHECK` is valid if the index is guaranteed to return all the required tuples, plus perhaps some additional tuples, which can be eliminated by performing the original operator comparison.

Consider again the situation where we are storing in the index only the bounding box of a complex object such as a polygon. In this case there's not much value in storing the whole polygon in the index entry --- we may as well store just a simpler object of type `box`. This situation is expressed by the `STORAGE` option in `CREATE OPERATOR CLASS`: we'd write something like

```
CREATE OPERATOR CLASS polygon_ops
```

```
DEFAULT FOR TYPE polygon USING gist AS
    ...
    STORAGE box;
```

At present, only the GiST access method supports a `STORAGE` type that's different from the column data type. The GiST `compress` and `decompress` support routines must deal with data-type conversion when `STORAGE` is used.

Chapter 15. Index Cost Estimation Functions

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Note: This must eventually become part of a much larger chapter about writing new index access methods.

Every index access method must provide a cost estimation function for use by the planner/optimizer. The procedure OID of this function is given in the `amcostestimate` field of the access method's `pg_am` entry.

Note: Prior to PostgreSQL 7.0, a different scheme was used for registering index-specific cost estimation functions.

The amcostestimate function is given a list of WHERE clauses that have been determined to be usable with the index. It must return estimates of the cost of accessing the index and the selectivity of the WHERE clauses (that is, the fraction of main-table tuples that will be retrieved during the index scan). For simple cases, nearly all the work of the cost estimator can be done by calling standard routines in the optimizer; the point of having an amcostestimate function is to allow index access methods to provide index-type-specific knowledge, in case it is possible to improve on the standard estimates.

Each amcostestimate function must have the signature:

```
void
amcostestimate (Query *root,
                RelOptInfo *rel,
                IndexOptInfo *index,
                List *indexQuals,
                Cost *indexStartupCost,
                Cost *indexTotalCost,
                Selectivity *indexSelectivity,
                double *indexCorrelation);
```

The first four parameters are inputs:

root

    The query being processed.

rel

    The relation the index is on.

index

The index itself.

indexQuals

List of index qual clauses (implicitly ANDed); a NIL list indicates no qualifiers are available.

The last four parameters are pass-by-reference outputs:

*indexStartupCost

Set to cost of index start-up processing

*indexTotalCost

Set to total cost of index processing

*indexSelectivity

Set to index selectivity

*indexCorrelation

Set to correlation coefficient between index scan order and underlying table's order

Note that cost estimate functions must be written in C, not in SQL or any available procedural language, because they must access internal data structures of the planner/optimizer.

The index access costs should be computed in the units used by `src/backend/optimizer/path/costsize.c`: a sequential disk block fetch has cost 1.0, a nonsequential fetch has cost random_page_cost, and the cost of processing one index tuple should usually be taken as cpu_index_tuple_cost (which is a user-adjustable optimizer parameter). In addition, an appropriate multiple of cpu_operator_cost should be charged for any comparison operators invoked during index processing (especially evaluation of the indexQuals themselves).

The access costs should include all disk and CPU costs associated with scanning the index itself, but NOT the costs of retrieving or processing the main-table tuples that are identified by the index.

The "start-up cost" is the part of the total scan cost that must be expended before we can begin to fetch the first tuple. For most indexes this can be taken as zero, but an index type with a high start-up cost might want to set it nonzero.

The indexSelectivity should be set to the estimated fraction of the main table tuples that will be retrieved during the index scan. In the case of a lossy index, this will typically be higher than the fraction of tuples that actually pass the given qual conditions.

The indexCorrelation should be set to the correlation (ranging between -1.0 and 1.0) between the index order and the table order. This is used to adjust the estimate for the cost of fetching tuples from the main table.

Cost Estimation

A typical cost estimator will proceed as follows:

1. Estimate and return the fraction of main-table tuples that will be visited based on the given qual conditions. In the absence of any index-type-specific knowledge, use the standard optimizer function `clauselist_selectivity()`:

   ```
   *indexSelectivity = clauselist_selectivity(root, indexQuals,
                                              lfirsti(rel->relids));
   ```

2. Estimate the number of index tuples that will be visited during the scan. For many index types this is the same as indexSelectivity times the number of tuples in the index, but it might be more. (Note that the index's size in pages and tuples is available from the IndexOptInfo struct.)
3. Estimate the number of index pages that will be retrieved during the scan. This might be just indexSelectivity times the index's size in pages.
4. Compute the index access cost. A generic estimator might do this:

   ```
   /*
    * Our generic assumption is that the index pages will be read
    * sequentially, so they have cost 1.0 each, not random_page_cost.
    * Also, we charge for evaluation of the indexquals at each index tuple.
    * All the costs are assumed to be paid incrementally during the scan.
    */
   *indexStartupCost = 0;
   *indexTotalCost = numIndexPages +
       (cpu_index_tuple_cost + cost_qual_eval(indexQuals)) * numIndexTuples;
   ```

5. Estimate the index correlation. For a simple ordered index on a single field, this can be retrieved from pg_statistic. If the correlation is not known, the conservative estimate is zero (no correlation).

Examples of cost estimator functions can be found in `src/backend/utils/adt/selfuncs.c`.

By convention, the `pg_proc` entry for an `amcostestimate` function should show eight arguments all declared as `internal` (since none of them have types that are known to SQL), and the return type is `void`.

Chapter 16. Triggers

PostgreSQL has various server-side function interfaces. Server-side functions can be written in SQL, C, or any defined procedural language. Trigger functions can be written in C and most procedural languages, but not in SQL. Note that statement-level trigger events are not supported in the current version. You can currently specify BEFORE or AFTER on INSERT, DELETE or UPDATE of a tuple as a trigger event.

16.1. Trigger Definition

If a trigger event occurs, the trigger manager (called by the Executor) sets up a `TriggerData` information structure (described below) and calls the trigger function to handle the event.

The trigger function must be defined before the trigger itself can be created. The trigger function must be declared as a function taking no arguments and returning type `trigger`. (The trigger function receives its input through a `TriggerData` structure, not in the form of ordinary function arguments.) If the function is written in C, it must use the "version 1" function manager interface.

The syntax for creating triggers is:

```
CREATE TRIGGER trigger [ BEFORE | AFTER ] [ INSERT | DELETE | UPDATE [ OR ... ] ]
    ON relation FOR EACH [ ROW | STATEMENT ]
    EXECUTE PROCEDURE procedure
     (args);
```

where the arguments are:

trigger

The trigger must have a name distinct from all other triggers on the same table. The name is needed if you ever have to delete the trigger.

BEFORE
AFTER

Determines whether the function is called before or after the event.

INSERT
DELETE
UPDATE

The next element of the command determines what event(s) will trigger the function. Multiple events can be specified separated by OR.

relation

The relation name indicates which table the event applies to.

ROW
STATEMENT

The FOR EACH clause determines whether the trigger is fired for each affected row or before (or after) the entire statement has completed. Currently only the ROW case is supported.

procedure

The procedure name is the function to be called.

args

The arguments passed to the function in the `TriggerData` structure. This is either empty or a list of one or more simple literal constants (which will be passed to the function as strings).

The purpose of including arguments in the trigger definition is to allow different triggers with similar requirements to call the same function. As an example, there could be a generalized trigger function that takes as its arguments two field names and puts the current user in one and the current time stamp in the other. Properly written, this trigger function would be independent of the specific table it is triggering on. So the same function could be used for INSERT events on any table with suitable fields, to automatically track creation of records in a transaction table for example. It could also be used to track last-update events if defined as an UPDATE trigger.

Trigger functions return a `HeapTuple` to the calling executor. The return value is ignored for triggers fired AFTER an operation, but it allows BEFORE triggers to:

- Return a `NULL` pointer to skip the operation for the current tuple (and so the tuple will not be inserted/updated/deleted).
- For INSERT and UPDATE triggers only, the returned tuple becomes the tuple which will be inserted or will replace the tuple being updated. This allows the trigger function to modify the row being inserted or updated.

A BEFORE trigger that does not intend to cause either of these behaviors must be careful to return the same NEW tuple it is passed.

Note that there is no initialization performed by the CREATE TRIGGER handler. This may be changed in the future.

If more than one trigger is defined for the same event on the same relation, the triggers will be fired in alphabetical order by name. In the case of BEFORE triggers, the possibly-modified tuple returned by each trigger becomes the input to the next trigger. If any BEFORE trigger returns `NULL`, the operation is abandoned and subsequent triggers are not fired.

If a trigger function executes SQL-queries (using SPI) then these queries may fire triggers again. This is known as cascading triggers. There is no direct limitation on the number of cascade levels. It is possible for cascades to cause recursive invocation of the same trigger --- for example, an INSERT trigger might execute a query that inserts an additional tuple into the same table, causing the INSERT trigger to be fired again. It is the trigger programmer’s responsibility to avoid infinite recursion in such scenarios.

16.2. Interaction with the Trigger Manager

This section describes the low-level details of the interface to a trigger function. This information is only needed when writing a trigger function in C. If you are using a higher-level function language then these details are handled for you.

> **Note:** The interface described here applies for PostgreSQL 7.1 and later. Earlier versions passed the `TriggerData` pointer in a global variable `CurrentTriggerData`.

When a function is called by the trigger manager, it is not passed any normal parameters, but it is passed a "context" pointer pointing to a `TriggerData` structure. C functions can check whether they were called from the trigger manager or not by executing the macro `CALLED_AS_TRIGGER(fcinfo)`, which expands to

```
((fcinfo)->context != NULL && IsA((fcinfo)->context, TriggerData))
```

If this returns true, then it is safe to cast `fcinfo->context` to type `TriggerData *` and make use of the pointed-to `TriggerData` structure. The function must *not* alter the `TriggerData` structure or any of the data it points to.

`struct TriggerData` is defined in `commands/trigger.h`:

```
typedef struct TriggerData
{
    NodeTag       type;
    TriggerEvent  tg_event;
    Relation      tg_relation;
    HeapTuple     tg_trigtuple;
    HeapTuple     tg_newtuple;
    Trigger      *tg_trigger;
} TriggerData;
```

where the members are defined as follows:

`type`

Always `T_TriggerData` if this is a trigger event.

`tg_event`

describes the event for which the function is called. You may use the following macros to examine `tg_event`:

TRIGGER_FIRED_BEFORE(tg_event)

returns TRUE if trigger fired BEFORE.

TRIGGER_FIRED_AFTER(tg_event)

Returns TRUE if trigger fired AFTER.

TRIGGER_FIRED_FOR_ROW(event)

Returns TRUE if trigger fired for a ROW-level event.

TRIGGER_FIRED_FOR_STATEMENT(event)

Returns TRUE if trigger fired for STATEMENT-level event.

TRIGGER_FIRED_BY_INSERT(event)

Returns TRUE if trigger fired by INSERT.

TRIGGER_FIRED_BY_DELETE(event)

Returns TRUE if trigger fired by DELETE.

TRIGGER_FIRED_BY_UPDATE(event)

Returns TRUE if trigger fired by UPDATE.

`tg_relation`

is a pointer to structure describing the triggered relation. Look at `utils/rel.h` for details about this structure. The most interesting things are `tg_relation->rd_att` (descriptor of the relation tuples) and `tg_relation->rd_rel->relname` (relation's name. This is not `char*`, but `NameData`. Use `SPI_getrelname(tg_relation)` to get `char*` if you need a copy of the name).

`tg_trigtuple`

is a pointer to the tuple for which the trigger is fired. This is the tuple being inserted (if INSERT), deleted (if DELETE) or updated (if UPDATE). If INSERT/DELETE then this is what you are to return to Executor if you don't want to replace tuple with another one (INSERT) or skip the operation.

`tg_newtuple`

is a pointer to the new version of tuple if UPDATE and `NULL` if this is for an INSERT or a DELETE. This is what you are to return to Executor if UPDATE and you don't want to replace this tuple with another one or skip the operation.

`tg_trigger`

is pointer to structure `Trigger` defined in `utils/rel.h`:

```
typedef struct Trigger
{
    Oid         tgoid;
    char       *tgname;
    Oid         tgfoid;
    int16       tgtype;
    bool        tgenabled;
    bool        tgisconstraint;
    Oid         tgconstrrelid;
    bool        tgdeferrable;
    bool        tginitdeferred;
    int16       tgnargs;
    int16       tgattr[FUNC_MAX_ARGS];
    char      **tgargs;
} Trigger;
```

where `tgname` is the trigger's name, `tgnargs` is number of arguments in `tgargs`, `tgargs` is an array of pointers to the arguments specified in the CREATE TRIGGER statement. Other members are for internal use only.

16.3. Visibility of Data Changes

PostgreSQL data changes visibility rule: during a query execution, data changes made by the query itself (via SQL-function, SPI-function, triggers) are invisible to the query scan. For example, in query

```
INSERT INTO a SELECT * FROM a;
```

tuples inserted are invisible for SELECT scan. In effect, this duplicates the database table within itself (subject to unique index rules, of course) without recursing.

But keep in mind this notice about visibility in the SPI documentation:

> Changes made by query Q are visible by queries that are started after query Q, no matter whether they are started inside Q (during the execution of Q) or after Q is done.

This is true for triggers as well so, though a tuple being inserted (`tg_trigtuple`) is not visible to queries in a BEFORE trigger, this tuple (just inserted) is visible to queries in an AFTER trigger, and to queries in BEFORE/AFTER triggers fired after this!

16.4. Examples

There are more complex examples in `src/test/regress/regress.c` and in `contrib/spi`.

Here is a very simple example of trigger usage. Function `trigf` reports the number of tuples in the triggered relation `ttest` and skips the operation if the query attempts to insert a null value into x (i.e - it acts as a not-null constraint but doesn't abort the transaction).

```
#include "executor/spi.h"       /* this is what you need to work with SPI */
#include "commands/trigger.h"   /* -"- and triggers */

extern Datum trigf(PG_FUNCTION_ARGS);

PG_FUNCTION_INFO_V1(trigf);

Datum
trigf(PG_FUNCTION_ARGS)
{
    TriggerData *trigdata = (TriggerData *) fcinfo->context;
    TupleDesc   tupdesc;
    HeapTuple   rettuple;
    char       *when;
    bool        checknull = false;
    bool        isnull;
    int         ret, i;

    /* Make sure trigdata is pointing at what I expect */
    if (!CALLED_AS_TRIGGER(fcinfo))
        elog(ERROR, "trigf: not fired by trigger manager");

    /* tuple to return to Executor */
    if (TRIGGER_FIRED_BY_UPDATE(trigdata->tg_event))
```

```
        rettuple = trigdata->tg_newtuple;
    else
        rettuple = trigdata->tg_trigtuple;

    /* check for null values */
    if (!TRIGGER_FIRED_BY_DELETE(trigdata->tg_event)
        && TRIGGER_FIRED_BEFORE(trigdata->tg_event))
        checknull = true;

    if (TRIGGER_FIRED_BEFORE(trigdata->tg_event))
        when = "before";
    else
        when = "after ";

    tupdesc = trigdata->tg_relation->rd_att;

    /* Connect to SPI manager */
    if ((ret = SPI_connect()) < 0)
        elog(INFO, "trigf (fired %s): SPI_connect returned %d", when, ret);

    /* Get number of tuples in relation */
    ret = SPI_exec("SELECT count(*) FROM ttest", 0);

    if (ret < 0)
        elog(NOTICE, "trigf (fired %s): SPI_exec returned %d", when, ret);

    /* count(*) returns int8 as of PG 7.2, so be careful to convert */
    i = (int) DatumGetInt64(SPI_getbinval(SPI_tuptable->vals[0],
                                          SPI_tuptable->tupdesc,
                                          1,
                                          &isnull));

    elog (NOTICE, "trigf (fired %s): there are %d tuples in ttest", when, i);

    SPI_finish();

    if (checknull)
    {
        (void) SPI_getbinval(rettuple, tupdesc, 1, &isnull);
        if (isnull)
            rettuple = NULL;
    }

    return PointerGetDatum(rettuple);
}
```

Now, compile and create the trigger function:

```
CREATE FUNCTION trigf () RETURNS TRIGGER AS
’...path_to_so’ LANGUAGE C;

CREATE TABLE ttest (x int4);
```

```
vac=> CREATE TRIGGER tbefore BEFORE INSERT OR UPDATE OR DELETE ON ttest
FOR EACH ROW EXECUTE PROCEDURE trigf();
CREATE
vac=> CREATE TRIGGER tafter AFTER INSERT OR UPDATE OR DELETE ON ttest
FOR EACH ROW EXECUTE PROCEDURE trigf();
CREATE
vac=> INSERT INTO ttest VALUES (NULL);
WARNING:  trigf (fired before): there are 0 tuples in ttest
INSERT 0 0

-- Insertion skipped and AFTER trigger is not fired

vac=> SELECT * FROM ttest;
 x
---
(0 rows)

vac=> INSERT INTO ttest VALUES (1);
INFO:  trigf (fired before): there are 0 tuples in ttest
INFO:  trigf (fired after ): there are 1 tuples in ttest
                                       ^^^^^^^^
                             remember what we said about visibility.
INSERT 167793 1
vac=> SELECT * FROM ttest;
 x
---
 1
(1 row)

vac=> INSERT INTO ttest SELECT x * 2 FROM ttest;
INFO:  trigf (fired before): there are 1 tuples in ttest
INFO:  trigf (fired after ): there are 2 tuples in ttest
                                       ^^^^^^^^
                             remember what we said about visibility.
INSERT 167794 1
vac=> SELECT * FROM ttest;
 x
---
 1
 2
(2 rows)

vac=> UPDATE ttest SET x = NULL WHERE x = 2;
INFO:  trigf (fired before): there are 2 tuples in ttest
UPDATE 0
vac=> UPDATE ttest SET x = 4 WHERE x = 2;
INFO:  trigf (fired before): there are 2 tuples in ttest
INFO:  trigf (fired after ): there are 2 tuples in ttest
UPDATE 1
vac=> SELECT * FROM ttest;
 x
---
 1
```

```
 4
(2 rows)

vac=> DELETE FROM ttest;
INFO:  trigf (fired before): there are 2 tuples in ttest
INFO:  trigf (fired after ): there are 1 tuples in ttest
INFO:  trigf (fired before): there are 1 tuples in ttest
INFO:  trigf (fired after ): there are 0 tuples in ttest
                                       ^^^^^^^^
                             remember what we said about visibility.
DELETE 2
vac=> SELECT * FROM ttest;
 x
---
(0 rows)
```

Chapter 17. Server Programming Interface

The *Server Programming Interface* (SPI) gives users the ability to run SQL queries inside user-defined C functions.

> **Note:** The available Procedural Languages (PL) give an alternate means to build functions that can execute queries.

In fact, SPI is just a set of native interface functions to simplify access to the Parser, Planner, Optimizer and Executor. SPI also does some memory management.

To avoid misunderstanding we'll use *function* to mean SPI interface functions and *procedure* for user-defined C-functions using SPI.

Procedures which use SPI are called by the Executor. The SPI calls recursively invoke the Executor in turn to run queries. When the Executor is invoked recursively, it may itself call procedures which may make SPI calls.

Note that if during execution of a query from a procedure the transaction is aborted, then control will not be returned to your procedure. Rather, all work will be rolled back and the server will wait for the next command from the client. This will probably be changed in future versions.

A related restriction is the inability to execute BEGIN, END and ABORT (transaction control statements). This will also be changed in the future.

If successful, SPI functions return a non-negative result (either via a returned integer value or in SPI_result global variable, as described below). On error, a negative or NULL result will be returned.

17.1. Interface Functions

SPI_connect

Name

`SPI_connect` — Connects your procedure to the SPI manager.

Synopsis

```
int SPI_connect(void)
```

Inputs

None

Outputs

int

Return status

SPI_OK_CONNECT

if connected

SPI_ERROR_CONNECT

if not connected

Description

`SPI_connect` opens a connection from a procedure invocation to the SPI manager. You must call this function if you will need to execute queries. Some utility SPI functions may be called from un-connected procedures.

If your procedure is already connected, `SPI_connect` will return an SPI_ERROR_CONNECT error. Note that this may happen if a procedure which has called `SPI_connect` directly calls another procedure which itself calls `SPI_connect`. While recursive calls to the SPI manager are permitted when an SPI query invokes another function which uses SPI, directly nested calls to `SPI_connect` and `SPI_finish` are forbidden.

Usage

Algorithm

`SPI_connect` performs the following: Initializes the SPI internal structures for query execution and memory management.

SPI_finish

Name

`SPI_finish` — Disconnects your procedure from the SPI manager.

Synopsis

```
SPI_finish(void)
```

Inputs

None

Outputs

int

SPI_OK_FINISH if properly disconnected
SPI_ERROR_UNCONNECTED if called from an un-connected procedure

Description

`SPI_finish` closes an existing connection to the SPI manager. You must call this function after completing the SPI operations needed during your procedure's current invocation.

You may get the error return SPI_ERROR_UNCONNECTED if `SPI_finish` is called without having a current valid connection. There is no fundamental problem with this; it means that nothing was done by the SPI manager.

Usage

`SPI_finish` *must* be called as a final step by a connected procedure, or you may get unpredictable results! However, you do not need to worry about making this happen if the transaction is aborted via elog(ERROR). In that case SPI will clean itself up.

Algorithm

`SPI_finish` performs the following: Disconnects your procedure from the SPI manager and frees all memory allocations made by your procedure via `palloc` since the `SPI_connect`. These allocations can't be used any more! See Memory management.

SPI_exec

Name

`SPI_exec` — Creates an execution plan (parser+planner+optimizer) and executes a query.

Synopsis

```
SPI_exec(query, tcount)
```

Inputs

char **query*

String containing query plan

int *tcount*

Maximum number of tuples to return

Outputs

int

SPI_ERROR_UNCONNECTED if called from an un-connected procedure
SPI_ERROR_ARGUMENT if query is NULL or *tcount* < 0.
SPI_ERROR_UNCONNECTED if procedure is unconnected.
SPI_ERROR_COPY if COPY TO/FROM stdin.
SPI_ERROR_CURSOR if DECLARE/CLOSE CURSOR, FETCH.
SPI_ERROR_TRANSACTION if BEGIN/ABORT/END.
SPI_ERROR_OPUNKNOWN if type of query is unknown (this shouldn't occur).

If execution of your query was successful then one of the following (non-negative) values will be returned:

SPI_OK_UTILITY if some utility (e.g. CREATE TABLE ...) was executed
SPI_OK_SELECT if SELECT (but not SELECT ... INTO!) was executed
SPI_OK_SELINTO if SELECT ... INTO was executed
SPI_OK_INSERT if INSERT (or INSERT ... SELECT) was executed
SPI_OK_DELETE if DELETE was executed
SPI_OK_UPDATE if UPDATE was executed

Description

`SPI_exec` creates an execution plan (parser+planner+optimizer) and executes the query for *tcount* tuples.

Usage

This should only be called from a connected procedure. If *tcount* is zero then it executes the query for all tuples returned by the query scan. Using *tcount* > 0 you may restrict the number of tuples for which the query will be executed (much like a LIMIT clause). For example,

```
SPI_exec ("INSERT INTO tab SELECT * FROM tab", 5);
```

will allow at most 5 tuples to be inserted into table. If execution of your query was successful then a non-negative value will be returned.

> **Note:** You may pass multiple queries in one string or query string may be re-written by RULEs. `SPI_exec` returns the result for the last query executed.

The actual number of tuples for which the (last) query was executed is returned in the global variable SPI_processed (if not SPI_OK_UTILITY). If SPI_OK_SELECT is returned then you may use global pointer SPITupleTable *SPI_tuptable to access the result tuples.

`SPI_exec` may return one of the following (negative) values:

SPI_ERROR_ARGUMENT if query is NULL or *tcount* < 0.
SPI_ERROR_UNCONNECTED if procedure is unconnected.
SPI_ERROR_COPY if COPY TO/FROM stdin.
SPI_ERROR_CURSOR if DECLARE/CLOSE CURSOR, FETCH.
SPI_ERROR_TRANSACTION if BEGIN/ABORT/END.
SPI_ERROR_OPUNKNOWN if type of query is unknown (this shouldn’t occur).

Structures

If SPI_OK_SELECT is returned then you may use the global pointer SPITupleTable *SPI_tuptable to access the selected tuples.

Structure SPITupleTable is defined in spi.h:

```
typedef struct
{
    MemoryContext tuptabcxt;    /* memory context of result table */
    uint32      alloced;        /* # of alloced vals */
    uint32      free;           /* # of free vals */
    TupleDesc   tupdesc;        /* tuple descriptor */
    HeapTuple  *vals;           /* tuples */
```

```
} SPITupleTable;
```

`vals` is an array of pointers to tuples (the number of useful entries is given by SPI_processed). `tupdesc` is a tuple descriptor which you may pass to SPI functions dealing with tuples. `tuptabcxt`, `alloced`, and `free` are internal fields not intended for use by SPI callers.

> **Note:** Functions `SPI_exec`, `SPI_execp` and `SPI_prepare` change both SPI_processed and SPI_tuptable (just the pointer, not the contents of the structure). Save these two global variables into local procedure variables if you need to access the result of one `SPI_exec` or `SPI_execp` across later calls.

`SPI_finish` frees all SPITupleTables allocated during the current procedure. You can free a particular result table earlier, if you are done with it, by calling `SPI_freetuptable`.

SPI_prepare

Name

`SPI_prepare` — Prepares a plan for a query, without executing it yet

Synopsis

```
SPI_prepare(query, nargs, argtypes)
```

Inputs

query

Query string

nargs

Number of input parameters ($1 ... $nargs - as in SQL-functions)

argtypes

Pointer to array of type OIDs for input parameter types

Outputs

void *

Pointer to an execution plan (parser+planner+optimizer)

Description

`SPI_prepare` creates and returns an execution plan (parser+planner+optimizer) but doesn't execute the query. Should only be called from a connected procedure.

Usage

When the same or similar query is to be executed repeatedly, it may be advantageous to perform query planning only once. `SPI_prepare` converts a query string into an execution plan that can be passed repeatedly to `SPI_execp`.

A prepared query can be generalized by writing parameters ($1, $2, etc) in place of what would be constants in a normal query. The values of the parameters are then specified when `SPI_execp` is called. This allows the prepared query to be used over a wider range of situations than would be possible without parameters.

> **Note:** However, there is a disadvantage: since the planner does not know the values that will be supplied for the parameters, it may make worse query planning choices than it would make for a simple query with all constants visible.

If the query uses parameters, their number and data types must be specified in the call to `SPI_prepare`.

The plan returned by `SPI_prepare` may be used only in current invocation of the procedure since `SPI_finish` frees memory allocated for a plan. But see `SPI_saveplan` to save a plan for longer.

If successful, a non-null pointer will be returned. Otherwise, you'll get a NULL plan. In both cases SPI_result will be set like the value returned by SPI_exec, except that it is set to SPI_ERROR_ARGUMENT if query is NULL or nargs < 0 or nargs > 0 && argtypes is NULL.

SPI_execp

Name

`SPI_execp` — Executes a plan from `SPI_prepare`

Synopsis

```
SPI_execp(plan,
values,
nulls,
tcount)
```

Inputs

void *`plan`

Execution plan

Datum *`values`

Actual parameter values

char *`nulls`

Array describing which parameters are NULLs

`n` indicates NULL (values[] entry ignored)
space indicates not NULL (values[] entry is valid)

int `tcount`

Number of tuples for which plan is to be executed

Outputs

int

Returns the same value as `SPI_exec` as well as

SPI_ERROR_ARGUMENT if `plan` is NULL or `tcount` < 0
SPI_ERROR_PARAM if `values` is NULL and `plan` was prepared with some parameters.

SPI_tuptable

initialized as in `SPI_exec` if successful

SPI_processed

initialized as in `SPI_exec` if successful

Description

`SPI_execp` executes a plan prepared by `SPI_prepare`. *`tcount`* has the same interpretation as in `SPI_exec`.

Usage

If *`nulls`* is NULL then `SPI_execp` assumes that all parameters (if any) are NOT NULL.

> **Note:** If one of the objects (a relation, function, etc.) referenced by the prepared plan is dropped during your session (by your backend or another process) then the results of `SPI_execp` for this plan will be unpredictable.

SPI_cursor_open

Name

`SPI_cursor_open` — Sets up a cursor using a plan created with `SPI_prepare`

Synopsis

```
SPI_cursor_open(name,
plan,
values,
nulls)
```

Inputs

char **`name`*

Name for portal, or NULL to let the system select a name

void **`plan`*

Execution plan

Datum **`values`*

Actual parameter values

char **`nulls`*

Array describing which parameters are NULLs

`n` indicates NULL (values[] entry ignored)
space indicates not NULL (values[] entry is valid)

Outputs

Portal

Pointer to Portal containing cursor, or NULL on error

Description

`SPI_cursor_open` sets up a cursor (internally, a Portal) that will execute a plan prepared by `SPI_prepare`.

Using a cursor instead of executing the plan directly has two benefits. First, the result rows can be retrieved a few at a time, avoiding memory overrun for queries that return many rows. Second, a Portal can outlive the current procedure (it can, in fact, live to the end of the current transaction). Returning the portal name to the procedure's caller provides a way of returning a rowset result.

Usage

If *`nulls`* is NULL then `SPI_cursor_open` assumes that all parameters (if any) are NOT NULL.

SPI_cursor_find

Name

`SPI_cursor_find` — Finds an existing cursor (Portal) by name

Synopsis

```
SPI_cursor_find(name)
```

Inputs

char *`name`

Name of portal

Outputs

Portal

Pointer to Portal with given name, or NULL if not found

Description

`SPI_cursor_find` finds a pre-existing Portal by name. This is primarily useful to resolve a cursor name returned as text by some other function.

SPI_cursor_fetch

Name

`SPI_cursor_fetch` — Fetches some rows from a cursor

Synopsis

```
SPI_cursor_fetch(portal,
forward,
count)
```

Inputs

Portal *portal*

Portal containing cursor

bool *forward*

True for fetch forward, false for fetch backward

int *count*

Maximum number of rows to fetch

Outputs

SPI_tuptable

initialized as in `SPI_exec` if successful

SPI_processed

initialized as in `SPI_exec` if successful

Description

`SPI_cursor_fetch` fetches some (more) rows from a cursor. This is equivalent to the SQL command `FETCH`.

SPI_cursor_move

Name

`SPI_cursor_move` — Moves a cursor

Synopsis

```
SPI_cursor_move(portal,
forward,
count)
```

Inputs

Portal *`portal`*

Portal containing cursor

bool *`forward`*

True for move forward, false for move backward

int *`count`*

Maximum number of rows to move

Outputs

None

Description

`SPI_cursor_move` skips over some number of rows in a cursor. This is equivalent to the SQL command `MOVE`.

SPI_cursor_close

Name

`SPI_cursor_close` — Closes a cursor

Synopsis

```
SPI_cursor_close(portal)
```

Inputs

Portal *`portal`*

Portal containing cursor

Outputs

None

Description

`SPI_cursor_close` closes a previously created cursor and releases its Portal storage.

Usage

All open cursors are closed implicitly at transaction end. `SPI_cursor_close` need only be invoked if it is desirable to release resources sooner.

SPI_saveplan

Name

SPI_saveplan — Saves a passed plan

Synopsis

```
SPI_saveplan(plan)
```

Inputs

void **query*

Passed plan

Outputs

void *

Execution plan location. NULL if unsuccessful.

SPI_result

SPI_ERROR_ARGUMENT if plan is NULL
SPI_ERROR_UNCONNECTED if procedure is un-connected

Description

`SPI_saveplan` stores a plan prepared by `SPI_prepare` in safe memory protected from freeing by `SPI_finish` or the transaction manager.

In the current version of PostgreSQL there is no ability to store prepared plans in the system catalog and fetch them from there for execution. This will be implemented in future versions. As an alternative, there is the ability to reuse prepared plans in the subsequent invocations of your procedure in the current session. Use `SPI_execp` to execute this saved plan.

Usage

`SPI_saveplan` saves a passed plan (prepared by `SPI_prepare`) in memory protected from freeing by `SPI_finish` and by the transaction manager and returns a pointer to the saved plan. You may save the pointer returned in a local variable. Always check if this pointer is NULL or not either when preparing a plan or using an already prepared plan in SPI_execp (see below).

> **Note:** If one of the objects (a relation, function, etc.) referenced by the prepared plan is dropped during your session (by your backend or another process) then the results of `SPI_execp` for this plan will be unpredictable.

17.2. Interface Support Functions

The functions described here provide convenient interfaces for extracting information from tuple sets returned by `SPI_exec` and other SPI interface functions.

All functions described in this section may be used by both connected and unconnected procedures.

SPI_fnumber

Name

`SPI_fnumber` — Finds the attribute number for specified attribute name

Synopsis

```
SPI_fnumber(tupdesc, fname)
```

Inputs

TupleDesc *tupdesc*

Input tuple description

char * *fname*

Field name

Outputs

int

Attribute number

Valid one-based index number of attribute
SPI_ERROR_NOATTRIBUTE if the named attribute is not found

Description

`SPI_fnumber` returns the attribute number for the attribute with name in fname.

Usage

Attribute numbers are 1 based.

If the given fname refers to a system attribute (eg, `oid`) then the appropriate negative attribute number will be returned. The caller should be careful to test for exact equality to SPI_ERROR_NOATTRIBUTE to detect error; testing for result <= 0 is not correct unless system attributes should be rejected.

SPI_fname

Name

`SPI_fname` — Finds the attribute name for the specified attribute number

Synopsis

```
SPI_fname(tupdesc, fnumber)
```

Inputs

TupleDesc *tupdesc*

Input tuple description

int *fnumber*

Attribute number

Outputs

char *

Attribute name

NULL if fnumber is out of range
SPI_result set to SPI_ERROR_NOATTRIBUTE on error

Description

`SPI_fname` returns the attribute name for the specified attribute.

Usage

Attribute numbers are 1 based.

Algorithm

Returns a newly-allocated copy of the attribute name. (Use pfree() to release the copy when done with it.)

SPI_getvalue

Name

`SPI_getvalue` — Returns the string value of the specified attribute

Synopsis

```
SPI_getvalue(tuple, tupdesc, fnumber)
```

Inputs

HeapTuple *`tuple`*

Input tuple to be examined

TupleDesc *`tupdesc`*

Input tuple description

int *`fnumber`*

Attribute number

Outputs

char *

Attribute value or NULL if

attribute is NULL
fnumber is out of range (SPI_result set to SPI_ERROR_NOATTRIBUTE)
no output function available (SPI_result set to SPI_ERROR_NOOUTFUNC)

Description

`SPI_getvalue` returns an external (string) representation of the value of the specified attribute.

Usage

Attribute numbers are 1 based.

Algorithm

The result is returned as a palloc'd string. (Use pfree() to release the string when done with it.)

SPI_getbinval

Name

`SPI_getbinval` — Returns the binary value of the specified attribute

Synopsis

```
SPI_getbinval(tuple, tupdesc, fnumber, isnull)
```

Inputs

HeapTuple *`tuple`*

Input tuple to be examined

TupleDesc *`tupdesc`*

Input tuple description

int *`fnumber`*

Attribute number

Outputs

Datum

Attribute binary value

bool * *`isnull`*

flag for null value in attribute

SPI_result

SPI_ERROR_NOATTRIBUTE

Description

`SPI_getbinval` returns the specified attribute's value in internal form (as a Datum).

Usage

Attribute numbers are 1 based.

Algorithm

Does not allocate new space for the datum. In the case of a pass-by- reference data type, the Datum will be a pointer into the given tuple.

SPI_gettype

Name

`SPI_gettype` — Returns the type name of the specified attribute

Synopsis

```
SPI_gettype(tupdesc, fnumber)
```

Inputs

TupleDesc *`tupdesc`*

Input tuple description

int *`fnumber`*

Attribute number

Outputs

char *

The type name for the specified attribute number

SPI_result

SPI_ERROR_NOATTRIBUTE

Description

`SPI_gettype` returns a copy of the type name for the specified attribute, or NULL on error.

Usage

Attribute numbers are 1 based.

Algorithm

Returns a newly-allocated copy of the type name. (Use pfree() to release the copy when done with it.)

SPI_gettypeid

Name

`SPI_gettypeid` — Returns the type OID of the specified attribute

Synopsis

```
SPI_gettypeid(tupdesc, fnumber)
```

Inputs

TupleDesc *`tupdesc`*

Input tuple description

int *`fnumber`*

Attribute number

Outputs

OID

The type OID for the specified attribute number

SPI_result

SPI_ERROR_NOATTRIBUTE

Description

`SPI_gettypeid` returns the type OID for the specified attribute.

Usage

Attribute numbers are 1 based.

SPI_getrelname

Name

`SPI_getrelname` — Returns the name of the specified relation

Synopsis

```
SPI_getrelname(rel)
```

Inputs

Relation *rel*

Input relation

Outputs

char *

The name of the specified relation

Description

`SPI_getrelname` returns the name of the specified relation.

Algorithm

Returns a newly-allocated copy of the rel name. (Use pfree() to release the copy when done with it.)

17.3. Memory Management

PostgreSQL allocates memory within memory *contexts*, which provide a convenient method of managing allocations made in many different places that need to live for differing amounts of time. Destroying a context releases all the memory that was allocated in it. Thus, it is not necessary to keep track of individual objects to avoid memory leaks --- only a relatively small number of contexts have to be managed. `palloc` and related functions allocate memory from the "current" context.

`SPI_connect` creates a new memory context and makes it current. `SPI_finish` restores the previous current memory context and destroys the context created by `SPI_connect`. These actions ensure that transient memory allocations made inside your procedure are reclaimed at procedure exit, avoiding memory leakage.

However, if your procedure needs to return an allocated memory object (such as a value of a pass-by-reference data type), you can't allocate the return object using `palloc`, at least not while you are connected to SPI. If you try, the object will be deallocated during `SPI_finish`, and your procedure will not work reliably!

To solve this problem, use `SPI_palloc` to allocate your return object. `SPI_palloc` allocates space from "upper Executor" memory --- that is, the memory context that was current when `SPI_connect` was called, which is precisely the right context for return values of your procedure.

If called while not connected to SPI, `SPI_palloc` acts the same as plain `palloc`.

Before a procedure connects to the SPI manager, the current memory context is the upper Executor context, so all allocations made by the procedure via `palloc` or by SPI utility functions are made in this context.

After `SPI_connect` is called, the current context is the procedure's private context made by `SPI_connect`. All allocations made via `palloc`/`repalloc` or by SPI utility functions (except for `SPI_copytuple`, `SPI_copytupledesc`, `SPI_copytupleintoslot`, `SPI_modifytuple`, and `SPI_palloc`) are made in this context.

When a procedure disconnects from the SPI manager (via `SPI_finish`) the current context is restored to the upper Executor context, and all allocations made in the procedure memory context are freed and can't be used any more!

All functions described in this section may be used by both connected and unconnected procedures. In an unconnected procedure, they act the same as the underlying ordinary backend functions (`palloc` etc).

SPI_copytuple

Name

`SPI_copytuple` — Makes copy of tuple in upper Executor context

Synopsis

```
SPI_copytuple(tuple)
```

Inputs

HeapTuple *`tuple`*

Input tuple to be copied

Outputs

HeapTuple

Copied tuple

non-NULL if *`tuple`* is not NULL and the copy was successful
NULL only if *`tuple`* is NULL

Description

`SPI_copytuple` makes a copy of tuple in upper Executor context.

Usage

TBD

SPI_copytupledesc

Name

`SPI_copytupledesc` — Makes copy of tuple descriptor in upper Executor context

Synopsis

```
SPI_copytupledesc(tupdesc)
```

Inputs

TupleDesc *tupdesc*

Input tuple descriptor to be copied

Outputs

TupleDesc

Copied tuple descriptor

non-NULL if *tupdesc* is not NULL and the copy was successful
NULL only if *tupdesc* is NULL

Description

`SPI_copytupledesc` makes a copy of tupdesc in upper Executor context.

Usage

TBD

SPI_copytupleintoslot

Name

`SPI_copytupleintoslot` — Makes copy of tuple and descriptor in upper Executor context

Synopsis

```
SPI_copytupleintoslot(tuple, tupdesc)
```

Inputs

HeapTuple *tuple*

Input tuple to be copied

TupleDesc *tupdesc*

Input tuple descriptor to be copied

Outputs

TupleTableSlot *

Tuple slot containing copied tuple and descriptor

non-NULL if *tuple* and *tupdesc* are not NULL and the copy was successful
NULL only if *tuple* or *tupdesc* is NULL

Description

`SPI_copytupleintoslot` makes a copy of tuple in upper Executor context, returning it in the form of a filled-in TupleTableSlot.

Usage

TBD

SPI_modifytuple

Name

`SPI_modifytuple` — Creates a tuple by replacing selected fields of a given tuple

Synopsis

```
SPI_modifytuple(rel, tuple, nattrs, attnum, Values, Nulls)
```

Inputs

Relation *`rel`*

Used only as source of tuple descriptor for tuple. (Passing a relation rather than a tuple descriptor is a misfeature.)

HeapTuple *`tuple`*

Input tuple to be modified

int *`nattrs`*

Number of attribute numbers in attnum array

int * *`attnum`*

Array of numbers of the attributes that are to be changed

Datum * *`Values`*

New values for the attributes specified

char * *`Nulls`*

Which new values are NULL, if any

Outputs

HeapTuple

New tuple with modifications

non-NULL if *`tuple`* is not NULL and the modify was successful
NULL only if *`tuple`* is NULL

SPI_result

SPI_ERROR_ARGUMENT if rel is NULL or tuple is NULL or natts <= 0 or attnum is NULL or Values is NULL.
SPI_ERROR_NOATTRIBUTE if there is an invalid attribute number in attnum (attnum <= 0 or > number of attributes in tuple)

Description

`SPI_modifytuple` creates a new tuple by substituting new values for selected attributes, copying the original tuple's attributes at other positions. The input tuple is not modified.

Usage

If successful, a pointer to the new tuple is returned. The new tuple is allocated in upper Executor context.

SPI_palloc

Name

`SPI_palloc` — Allocates memory in upper Executor context

Synopsis

```
SPI_palloc(size)
```

Inputs

Size *`size`*

Octet size of storage to allocate

Outputs

void *

New storage space of specified size

Description

`SPI_palloc` allocates memory in upper Executor context.

Usage

TBD

SPI_repalloc

Name

`SPI_repalloc` — Re-allocates memory in upper Executor context

Synopsis

```
SPI_repalloc(pointer, size)
```

Inputs

void * *`pointer`*

Pointer to existing storage

Size *`size`*

Octet size of storage to allocate

Outputs

void *

New storage space of specified size with contents copied from existing area

Description

`SPI_repalloc` re-allocates memory in upper Executor context.

Usage

This function is no longer different from plain `repalloc`. It's kept just for backward compatibility of existing code.

SPI_pfree

Name

`SPI_pfree` — Frees memory in upper Executor context

Synopsis

```
SPI_pfree(pointer)
```

Inputs

void * *`pointer`*

Pointer to existing storage

Outputs

None

Description

`SPI_pfree` frees memory in upper Executor context.

Usage

This function is no longer different from plain `pfree`. It's kept just for backward compatibility of existing code.

SPI_freetuple

Name

`SPI_freetuple` — Frees a tuple allocated in upper Executor context

Synopsis

```
SPI_freetuple(pointer)
```

Inputs

HeapTuple *pointer*

Pointer to allocated tuple

Outputs

None

Description

`SPI_freetuple` frees a tuple previously allocated in upper Executor context.

Usage

This function is no longer different from plain `heap_freetuple`. It's kept just for backward compatibility of existing code.

SPI_freetuptable

Name

`SPI_freetuptable` — Frees a tuple set created by `SPI_exec` or similar function

Synopsis

```
SPI_freetuptable(tuptable)
```

Inputs

SPITupleTable * *`tuptable`*

Pointer to tuple table

Outputs

None

Description

`SPI_freetuptable` frees a tuple set created by a prior SPI query function, such as `SPI_exec`.

Usage

This function is useful if a SPI procedure needs to execute multiple queries and does not want to keep the results of earlier queries around until it ends. Note that any unfreed tuple sets will be freed anyway at `SPI_finish`.

SPI_freeplan

Name

`SPI_freeplan` — Releases a previously saved plan

Synopsis

```
SPI_freeplan(plan)
```

Inputs

void *`plan`

Passed plan

Outputs

int

SPI_ERROR_ARGUMENT if plan is NULL

Description

`SPI_freeplan` releases a query plan previously returned by `SPI_prepare` or saved by `SPI_saveplan`.

17.4. Visibility of Data Changes

PostgreSQL data changes visibility rule: during a query execution, data changes made by the query itself (via SQL-function, SPI-function, triggers) are invisible to the query scan. For example, in query

```
INSERT INTO a SELECT * FROM a
```

tuples inserted are invisible for SELECT's scan. In effect, this duplicates the database table within itself (subject to unique index rules, of course) without recursing.

Changes made by query Q are visible to queries that are started after query Q, no matter whether they are started inside Q (during the execution of Q) or after Q is done.

17.5. Examples

This example of SPI usage demonstrates the visibility rule. There are more complex examples in src/test/regress/regress.c and in contrib/spi.

This is a very simple example of SPI usage. The procedure execq accepts an SQL-query in its first argument and tcount in its second, executes the query using SPI_exec and returns the number of tuples for which the query executed:

```
#include "executor/spi.h"   /* this is what you need to work with SPI */

int execq(text *sql, int cnt);

int
execq(text *sql, int cnt)
{
    char *query;
    int ret;
    int proc;

    /* Convert given TEXT object to a C string */
    query = DatumGetCString(DirectFunctionCall1(textout,
                                            PointerGetDatum(sql)));

    SPI_connect();

    ret = SPI_exec(query, cnt);

    proc = SPI_processed;
    /*
     * If this is SELECT and some tuple(s) fetched -
     * returns tuples to the caller via elog (INFO).
     */
    if ( ret == SPI_OK_SELECT && SPI_processed > 0 )
    {
        TupleDesc tupdesc = SPI_tuptable->tupdesc;
        SPITupleTable *tuptable = SPI_tuptable;
        char buf[8192];
        int i,j;
```

```
        for (j = 0; j < proc; j++)
        {
            HeapTuple tuple = tuptable->vals[j];

            for (i = 1, buf[0] = 0; i <= tupdesc->natts; i++)
                snprintf(buf + strlen (buf), sizeof(buf) - strlen(buf)," %s%s",
                        SPI_getvalue(tuple, tupdesc, i),
                        (i == tupdesc->natts) ? " " : " |");
            elog (INFO, "EXECQ: %s", buf);
        }
    }

    SPI_finish();

    pfree(query);

    return (proc);
}
```

Now, compile and create the function:

```
CREATE FUNCTION execq (text, integer) RETURNS integer
    AS '...path_to_so'
    LANGUAGE C;

vac=> SELECT execq('CREATE TABLE a (x INTEGER)', 0);
execq
-----
    0
(1 row)

vac=> INSERT INTO a VALUES (execq('INSERT INTO a VALUES (0)',0));
INSERT 167631 1
vac=> SELECT execq('SELECT * FROM a',0);
INFO:  EXECQ:  0 <<< inserted by execq

INFO:  EXECQ:  1 <<< value returned by execq and inserted by upper INSERT

execq
-----
    2
(1 row)

vac=> SELECT execq('INSERT INTO a SELECT x + 2 FROM a',1);
execq
-----
    1
(1 row)

vac=> SELECT execq('SELECT * FROM a', 10);
INFO:  EXECQ:  0
```

```
INFO:  EXECQ:  1

INFO:  EXECQ:  2 <<< 0 + 2, only one tuple inserted - as specified

execq
-----
    3            <<< 10 is max value only, 3 is real # of tuples
(1 row)

vac=> DELETE FROM a;
DELETE 3
vac=> INSERT INTO a VALUES (execq('SELECT * FROM a', 0) + 1);
INSERT 167712 1
vac=> SELECT * FROM a;
x
-
1                <<< no tuples in a (0) + 1
(1 row)

vac=> INSERT INTO a VALUES (execq('SELECT * FROM a', 0) + 1);
INFO:  EXECQ:  0
INSERT 167713 1
vac=> SELECT * FROM a;
x
-
1
2                <<< there was single tuple in a + 1
(2 rows)

--   This demonstrates data changes visibility rule:

vac=> INSERT INTO a SELECT execq('SELECT * FROM a', 0) * x FROM a;
INFO:  EXECQ:  1
INFO:  EXECQ:  2
INFO:  EXECQ:  1
INFO:  EXECQ:  2
INFO:  EXECQ:  2
INSERT 0 2
vac=> SELECT * FROM a;
x
-
1
2
2                <<< 2 tuples * 1 (x in first tuple)
6                <<< 3 tuples (2 + 1 just inserted) * 2 (x in second tuple)
(4 rows)             ^^^^^^^^
                     tuples visible to execq() in different invocations
```

III. Procedural Languages

This part documents the procedural languages available in the PostgreSQL distribution as well as general issues concerning procedural languages.

Chapter 18. Procedural Languages

18.1. Introduction

PostgreSQL allows users to add new programming languages to be available for writing functions and procedures. These are called *procedural languages* (PL). In the case of a function or trigger procedure written in a procedural language, the database server has no built-in knowledge about how to interpret the function's source text. Instead, the task is passed to a special handler that knows the details of the language. The handler could either do all the work of parsing, syntax analysis, execution, etc. itself, or it could serve as "glue" between PostgreSQL and an existing implementation of a programming language. The handler itself is a special programming language function compiled into a shared object and loaded on demand.

Writing a handler for a new procedural language is described in Section 9.8. Several procedural languages are available in the standard PostgreSQL distribution, which can serve as examples.

18.2. Installing Procedural Languages

A procedural language must be "installed" into each database where it is to be used. But procedural languages installed in the template1 database are automatically available in all subsequently created databases. So the database administrator can decide which languages are available in which databases, and can make some languages available by default if he chooses.

For the languages supplied with the standard distribution, the shell script `createlang` may be used instead of carrying out the details by hand. For example, to install PL/pgSQL into the template1 database, use

```
createlang plpgsql template1
```

The manual procedure described below is only recommended for installing custom languages that `createlang` does not know about.

Manual Procedural Language Installation

A procedural language is installed in the database in three steps, which must be carried out by a database superuser.

1. The shared object for the language handler must be compiled and installed into an appropriate library directory. This works in the same way as building and installing modules with regular user-defined C functions does; see Section 9.5.8.

2. The handler must be declared with the command

   ```
   CREATE FUNCTION handler_function_name ()
       RETURNS LANGUAGE_HANDLER AS
       'path-to-shared-object' LANGUAGE C;
   ```

   The special return type of `LANGUAGE_HANDLER` tells the database that this function does not return one of the defined SQL data types and is not directly usable in SQL statements.

3. The PL must be declared with the command

   ```
   CREATE [TRUSTED] [PROCEDURAL] LANGUAGE language-name
       HANDLER handler_function_name;
   ```

   The optional key word `TRUSTED` tells whether ordinary database users that have no superuser privileges should be allowed to use this language to create functions and trigger procedures. Since PL functions are executed inside the database server, the `TRUSTED` flag should only be given for languages that do not allow access to database server internals or the file system. The languages PL/pgSQL, PL/Tcl, PL/Perl, and PL/Python are known to be trusted; the languages PL/TclU and PL/PerlU are designed to provide unlimited functionality should *not* be marked trusted.

In a default PostgreSQL installation, the handler for the PL/pgSQL language is built and installed into the "library" directory. If Tcl/Tk support is configured in, the handlers for PL/Tcl and PL/TclU are also built and installed in the same location. Likewise, the PL/Perl and PL/PerlU handlers are built and installed if Perl support is configured, and PL/Python is installed if Python support is configured. The `createlang` script automates step 2 and step 3 described above.

Example 18-1. Manual Installation of PL/pgSQL

The following command tells the database server where to find the shared object for the PL/pgSQL language's call handler function.

```
CREATE FUNCTION plpgsql_call_handler () RETURNS LANGUAGE_HANDLER AS
    '$libdir/plpgsql' LANGUAGE C;
```

The command

```
CREATE TRUSTED PROCEDURAL LANGUAGE plpgsql
    HANDLER plpgsql_call_handler;
```

then defines that the previously declared call handler function should be invoked for functions and trigger procedures where the language attribute is `plpgsql`.

Chapter 19. PL/pgSQL - SQL Procedural Language

PL/pgSQL is a loadable procedural language for the PostgreSQL database system.

This package was originally written by Jan Wieck. This documentation was in part written by Roberto Mello (<rmello@fslc.usu.edu>).

19.1. Overview

The design goals of PL/pgSQL were to create a loadable procedural language that

- can be used to create functions and trigger procedures,
- adds control structures to the SQL language,
- can perform complex computations,
- inherits all user defined types, functions and operators,
- can be defined to be trusted by the server,
- is easy to use.

The PL/pgSQL call handler parses the function's source text and produces an internal binary instruction tree the first time the function is called (within any one backend process). The instruction tree fully translates the PL/pgSQL statement structure, but individual SQL expressions and SQL queries used in the function are not translated immediately.

As each expression and SQL query is first used in the function, the PL/pgSQL interpreter creates a prepared execution plan (using the SPI manager's `SPI_prepare` and `SPI_saveplan` functions). Subsequent visits to that expression or query re-use the prepared plan. Thus, a function with conditional code that contains many statements for which execution plans might be required will only prepare and save those plans that are really used during the lifetime of the database connection. This can substantially reduce the total amount of time required to parse, and generate query plans for the statements in a procedural language function. A disadvantage is that errors in a specific expression or query may not be detected until that part of the function is reached in execution.

Once PL/pgSQL has made a query plan for a particular query in a function, it will re-use that plan for the life of the database connection. This is usually a win for performance, but it can cause some problems if you dynamically alter your database schema. For example:

```
CREATE FUNCTION populate() RETURNS INTEGER AS '
DECLARE
    -- Declarations
BEGIN
    PERFORM my_function();
END;
' LANGUAGE 'plpgsql';
```

If you execute the above function, it will reference the OID for `my_function()` in the query plan produced for the PERFORM statement. Later, if you drop and re-create `my_function()`, then `populate()` will not be able to find `my_function()` anymore. You would then have to re-create `populate()`, or at least start a new database session so that it will be compiled afresh.

Because PL/pgSQL saves execution plans in this way, queries that appear directly in a PL/pgSQL function must refer to the same tables and fields on every execution; that is, you cannot use a parameter as the name of a table or field in a query. To get around this restriction, you can construct dynamic queries using the PL/pgSQL EXECUTE statement --- at the price of constructing a new query plan on every execution.

> **Note:** The PL/pgSQL EXECUTE statement is not related to the EXECUTE statement supported by the PostgreSQL backend. The backend EXECUTE statement cannot be used within PL/pgSQL functions (and is not needed).

Except for input/output conversion and calculation functions for user defined types, anything that can be defined in C language functions can also be done with PL/pgSQL. It is possible to create complex conditional computation functions and later use them to define operators or use them in functional indexes.

19.1.1. Advantages of Using PL/pgSQL

- Better performance (see Section 19.1.1.1)
- SQL support (see Section 19.1.1.2)
- Portability (see Section 19.1.1.3)

19.1.1.1. Better Performance

SQL is the language PostgreSQL (and most other relational databases) use as query language. It's portable and easy to learn. But every SQL statement must be executed individually by the database server.

That means that your client application must send each query to the database server, wait for it to process it, receive the results, do some computation, then send other queries to the server. All this incurs interprocess communication and may also incur network overhead if your client is on a different machine than the database server.

With PL/pgSQL you can group a block of computation and a series of queries *inside* the database server, thus having the power of a procedural language and the ease of use of SQL, but saving lots of time because you don't have the whole client/server communication overhead. This can make for a considerable performance increase.

19.1.1.2. SQL Support

PL/pgSQL adds the power of a procedural language to the flexibility and ease of SQL. With PL/pgSQL you can use all the data types, columns, operators and functions of SQL.

19.1.1.3. Portability

Because PL/pgSQL functions run inside PostgreSQL, these functions will run on any platform where PostgreSQL runs. Thus you can reuse code and reduce development costs.

19.1.2. Developing in PL/pgSQL

Developing in PL/pgSQL is pretty straight forward, especially if you have developed in other database procedural languages, such as Oracle's PL/SQL. Two good ways of developing in PL/pgSQL are:

- Using a text editor and reloading the file with `psql`
- Using PostgreSQL's GUI Tool: PgAccess

One good way to develop in PL/pgSQL is to simply use the text editor of your choice to create your functions, and in another window, use `psql` (PostgreSQL's interactive monitor) to load those functions. If you are doing it this way, it is a good idea to write the function using `CREATE OR REPLACE FUNCTION`. That way you can reload the file to update the function definition. For example:

```
CREATE OR REPLACE FUNCTION testfunc(INTEGER) RETURNS INTEGER AS '
   ....
end;
' LANGUAGE 'plpgsql';
```

While running `psql`, you can load or reload such a function definition file with

```
\i filename.sql
```

and then immediately issue SQL commands to test the function.

Another good way to develop in PL/pgSQL is using PostgreSQL's GUI tool: PgAccess. It does some nice things for you, like escaping single-quotes, and making it easy to recreate and debug functions.

19.2. Structure of PL/pgSQL

PL/pgSQL is a *block structured* language. The complete text of a function definition must be a *block*. A block is defined as:

```
[ <<label>> ]
[ DECLARE
declarations ]
BEGIN
    statements
END;
```

Any *statement* in the statement section of a block can be a *sub-block*. Sub-blocks can be used for logical grouping or to localize variables to a small group of statements.

The variables declared in the declarations section preceding a block are initialized to their default values every time the block is entered, not only once per function call. For example:

```
CREATE FUNCTION somefunc() RETURNS INTEGER AS ’
DECLARE
   quantity INTEGER := 30;
BEGIN
   RAISE NOTICE ”Quantity here is %”,quantity;  -- Quantity here is 30
   quantity := 50;
   --
   -- Create a sub-block
   --
   DECLARE
      quantity INTEGER := 80;
   BEGIN
      RAISE NOTICE ”Quantity here is %”,quantity;  -- Quantity here is 80
   END;

   RAISE NOTICE ”Quantity here is %”,quantity;  -- Quantity here is 50

   RETURN quantity;
END;
’ LANGUAGE ’plpgsql’;
```

It is important not to confuse the use of BEGIN/END for grouping statements in PL/pgSQL with the database commands for transaction control. PL/pgSQL’s BEGIN/END are only for grouping; they do not start or end a transaction. Functions and trigger procedures are always executed within a transaction established by an outer query --- they cannot start or commit transactions, since PostgreSQL does not have nested transactions.

19.2.1. Lexical Details

Each statement and declaration within a block is terminated by a semicolon.

All keywords and identifiers can be written in mixed upper- and lower-case. Identifiers are implicitly converted to lower-case unless double-quoted.

There are two types of comments in PL/pgSQL. A double dash `--` starts a comment that extends to the end of the line. A `/*` starts a block comment that extends to the next occurrence of `*/`. Block comments cannot be nested, but double dash comments can be enclosed into a block comment and a double dash can hide the block comment delimiters `/*` and `*/`.

19.3. Declarations

All variables, rows and records used in a block must be declared in the declarations section of the block. (The only exception is that the loop variable of a FOR loop iterating over a range of integer values is automatically declared as an integer variable.)

PL/pgSQL variables can have any SQL data type, such as `INTEGER`, `VARCHAR` and `CHAR`.

Here are some examples of variable declarations:

```
user_id INTEGER;
quantity NUMERIC(5);
url VARCHAR;
myrow tablename%ROWTYPE;
myfield tablename.fieldname%TYPE;
arow RECORD;
```

The general syntax of a variable declaration is:

```
name [ CONSTANT ] type [ NOT NULL ] [ { DEFAULT | := } expression ];
```

The DEFAULT clause, if given, specifies the initial value assigned to the variable when the block is entered. If the DEFAULT clause is not given then the variable is initialized to the SQL NULL value.

The CONSTANT option prevents the variable from being assigned to, so that its value remains constant for the duration of the block. If NOT NULL is specified, an assignment of a NULL value results in a run-time error. All variables declared as NOT NULL must have a non-NULL default value specified.

The default value is evaluated every time the block is entered. So, for example, assigning ’`now`’ to a variable of type `timestamp` causes the variable to have the time of the current function call, not when the function was precompiled.

Examples:

```
quantity INTEGER DEFAULT 32;
url varchar := ”http://mysite.com”;
user_id CONSTANT INTEGER := 10;
```

19.3.1. Aliases for Function Parameters

```
name ALIAS FOR $n;
```

Parameters passed to functions are named with the identifiers `$1`, `$2`, etc. Optionally, aliases can be declared for `$n` parameter names for increased readability. Either the alias or the numeric identifier can then be used to refer to the parameter value. Some examples:

```
CREATE FUNCTION sales_tax(REAL) RETURNS REAL AS ’
```

```
DECLARE
    subtotal ALIAS FOR $1;
BEGIN
    return subtotal * 0.06;
END;
' LANGUAGE 'plpgsql';


CREATE FUNCTION instr(VARCHAR,INTEGER) RETURNS INTEGER AS '
DECLARE
    v_string ALIAS FOR $1;
    index ALIAS FOR $2;
BEGIN
    -- Some computations here
END;
' LANGUAGE 'plpgsql';


CREATE FUNCTION use_many_fields(tablename) RETURNS TEXT AS '
DECLARE
    in_t ALIAS FOR $1;
BEGIN
    RETURN in_t.f1 || in_t.f3 || in_t.f5 || in_t.f7;
END;
' LANGUAGE 'plpgsql';
```

19.3.2. Row Types

```
name tablename%ROWTYPE;
```

A variable of a composite type is called a *row* variable (or *row-type* variable). Such a variable can hold a whole row of a SELECT or FOR query result, so long as that query's column set matches the declared type of the variable. The individual fields of the row value are accessed using the usual dot notation, for example `rowvar.field`.

Presently, a row variable can only be declared using the `%ROWTYPE` notation; although one might expect a bare table name to work as a type declaration, it won't be accepted within PL/pgSQL functions.

Parameters to a function can be composite types (complete table rows). In that case, the corresponding identifier $n will be a row variable, and fields can be selected from it, for example `$1.user_id`.

Only the user-defined attributes of a table row are accessible in a row-type variable, not OID or other system attributes (because the row could be from a view). The fields of the row type inherit the table's field size or precision for data types such as `char(n)`.

```
CREATE FUNCTION use_two_tables(tablename) RETURNS TEXT AS '
DECLARE
    in_t ALIAS FOR $1;
```

```
    use_t table2name%ROWTYPE;
BEGIN
    SELECT * INTO use_t FROM table2name WHERE ... ;
    RETURN in_t.f1 || use_t.f3 || in_t.f5 || use_t.f7;
END;
' LANGUAGE 'plpgsql';
```

19.3.3. Records

```
name RECORD;
```

Record variables are similar to row-type variables, but they have no predefined structure. They take on the actual row structure of the row they are assigned during a SELECT or FOR command. The substructure of a record variable can change each time it is assigned to. A consequence of this is that until a record variable is first assigned to, *it has no* substructure, and any attempt to access a field in it will draw a run-time error.

Note that `RECORD` is not a true data type, only a placeholder.

19.3.4. Attributes

Using the `%TYPE` and `%ROWTYPE` attributes, you can declare variables with the same data type or structure as another database item (e.g: a table field).

`variable`%TYPE

`%TYPE` provides the data type of a variable or database column. You can use this to declare variables that will hold database values. For example, let's say you have a column named `user_id` in your `users` table. To declare a variable with the same data type as `users.user_id` you write:

```
user_id   users.user_id%TYPE;
```

By using `%TYPE` you don't need to know the data type of the structure you are referencing, and most important, if the data type of the referenced item changes in the future (e.g: you change your table definition of user_id from INTEGER to REAL), you may not need to change your function definition.

`table``%ROWTYPE`

`%ROWTYPE` provides the composite data type corresponding to a whole row of the specified table. *`table`* must be an existing table or view name of the database.

```
DECLARE
    users_rec users%ROWTYPE;
    user_id users.user_id%TYPE;
BEGIN
    user_id := users_rec.user_id;
```

```
    ...

CREATE FUNCTION does_view_exist(INTEGER) RETURNS bool AS '
   DECLARE
        key ALIAS FOR $1;
        table_data cs_materialized_views%ROWTYPE;
   BEGIN
        SELECT INTO table_data * FROM cs_materialized_views
               WHERE sort_key=key;

        IF NOT FOUND THEN
           RETURN false;
        END IF;
        RETURN true;
   END;
' LANGUAGE 'plpgsql';
```

19.3.5. RENAME

```
RENAME oldname TO newname;
```

Using the RENAME declaration you can change the name of a variable, record or row. This is primarily useful if NEW or OLD should be referenced by another name inside a trigger procedure. See also ALIAS.

Examples:

```
RENAME id TO user_id;
RENAME this_var TO that_var;
```

Note: RENAME appears to be broken as of PostgreSQL 7.3. Fixing this is of low priority, since ALIAS covers most of the practical uses of RENAME.

19.4. Expressions

All expressions used in PL/pgSQL statements are processed using the server's regular SQL executor. Expressions that appear to contain constants may in fact require run-time evaluation (e.g. `'now'` for the `timestamp` type) so it is impossible for the PL/pgSQL parser to identify real constant values other than the NULL keyword. All expressions are evaluated internally by executing a query

```
SELECT expression
```

using the SPI manager. In the expression, occurrences of PL/pgSQL variable identifiers are replaced by parameters and the actual values from the variables are passed to the executor in the parameter array.

This allows the query plan for the SELECT to be prepared just once and then re-used for subsequent evaluations.

The evaluation done by the PostgreSQL main parser has some side effects on the interpretation of constant values. In detail there is a difference between what these two functions do:

```
CREATE FUNCTION logfunc1 (TEXT) RETURNS TIMESTAMP AS '
    DECLARE
        logtxt ALIAS FOR $1;
    BEGIN
        INSERT INTO logtable VALUES (logtxt, ''now'');
        RETURN ''now'';
    END;
' LANGUAGE 'plpgsql';
```

and

```
CREATE FUNCTION logfunc2 (TEXT) RETURNS TIMESTAMP AS '
    DECLARE
        logtxt ALIAS FOR $1;
        curtime timestamp;
    BEGIN
        curtime := ''now'';
        INSERT INTO logtable VALUES (logtxt, curtime);
        RETURN curtime;
    END;
' LANGUAGE 'plpgsql';
```

In the case of `logfunc1()`, the PostgreSQL main parser knows when preparing the plan for the INSERT, that the string `'now'` should be interpreted as `timestamp` because the target field of `logtable` is of that type. Thus, it will make a constant from it at this time and this constant value is then used in all invocations of `logfunc1()` during the lifetime of the backend. Needless to say that this isn't what the programmer wanted.

In the case of `logfunc2()`, the PostgreSQL main parser does not know what type `'now'` should become and therefore it returns a data value of type `text` containing the string `'now'`. During the ensuing assignment to the local variable `curtime`, the PL/pgSQL interpreter casts this string to the `timestamp` type by calling the `text_out()` and `timestamp_in()` functions for the conversion. So, the computed time stamp is updated on each execution as the programmer expects.

The mutable nature of record variables presents a problem in this connection. When fields of a record variable are used in expressions or statements, the data types of the fields must not change between calls of one and the same expression, since the expression will be planned using the data type that is present when the expression is first reached. Keep this in mind when writing trigger procedures that handle events for more than one table. (EXECUTE can be used to get around this problem when necessary.)

19.5. Basic Statements

In this section and the following ones, we describe all the statement types that are explicitly understood by PL/pgSQL. Anything not recognized as one of these statement types is presumed to be an SQL query, and is sent to the main database engine to execute (after substitution for any PL/pgSQL variables used in the statement). Thus, for example, SQL `INSERT`, `UPDATE`, and `DELETE` commands may be considered to be statements of PL/pgSQL. But they are not specifically listed here.

19.5.1. Assignment

An assignment of a value to a variable or row/record field is written as:

```
identifier := expression;
```

As explained above, the expression in such a statement is evaluated by means of an SQL `SELECT` command sent to the main database engine. The expression must yield a single value.

If the expression's result data type doesn't match the variable's data type, or the variable has a specific size/precision (like `char(20)`), the result value will be implicitly converted by the PL/pgSQL interpreter using the result type's output-function and the variable type's input-function. Note that this could potentially result in run-time errors generated by the input function, if the string form of the result value is not acceptable to the input function.

Examples:

```
user_id := 20;
tax := subtotal * 0.06;
```

19.5.2. SELECT INTO

The result of a SELECT command yielding multiple columns (but only one row) can be assigned to a record variable, row-type variable, or list of scalar variables. This is done by:

```
SELECT INTO target expressions FROM ...;
```

where *`target`* can be a record variable, a row variable, or a comma-separated list of simple variables and record/row fields. Note that this is quite different from PostgreSQL's normal interpretation of SELECT INTO, which is that the INTO target is a newly created table. (If you want to create a table from a SELECT result inside a PL/pgSQL function, use the syntax `CREATE TABLE ... AS SELECT`.)

If a row or a variable list is used as target, the selected values must exactly match the structure of the target(s), or a run-time error occurs. When a record variable is the target, it automatically configures itself to the row type of the query result columns.

Except for the INTO clause, the SELECT statement is the same as a normal SQL SELECT query and can use the full power of SELECT.

If the SELECT query returns zero rows, null values are assigned to the target(s). If the SELECT query returns multiple rows, the first row is assigned to the target(s) and the rest are discarded. (Note that "the first row" is not well-defined unless you've used ORDER BY.)

At present, the INTO clause can appear almost anywhere in the SELECT query, but it is recommended to place it immediately after the SELECT keyword as depicted above. Future versions of PL/pgSQL may be less forgiving about placement of the INTO clause.

You can use `FOUND` immediately after a SELECT INTO statement to determine whether the assignment was successful (that is, at least one row was was returned by the SELECT statement). For example:

```
SELECT INTO myrec * FROM EMP WHERE empname = myname;
IF NOT FOUND THEN
    RAISE EXCEPTION ”employee % not found”, myname;
END IF;
```

Alternatively, you can use the `IS NULL` (or `ISNULL`) conditional to test for whether a RECORD/ROW result is null. Note that there is no way to tell whether any additional rows might have been discarded.

```
DECLARE
    users_rec RECORD;
    full_name varchar;
BEGIN
    SELECT INTO users_rec * FROM users WHERE user_id=3;

    IF users_rec.homepage IS NULL THEN
        -- user entered no homepage, return "http://"

        RETURN ”http://”;
    END IF;
END;
```

19.5.3. Executing an expression or query with no result

Sometimes one wishes to evaluate an expression or query but discard the result (typically because one is calling a function that has useful side-effects but no useful result value). To do this in PL/pgSQL, use the PERFORM statement:

```
PERFORM query;
```

This executes a `SELECT` *`query`* and discards the result. PL/pgSQL variables are substituted in the query as usual. Also, the special variable `FOUND` is set to true if the query produced at least one row, or false if it produced no rows.

> **Note:** One might expect that SELECT with no INTO clause would accomplish this result, but at present the only accepted way to do it is PERFORM.

An example:

```
PERFORM create_mv(”cs_session_page_requests_mv”, my_query);
```

19.5.4. Executing dynamic queries

Oftentimes you will want to generate dynamic queries inside your PL/pgSQL functions, that is, queries that will involve different tables or different data types each time they are executed. PL/pgSQL's normal attempts to cache plans for queries will not work in such scenarios. To handle this sort of problem, the EXECUTE statement is provided:

```
EXECUTE query-string;
```

where *query-string* is an expression yielding a string (of type `text`) containing the *query* to be executed. This string is fed literally to the SQL engine.

Note in particular that no substitution of PL/pgSQL variables is done on the query string. The values of variables must be inserted in the query string as it is constructed.

When working with dynamic queries you will have to face escaping of single quotes in PL/pgSQL. Please refer to the table in Section 19.11 for a detailed explanation that will save you some effort.

Unlike all other queries in PL/pgSQL, a *query* run by an EXECUTE statement is not prepared and saved just once during the life of the server. Instead, the *query* is prepared each time the statement is run. The *query-string* can be dynamically created within the procedure to perform actions on variable tables and fields.

The results from SELECT queries are discarded by EXECUTE, and SELECT INTO is not currently supported within EXECUTE. So, the only way to extract a result from a dynamically-created SELECT is to use the FOR-IN-EXECUTE form described later.

An example:

```
EXECUTE ''UPDATE tbl SET ''
        || quote_ident(fieldname)
        || '' = ''
        || quote_literal(newvalue)
        || '' WHERE ...'';
```

This example shows use of the functions `quote_ident`(`TEXT`) and `quote_literal`(`TEXT`). Variables containing field and table identifiers should be passed to function `quote_ident()`. Variables containing literal elements of the dynamic query string should be passed to `quote_literal()`. Both take the appropriate steps to return the input text enclosed in single or double quotes and with any embedded special characters properly escaped.

Here is a much larger example of a dynamic query and EXECUTE:

```
CREATE FUNCTION cs_update_referrer_type_proc() RETURNS INTEGER AS '
DECLARE
    referrer_keys RECORD;  -- Declare a generic record to be used in a FOR
    a_output varchar(4000);
BEGIN
    a_output := ''CREATE FUNCTION cs_find_referrer_type(varchar,varchar,varchar)
                  RETURNS VARCHAR AS ''''
                     DECLARE
                         v_host ALIAS FOR $1;
                         v_domain ALIAS FOR $2;
```

```
                        v_url ALIAS FOR $3;
                    BEGIN ";

    --
    -- Notice how we scan through the results of a query in a FOR loop
    -- using the FOR <record> construct.
    --

    FOR referrer_keys IN SELECT * FROM cs_referrer_keys ORDER BY try_order LOOP
        a_output := a_output || " IF v_" || referrer_keys.kind || " LIKE """""
                 || referrer_keys.key_string || """"" THEN RETURN """
                 || referrer_keys.referrer_type || """; END IF;";
    END LOOP;

    a_output := a_output || " RETURN NULL; END; "" LANGUAGE ""plpgsql"";";

    -- This works because we are not substituting any variables
    -- Otherwise it would fail. Look at PERFORM for another way to run functions

    EXECUTE a_output;
END;
' LANGUAGE 'plpgsql';
```

19.5.5. Obtaining result status

There are several ways to determine the effect of a command. The first method is to use the `GET DIAGNOSTICS`, which has the form:

```
GET DIAGNOSTICS variable = item [ , ... ] ;
```

This command allows retrieval of system status indicators. Each *item* is a keyword identifying a state value to be assigned to the specified variable (which should be of the right data type to receive it). The currently available status items are `ROW_COUNT`, the number of rows processed by the last SQL query sent down to the SQL engine; and `RESULT_OID`, the OID of the last row inserted by the most recent SQL query. Note that `RESULT_OID` is only useful after an INSERT query.

```
GET DIAGNOSTICS var_integer = ROW_COUNT;
```

There is a special variable named `FOUND` of type `boolean`. `FOUND` starts out false within each PL/pgSQL function. It is set by each of the following types of statements:

- A SELECT INTO statement sets `FOUND` true if it returns a row, false if no row is returned.
- A PERFORM statement sets `FOUND` true if it produces (discards) a row, false if no row is produced.
- UPDATE, INSERT, and DELETE statements set `FOUND` true if at least one row is affected, false if no row is affected.

- A FETCH statement sets `FOUND` true if it returns a row, false if no row is returned.
- A FOR statement sets `FOUND` true if it iterates one or more times, else false. This applies to all three variants of the FOR statement (integer FOR loops, record-set FOR loops, and dynamic record-set FOR loops). `FOUND` is only set when the FOR loop exits: inside the execution of the loop, `FOUND` is not modified by the FOR statement, although it may be changed by the execution of other statements within the loop body.

`FOUND` is a local variable; any changes to it affect only the current PL/pgSQL function.

19.6. Control Structures

Control structures are probably the most useful (and important) part of PL/pgSQL. With PL/pgSQL's control structures, you can manipulate PostgreSQL data in a very flexible and powerful way.

19.6.1. Returning from a function

```
RETURN expression;
```

RETURN with an expression is used to return from a PL/pgSQL function that does not return a set. The function terminates and the value of *`expression`* is returned to the caller.

To return a composite (row) value, you must write a record or row variable as the *`expression`*. When returning a scalar type, any expression can be used. The expression's result will be automatically cast into the function's return type as described for assignments. (If you have declared the function to return `void`, then the expression can be omitted, and will be ignored in any case.)

The return value of a function cannot be left undefined. If control reaches the end of the top-level block of the function without hitting a RETURN statement, a run-time error will occur.

When a PL/pgSQL function is declared to return `SETOF` *`sometype`*, the procedure to follow is slightly different. In that case, the individual items to return are specified in RETURN NEXT commands, and then a final RETURN command with no arguments is used to indicate that the function has finished executing. RETURN NEXT can be used with both scalar and composite data types; in the later case, an entire "table" of results will be returned. Functions that use RETURN NEXT should be called in the following fashion:

```
SELECT * FROM some_func();
```

That is, the function is used as a table source in a FROM clause.

```
RETURN NEXT expression;
```

RETURN NEXT does not actually return from the function; it simply saves away the value of the expression (or record or row variable, as appropriate for the data type being returned). Execution then continues with the next statement in the PL/pgSQL function. As successive RETURN NEXT commands are executed, the result set is built up. A final RETURN, which need have no argument, causes control to exit the function.

> **Note:** The current implementation of RETURN NEXT for PL/pgSQL stores the entire result set before returning from the function, as discussed above. That means that if a PL/pgSQL function produces

a very large result set, performance may be poor: data will be written to disk to avoid memory exhaustion, but the function itself will not return until the entire result set has been generated. A future version of PL/pgSQL may allow users to allow users to define set-returning functions that do not have this limitation. Currently, the point at which data begins being written to disk is controlled by the `SORT_MEM` configuration variable. Administrators who have sufficient memory to store larger result sets in memory should consider increasing this parameter.

19.6.2. Conditionals

`IF` statements let you execute commands based on certain conditions. PL/pgSQL has four forms of `IF`:

- `IF ... THEN`
- `IF ... THEN ... ELSE`
- `IF ... THEN ... ELSE IF` and
- `IF ... THEN ... ELSIF ... THEN ... ELSE`

19.6.2.1. IF-THEN

```
IF boolean-expression THEN
    statements
END IF;
```

IF-THEN statements are the simplest form of IF. The statements between THEN and END IF will be executed if the condition is true. Otherwise, they are skipped.

```
IF v_user_id <> 0 THEN
    UPDATE users SET email = v_email WHERE user_id = v_user_id;
END IF;
```

19.6.2.2. IF-THEN-ELSE

```
IF boolean-expression THEN
    statements
ELSE
    statements
END IF;
```

IF-THEN-ELSE statements add to IF-THEN by letting you specify an alternative set of statements that should be executed if the condition evaluates to FALSE.

```
IF parentid IS NULL or parentid = ''
THEN
```

```
        return fullname;
    ELSE
        return hp_true_filename(parentid) || ”/” || fullname;
    END IF;


    IF v_count > 0 THEN
        INSERT INTO users_count(count) VALUES(v_count);
        return ”t”;
    ELSE
        return ”f”;
    END IF;
```

19.6.2.3. `IF-THEN-ELSE IF`

IF statements can be nested, as in the following example:

```
    IF demo_row.sex = ”m” THEN
      pretty_sex := ”man”;
    ELSE
      IF demo_row.sex = ”f” THEN
        pretty_sex := ”woman”;
      END IF;
    END IF;
```

When you use this form, you are actually nesting an IF statement inside the ELSE part of an outer IF statement. Thus you need one END IF statement for each nested IF and one for the parent IF-ELSE. This is workable but grows tedious when there are many alternatives to be checked.

19.6.2.4. `IF-THEN-ELSIF-ELSE`

```
    IF boolean-expression THEN
        statements
    [ ELSIF boolean-expression THEN
    statements
[ ELSIF boolean-expression THEN
    statements
    ...]]
    [ ELSE
    statements ]
    END IF;
```

`IF-THEN-ELSIF-ELSE` provides a more convenient method of checking many alternatives in one statement. Formally it is equivalent to nested `IF-THEN-ELSE-IF-THEN` commands, but only one `END IF` is needed.

Here is an example:

```
IF number = 0 THEN
    result := ”zero”;
ELSIF number > 0 THEN
    result := ”positive”;
ELSIF number < 0 THEN
    result := ”negative”;
ELSE
    -- hmm, the only other possibility is that number IS NULL
    result := ”NULL”;
END IF;
```

The final ELSE section is optional.

19.6.3. Simple Loops

With the LOOP, EXIT, WHILE and FOR statements, you can arrange for your PL/pgSQL function to repeat a series of commands.

19.6.3.1. LOOP

```
[<<label>>]
LOOP
    statements
END LOOP;
```

LOOP defines an unconditional loop that is repeated indefinitely until terminated by an EXIT or RETURN statement. The optional label can be used by EXIT statements in nested loops to specify which level of nesting should be terminated.

19.6.3.2. EXIT

```
EXIT [ label ] [ WHEN expression ];
```

If no *label* is given, the innermost loop is terminated and the statement following END LOOP is executed next. If *label* is given, it must be the label of the current or some outer level of nested loop or block. Then the named loop or block is terminated and control continues with the statement after the loop's/block's corresponding END.

If WHEN is present, loop exit occurs only if the specified condition is true, otherwise control passes to the statement after EXIT.

Examples:

```
LOOP
    -- some computations
    IF count > 0 THEN
        EXIT;  -- exit loop
```

```
    END IF;
END LOOP;

LOOP
    -- some computations
    EXIT WHEN count > 0;
END LOOP;

BEGIN
    -- some computations
    IF stocks > 100000 THEN
        EXIT;  -- illegal. Can't use EXIT outside of a LOOP
    END IF;
END;
```

19.6.3.3. WHILE

```
[<<label>>]
WHILE expression LOOP
    statements
END LOOP;
```

The WHILE statement repeats a sequence of statements so long as the condition expression evaluates to true. The condition is checked just before each entry to the loop body.

For example:

```
WHILE amount_owed > 0 AND gift_certificate_balance > 0 LOOP
    -- some computations here
END LOOP;

WHILE NOT boolean_expression LOOP
    -- some computations here
END LOOP;
```

19.6.3.4. FOR (integer for-loop)

```
[<<label>>]
FOR name IN [ REVERSE ] expression .. expression LOOP
    statements
END LOOP;
```

This form of FOR creates a loop that iterates over a range of integer values. The variable *name* is automatically defined as type integer and exists only inside the loop. The two expressions giving the lower and upper bound of the range are evaluated once when entering the loop. The iteration step is normally 1, but is -1 when REVERSE is specified.

Some examples of integer FOR loops:

```
FOR i IN 1..10 LOOP
  -- some expressions here

    RAISE NOTICE ''i is %'',i;
END LOOP;

FOR i IN REVERSE 10..1 LOOP
    -- some expressions here
END LOOP;
```

19.6.4. Looping Through Query Results

Using a different type of FOR loop, you can iterate through the results of a query and manipulate that data accordingly. The syntax is:

```
[<<label>>]
FOR record | row IN select_query LOOP
    statements
END LOOP;
```

The record or row variable is successively assigned all the rows resulting from the SELECT query and the loop body is executed for each row. Here is an example:

```
CREATE FUNCTION cs_refresh_mviews () RETURNS INTEGER AS '
DECLARE
     mviews RECORD;
BEGIN
     PERFORM cs_log(''Refreshing materialized views...'');

     FOR mviews IN SELECT * FROM cs_materialized_views ORDER BY sort_key LOOP

         -- Now "mviews" has one record from cs_materialized_views

         PERFORM cs_log(''Refreshing materialized view '' || quote_ident(mviews.mv_name)
         EXECUTE ''TRUNCATE TABLE  '' || quote_ident(mviews.mv_name);
         EXECUTE ''INSERT INTO '' || quote_ident(mviews.mv_name) || '' '' || mviews.mv_quer
     END LOOP;

     PERFORM cs_log(''Done refreshing materialized views.'');
     RETURN 1;
end;
' LANGUAGE 'plpgsql';
```

If the loop is terminated by an EXIT statement, the last assigned row value is still accessible after the loop.

The FOR-IN-EXECUTE statement is another way to iterate over records:

```
[<<label>>]
FOR record | row IN EXECUTE text_expression LOOP
    statements
END LOOP;
```

This is like the previous form, except that the source SELECT statement is specified as a string expression, which is evaluated and re-planned on each entry to the FOR loop. This allows the programmer to choose the speed of a pre-planned query or the flexibility of a dynamic query, just as with a plain EXECUTE statement.

> **Note:** The PL/pgSQL parser presently distinguishes the two kinds of FOR loops (integer or record-returning) by checking whether the target variable mentioned just after FOR has been declared as a record/row variable. If not, it's presumed to be an integer FOR loop. This can cause rather nonintuitive error messages when the true problem is, say, that one has misspelled the FOR variable name.

19.7. Cursors

Rather than executing a whole query at once, it is possible to set up a *cursor* that encapsulates the query, and then read the query result a few rows at a time. One reason for doing this is to avoid memory overrun when the result contains a large number of rows. (However, PL/pgSQL users don't normally need to worry about that, since FOR loops automatically use a cursor internally to avoid memory problems.) A more interesting usage is to return a reference to a cursor that it has created, allowing the caller to read the rows. This provides an efficient way to return large row sets from functions.

19.7.1. Declaring Cursor Variables

All access to cursors in PL/pgSQL goes through cursor variables, which are always of the special data type `refcursor`. One way to create a cursor variable is just to declare it as a variable of type `refcursor`. Another way is to use the cursor declaration syntax, which in general is:

```
name CURSOR [ ( arguments ) ] FOR select_query ;
```

(`FOR` may be replaced by `IS` for Oracle compatibility.) *`arguments`*, if any, are a comma-separated list of *`name`* *`datatype`* pairs that define names to be replaced by parameter values in the given query. The actual values to substitute for these names will be specified later, when the cursor is opened.

Some examples:

```
DECLARE
    curs1 refcursor;
    curs2 CURSOR FOR SELECT * from tenk1;
    curs3 CURSOR (key int) IS SELECT * from tenk1 where unique1 = key;
```

All three of these variables have the data type `refcursor`, but the first may be used with any query, while the second has a fully specified query already *bound* to it, and the last has a parameterized query bound to it. (`key` will be replaced by an integer parameter value when the cursor is opened.) The variable `curs1` is said to be *unbound* since it is not bound to any particular query.

19.7.2. Opening Cursors

Before a cursor can be used to retrieve rows, it must be *opened*. (This is the equivalent action to the SQL command `DECLARE CURSOR`.) PL/pgSQL has four forms of the OPEN statement, two of which use unbound cursor variables and the other two use bound cursor variables.

19.7.2.1. OPEN FOR SELECT

```
OPEN unbound-cursor FOR SELECT ...;
```

The cursor variable is opened and given the specified query to execute. The cursor cannot be open already, and it must have been declared as an unbound cursor (that is, as a simple `refcursor` variable). The SELECT query is treated in the same way as other SELECT statements in PL/pgSQL: PL/pgSQL variable names are substituted, and the query plan is cached for possible re-use.

```
OPEN curs1 FOR SELECT * FROM foo WHERE key = mykey;
```

19.7.2.2. OPEN FOR EXECUTE

```
OPEN unbound-cursor FOR EXECUTE query-string;
```

The cursor variable is opened and given the specified query to execute. The cursor cannot be open already, and it must have been declared as an unbound cursor (that is, as a simple `refcursor` variable). The query is specified as a string expression in the same way as in the EXECUTE command. As usual, this gives flexibility so the query can vary from one run to the next.

```
OPEN curs1 FOR EXECUTE ”SELECT * FROM ” || quote_ident($1);
```

19.7.2.3. Opening a bound cursor

```
OPEN bound-cursor [ ( argument_values ) ];
```

This form of OPEN is used to open a cursor variable whose query was bound to it when it was declared. The cursor cannot be open already. A list of actual argument value expressions must appear if and only if the cursor was declared to take arguments. These values will be substituted in the query. The query plan for a bound cursor is always considered cacheable --- there is no equivalent of EXECUTE in this case.

```
OPEN curs2;
OPEN curs3(42);
```

19.7.3. Using Cursors

Once a cursor has been opened, it can be manipulated with the statements described here.

These manipulations need not occur in the same function that opened the cursor to begin with. You can return a `refcursor` value out of a function and let the caller operate on the cursor. (Internally, a `refcursor` value is simply the string name of a Portal containing the active query for the cursor. This name can be passed around, assigned to other `refcursor` variables, and so on, without disturbing the Portal.)

All Portals are implicitly closed at transaction end. Therefore a `refcursor` value is useful to reference an open cursor only until the end of the transaction.

19.7.3.1. FETCH

```
FETCH cursor INTO target;
```

FETCH retrieves the next row from the cursor into a target, which may be a row variable, a record variable, or a comma-separated list of simple variables, just like SELECT INTO. As with SELECT INTO, the special variable `FOUND` may be checked to see whether a row was obtained or not.

```
FETCH curs1 INTO rowvar;
FETCH curs2 INTO foo,bar,baz;
```

19.7.3.2. CLOSE

```
CLOSE cursor;
```

CLOSE closes the Portal underlying an open cursor. This can be used to release resources earlier than end of transaction, or to free up the cursor variable to be opened again.

```
CLOSE curs1;
```

19.7.3.3. Returning Cursors

PL/pgSQL functions can return cursors to the caller. This is used to return multiple rows or columns from the function. The function opens the cursor and returns the cursor name to the caller. The caller can then FETCH rows from the cursor. The cursor can be closed by the caller, or it will be closed automatically when the transaction closes.

The cursor name returned by the function can be specified by the caller or automatically generated. The following example shows how a cursor name can be supplied by the caller:

```
CREATE TABLE test (col text);
INSERT INTO test VALUES (’123’);

CREATE FUNCTION reffunc(refcursor) RETURNS refcursor AS ’
BEGIN
```

```
        OPEN $1 FOR SELECT col FROM test;
        RETURN $1;
END;
' LANGUAGE 'plpgsql';

BEGIN;
SELECT reffunc('funccursor');
FETCH ALL IN funccursor;
COMMIT;
```

The following example uses automatic cursor name generation:

```
CREATE FUNCTION reffunc2() RETURNS refcursor AS '
DECLARE
        ref refcursor;
BEGIN
        OPEN ref FOR SELECT col FROM test;
        RETURN ref;
END;
' LANGUAGE 'plpgsql';

BEGIN;
SELECT reffunc2();

        reffunc2
  --------------------
   <unnamed cursor 1>
  (1 row)

FETCH ALL IN "<unnamed cursor 1>";
COMMIT;
```

19.8. Errors and Messages

Use the RAISE statement to report messages and raise errors.

```
RAISE level 'format' [, variable [...]];
```

Possible levels are `DEBUG` (write the message to the server log), `LOG` (write the message to the server log with a higher priority), `INFO`, `NOTICE` and `WARNING` (write the message to the server log and send it to the client, with respectively higher priorities), and `EXCEPTION` (raise an error and abort the current transaction). Whether error messages of a particular priority are reported to the client, written to the server log, or both is controlled by the `SERVER_MIN_MESSAGES` and `CLIENT_MIN_MESSAGES` configuration variables. See the *PostgreSQL Administrator's Guide* for more information.

Inside the format string, `%` is replaced by the next optional argument's external representation. Write `%%` to emit a literal `%`. Note that the optional arguments must presently be simple variables, not expressions, and the format must be a simple string literal.

Examples:

```
RAISE NOTICE ”Calling cs_create_job(%)”,v_job_id;
```

In this example, the value of v_job_id will replace the `%` in the string.

```
RAISE EXCEPTION ”Inexistent ID --> %”,user_id;
```

This will abort the transaction with the given error message.

19.8.1. Exceptions

PostgreSQL does not have a very smart exception handling model. Whenever the parser, planner/optimizer or executor decide that a statement cannot be processed any longer, the whole transaction gets aborted and the system jumps back into the main loop to get the next query from the client application.

It is possible to hook into the error mechanism to notice that this happens. But currently it is impossible to tell what really caused the abort (input/output conversion error, floating-point error, parse error). And it is possible that the database backend is in an inconsistent state at this point so returning to the upper executor or issuing more commands might corrupt the whole database.

Thus, the only thing PL/pgSQL currently does when it encounters an abort during execution of a function or trigger procedure is to write some additional `NOTICE` level log messages telling in which function and where (line number and type of statement) this happened. The error always stops execution of the function.

19.9. Trigger Procedures

PL/pgSQL can be used to define trigger procedures. A trigger procedure is created with the `CREATE FUNCTION` command as a function with no arguments and a return type of `TRIGGER`. Note that the function must be declared with no arguments even if it expects to receive arguments specified in `CREATE TRIGGER` --- trigger arguments are passed via `TG_ARGV`, as described below.

When a PL/pgSQL function is called as a trigger, several special variables are created automatically in the top-level block. They are:

`NEW`

Data type `RECORD`; variable holding the new database row for INSERT/UPDATE operations in ROW level triggers.

`OLD`

Data type `RECORD`; variable holding the old database row for UPDATE/DELETE operations in ROW level triggers.

`TG_NAME`

Data type `name`; variable that contains the name of the trigger actually fired.

`TG_WHEN`

Data type `text`; a string of either `BEFORE` or `AFTER` depending on the trigger's definition.

`TG_LEVEL`

Data type `text`; a string of either `ROW` or `STATEMENT` depending on the trigger's definition.

`TG_OP`

Data type `text`; a string of `INSERT`, `UPDATE` or `DELETE` telling for which operation the trigger is fired.

`TG_RELID`

Data type `oid`; the object ID of the table that caused the trigger invocation.

`TG_RELNAME`

Data type `name`; the name of the table that caused the trigger invocation.

`TG_NARGS`

Data type `integer`; the number of arguments given to the trigger procedure in the `CREATE TRIGGER` statement.

`TG_ARGV[]`

Data type array of `text`; the arguments from the `CREATE TRIGGER` statement. The index counts from 0 and can be given as an expression. Invalid indices (< 0 or >= `tg_nargs`) result in a null value.

A trigger function must return either NULL or a record/row value having exactly the structure of the table the trigger was fired for. Triggers fired BEFORE may return NULL to signal the trigger manager to skip the rest of the operation for this row (ie, subsequent triggers are not fired, and the INSERT/UPDATE/DELETE does not occur for this row). If a non-NULL value is returned then the operation proceeds with that row value. Note that returning a row value different from the original value of NEW alters the row that will be inserted or updated. It is possible to replace single values directly in NEW and return that, or to build a complete new record/row to return.

The return value of a trigger fired AFTER is ignored; it may as well always return a NULL value. But an AFTER trigger can still abort the operation by raising an error.

Example 19-1. A PL/pgSQL Trigger Procedure Example

This example trigger ensures that any time a row is inserted or updated in the table, the current user name and time are stamped into the row. And it ensures that an employee's name is given and that the salary is a positive value.

```
CREATE TABLE emp (
    empname text,
    salary integer,
    last_date timestamp,
```

```
    last_user text
);

CREATE FUNCTION emp_stamp () RETURNS TRIGGER AS ’
    BEGIN
        -- Check that empname and salary are given
        IF NEW.empname ISNULL THEN
            RAISE EXCEPTION ”empname cannot be NULL value”;
        END IF;
        IF NEW.salary ISNULL THEN
            RAISE EXCEPTION ”% cannot have NULL salary”, NEW.empname;
        END IF;

        -- Who works for us when she must pay for?
        IF NEW.salary < 0 THEN
            RAISE EXCEPTION ”% cannot have a negative salary”, NEW.empname;
        END IF;

        -- Remember who changed the payroll when
        NEW.last_date := ”now”;
        NEW.last_user := current_user;
        RETURN NEW;
    END;
’ LANGUAGE ’plpgsql’;

CREATE TRIGGER emp_stamp BEFORE INSERT OR UPDATE ON emp
    FOR EACH ROW EXECUTE PROCEDURE emp_stamp();
```

19.10. Examples

Here are only a few functions to demonstrate how easy it is to write PL/pgSQL functions. For more complex examples the programmer might look at the regression test for PL/pgSQL.

One painful detail in writing functions in PL/pgSQL is the handling of single quotes. The function’s source text in `CREATE FUNCTION` must be a literal string. Single quotes inside of literal strings must be either doubled or quoted with a backslash. We are still looking for an elegant alternative. In the meantime, doubling the single quotes as in the examples below should be used. Any solution for this in future versions of PostgreSQL will be forward compatible.

For a detailed explanation and examples of how to escape single quotes in different situations, please see Section 19.11.1.1.

Example 19-2. A Simple PL/pgSQL Function to Increment an Integer

The following two PL/pgSQL functions are identical to their counterparts from the C language function discussion. This function receives an `integer` and increments it by one, returning the incremented value.

```
CREATE FUNCTION add_one (integer) RETURNS INTEGER AS ’
    BEGIN
        RETURN $1 + 1;
```

```
    END;
' LANGUAGE 'plpgsql';
```

Example 19-3. A Simple PL/pgSQL Function to Concatenate Text

This function receives two `text` parameters and returns the result of concatenating them.

```
CREATE FUNCTION concat_text (TEXT, TEXT) RETURNS TEXT AS '
    BEGIN
        RETURN $1 || $2;
    END;
' LANGUAGE 'plpgsql';
```

Example 19-4. A PL/pgSQL Function on Composite Type

In this example, we take `EMP` (a table) and an `integer` as arguments to our function, which returns a `boolean`. If the `salary` field of the `EMP` table is `NULL`, we return `f`. Otherwise we compare with that field with the `integer` passed to the function and return the `boolean` result of the comparison (t or f). This is the PL/pgSQL equivalent to the example from the C functions.

```
CREATE FUNCTION c_overpaid (EMP, INTEGER) RETURNS BOOLEAN AS '
    DECLARE
        emprec ALIAS FOR $1;
        sallim ALIAS FOR $2;
    BEGIN
        IF emprec.salary ISNULL THEN
            RETURN ''f'';
        END IF;
        RETURN emprec.salary > sallim;
    END;
' LANGUAGE 'plpgsql';
```

19.11. Porting from Oracle PL/SQL

Author: Roberto Mello (<rmello@fslc.usu.edu>)

This section explains differences between Oracle's PL/SQL and PostgreSQL's PL/pgSQL languages in the hopes of helping developers port applications from Oracle to PostgreSQL. Most of the code here is from the ArsDigita[1] Clickstream module[2] that I ported to PostgreSQL when I took an internship with OpenForce Inc.[3] in the Summer of 2000.

PL/pgSQL is similar to PL/SQL in many aspects. It is a block structured, imperative language (all variables have to be declared). PL/SQL has many more features than its PostgreSQL counterpart, but PL/pgSQL allows for a great deal of functionality and it is being improved constantly.

1. http://www.arsdigita.com
2. http://www.arsdigita.com/asj/clickstream
3. http://www.openforce.net

19.11.1. Main Differences

Some things you should keep in mind when porting from Oracle to PostgreSQL:

- No default parameters in PostgreSQL.
- You can overload functions in PostgreSQL. This is often used to work around the lack of default parameters.
- Assignments, loops and conditionals are similar.
- No need for cursors in PostgreSQL, just put the query in the FOR statement (see example below)
- In PostgreSQL you *need* to escape single quotes. See Section 19.11.1.1.

19.11.1.1. Quote Me on That: Escaping Single Quotes

In PostgreSQL you need to escape single quotes inside your function definition. This can lead to quite amusing code at times, especially if you are creating a function that generates other function(s), as in Example 19-6. One thing to keep in mind when escaping lots of single quotes is that, except for the beginning/ending quotes, all the others will come in even quantity.

Table 19-1 gives the scoop. (You’ll love this little chart.)

Table 19-1. Single Quotes Escaping Chart

No. of Quotes	Usage	Example	Result
1	To begin/terminate function bodies	`CREATE FUNCTION foo() RETURNS INTEGER AS ’...’ LANGUAGE ’plpgsql’;`	as is
2	In assignments, SELECT statements, to delimit strings, etc.	`a_output := ″Blah″; SELECT * FROM users WHERE f_name=″foobar″;`	`SELECT * FROM users WHERE f_name=’foobar’;`
4	When you need two single quotes in your resulting string without terminating that string.	`a_output := a_output ‖ ″ AND name LIKE ″″foobar″″ AND ...″`	`AND name LIKE ’foobar’ AND ...`
6	When you want double quotes in your resulting string *and* terminate that string.	`a_output := a_output ‖ ″ AND name LIKE ″″foobar″″″`	`AND name LIKE ’foobar’`

<table>
<tr><th>No. of Quotes</th><th>Usage</th><th>Example</th><th>Result</th></tr>
<tr><td>10</td><td>When you want two single quotes in the resulting string (which accounts for 8 quotes) and terminate that string (2 more). You will probably only need that if you were using a function to generate other functions (like in Example 19-6).</td><td><code>a_output := a_output || ″ if v_″ || referrer_keys.kind || ″ like ″″″″″ || referrer_keys.key_string || ″″″″″ then return ″″″ || referrer_keys.referrer_type || ″″″; end if;″;</code></td><td><code>if v_<...> like ″<...>″ then return ″<...>″; end if;</code></td></tr>
</table>

19.11.2. Porting Functions

Example 19-5. A Simple Function

Here is an Oracle function:

```
    CREATE OR REPLACE FUNCTION cs_fmt_browser_version(v_name IN varchar, v_version IN var-
char)
    RETURN varchar IS
    BEGIN
        IF v_version IS NULL THEN
            RETURN v_name;
        END IF;
        RETURN v_name || ’/’ || v_version;
    END;
    /
    SHOW ERRORS;
```

Let’s go through this function and see the differences to PL/pgSQL:

- PostgreSQL does not have named parameters. You have to explicitly alias them inside your function.
- Oracle can have `IN`, `OUT`, and `INOUT` parameters passed to functions. The `INOUT`, for example, means that the parameter will receive a value and return another. PostgreSQL only has “IN” parameters and functions can return only a single value.
- The `RETURN` key word in the function prototype (not the function body) becomes `RETURNS` in PostgreSQL.
- On PostgreSQL functions are created using single quotes as delimiters, so you have to escape single quotes inside your functions (which can be quite annoying at times; see Section 19.11.1.1).
- The `/show errors` command does not exist in PostgreSQL.

So let’s see how this function would look when ported to PostgreSQL:

```
    CREATE OR REPLACE FUNCTION cs_fmt_browser_version(VARCHAR, VARCHAR)
```

```
RETURNS VARCHAR AS ’
DECLARE
    v_name ALIAS FOR $1;
    v_version ALIAS FOR $2;
BEGIN
    IF v_version IS NULL THEN
        return v_name;
    END IF;
    RETURN v_name || ”/” || v_version;
END;
’ LANGUAGE ’plpgsql’;
```

Example 19-6. A Function that Creates Another Function

The following procedure grabs rows from a `SELECT` statement and builds a large function with the results in `IF` statements, for the sake of efficiency. Notice particularly the differences in cursors, `FOR` loops, and the need to escape single quotes in PostgreSQL.

```
CREATE OR REPLACE PROCEDURE cs_update_referrer_type_proc IS
    CURSOR referrer_keys IS
        SELECT * FROM cs_referrer_keys
        ORDER BY try_order;

    a_output VARCHAR(4000);
BEGIN
    a_output := ’CREATE OR REPLACE FUNCTION cs_find_referrer_type(v_host IN VAR-
CHAR, v_domain IN VARCHAR,
v_url IN VARCHAR) RETURN VARCHAR IS BEGIN’;

    FOR referrer_key IN referrer_keys LOOP
        a_output := a_output || ’ IF v_’ || referrer_key.kind || ’ LIKE ”’ ||
referrer_key.key_string || ”’ THEN RETURN ”’ || referrer_key.referrer_type ||
”’; END IF;’;
    END LOOP;

    a_output := a_output || ’ RETURN NULL; END;’;
    EXECUTE IMMEDIATE a_output;
END;
/
show errors
```

Here is how this function would end up in PostgreSQL:

```
CREATE FUNCTION cs_update_referrer_type_proc() RETURNS INTEGER AS ’
DECLARE
    referrer_keys RECORD;  -- Declare a generic record to be used in a FOR
    a_output varchar(4000);
BEGIN
    a_output := ”CREATE FUNCTION cs_find_referrer_type(VARCHAR,VARCHAR,VARCHAR)
                 RETURNS VARCHAR AS ””
                    DECLARE
                        v_host ALIAS FOR $1;
```

```
                          v_domain ALIAS FOR $2;
                          v_url ALIAS FOR $3;
                      BEGIN ”;

    --
    -- Notice how we scan through the results of a query in a FOR loop
    -- using the FOR <record> construct.
    --

    FOR referrer_keys IN SELECT * FROM cs_referrer_keys ORDER BY try_order LOOP
        a_output := a_output || ” IF v_” || referrer_keys.kind || ” LIKE ”””””
                 || referrer_keys.key_string || ””””” THEN RETURN ”””
                 || referrer_keys.referrer_type || ”””; END IF;”;
    END LOOP;

    a_output := a_output || ” RETURN NULL; END; ”” LANGUAGE ””plpgsql””;”;

    -- This works because we are not substituting any variables
    -- Otherwise it would fail. Look at PERFORM for another way to run functions

    EXECUTE a_output;
END;
’ LANGUAGE ’plpgsql’;
```

Example 19-7. A Procedure with a lot of String Manipulation and OUT Parameters

The following Oracle PL/SQL procedure is used to parse a URL and return several elements (host, path and query). It is an procedure because in PL/pgSQL functions only one value can be returned (see Section 19.11.3). In PostgreSQL, one way to work around this is to split the procedure in three different functions: one to return the host, another for the path and another for the query.

```
CREATE OR REPLACE PROCEDURE cs_parse_url(
    v_url IN VARCHAR,
    v_host OUT VARCHAR,  -- This will be passed back
    v_path OUT VARCHAR,  -- This one too
    v_query OUT VARCHAR) -- And this one
is
    a_pos1 INTEGER;
    a_pos2 INTEGER;
begin
    v_host := NULL;
    v_path := NULL;
    v_query := NULL;
    a_pos1 := instr(v_url, ’//’); -- PostgreSQL doesn’t have an instr function

    IF a_pos1 = 0 THEN
        RETURN;
    END IF;
    a_pos2 := instr(v_url, ’/’, a_pos1 + 2);
    IF a_pos2 = 0 THEN
        v_host := substr(v_url, a_pos1 + 2);
```

```
        v_path := '/';
        RETURN;
    END IF;

    v_host := substr(v_url, a_pos1 + 2, a_pos2 - a_pos1 - 2);
    a_pos1 := instr(v_url, '?', a_pos2 + 1);

    IF a_pos1 = 0 THEN
        v_path := substr(v_url, a_pos2);
        RETURN;
    END IF;

    v_path := substr(v_url, a_pos2, a_pos1 - a_pos2);
    v_query := substr(v_url, a_pos1 + 1);
END;
/
show errors;
```

Here is how this procedure could be translated for PostgreSQL:

```
CREATE OR REPLACE FUNCTION cs_parse_url_host(VARCHAR) RETURNS VARCHAR AS '
DECLARE
    v_url ALIAS FOR $1;
    v_host VARCHAR;
    v_path VARCHAR;
    a_pos1 INTEGER;
    a_pos2 INTEGER;
    a_pos3 INTEGER;
BEGIN
    v_host := NULL;
    a_pos1 := instr(v_url,''//'');

    IF a_pos1 = 0 THEN
        RETURN '''';  -- Return a blank
    END IF;

    a_pos2 := instr(v_url,''/'',a_pos1 + 2);
    IF a_pos2 = 0 THEN
        v_host := substr(v_url, a_pos1 + 2);
        v_path := ''/'';
        RETURN v_host;
    END IF;

    v_host := substr(v_url, a_pos1 + 2, a_pos2 - a_pos1 - 2 );
    RETURN v_host;
END;
' LANGUAGE 'plpgsql';
```

Note: PostgreSQL does not have an `instr` function, so you can work around it using a combination of other functions. I got tired of doing this and created my own `instr` functions that behave exactly like Oracle's (it makes life easier). See the Section 19.11.6 for the code.

19.11.3. Procedures

Oracle procedures give a little more flexibility to the developer because nothing needs to be explicitly returned, but it can be through the use of `INOUT` or `OUT` parameters.

An example:

```
CREATE OR REPLACE PROCEDURE cs_create_job(v_job_id IN INTEGER) IS
    a_running_job_count INTEGER;
    PRAGMA AUTONOMOUS_TRANSACTION;❶
BEGIN
    LOCK TABLE cs_jobs IN EXCLUSIVE MODE;❷

    SELECT count(*) INTO a_running_job_count
    FROM cs_jobs
    WHERE end_stamp IS NULL;

    IF a_running_job_count > 0 THEN
        COMMIT; -- free lock❸
        raise_application_error(-20000, 'Unable to create a new job: a job is cur-
rently running.');
    END IF;

    DELETE FROM cs_active_job;
    INSERT INTO cs_active_job(job_id) VALUES (v_job_id);

    BEGIN
        INSERT INTO cs_jobs (job_id, start_stamp) VALUES (v_job_id, sysdate);
        EXCEPTION WHEN dup_val_on_index THEN NULL; -- don't worry if it al-
ready exists❹
    END;
    COMMIT;
END;
/
show errors
```

Procedures like this can be easily converted into PostgreSQL functions returning an `INTEGER`. This procedure in particular is interesting because it can teach us some things:

❶ There is no `pragma` statement in PostgreSQL.

❷ If you do a `LOCK TABLE` in PL/pgSQL, the lock will not be released until the calling transaction is finished.

❸ You also cannot have transactions in PL/pgSQL procedures. The entire function (and other functions called from therein) is executed in a transaction and PostgreSQL rolls back the results if something goes wrong. Therefore only one `BEGIN` statement is allowed.

❹ The exception when would have to be replaced by an `IF` statement.

So let's see one of the ways we could port this procedure to PL/pgSQL:

```
CREATE OR REPLACE FUNCTION cs_create_job(INTEGER) RETURNS INTEGER AS ’
DECLARE
    v_job_id ALIAS FOR $1;
    a_running_job_count INTEGER;
    a_num INTEGER;
    -- PRAGMA AUTONOMOUS_TRANSACTION;
BEGIN
    LOCK TABLE cs_jobs IN EXCLUSIVE MODE;
    SELECT count(*) INTO a_running_job_count
    FROM cs_jobs
    WHERE end_stamp IS NULL;

    IF a_running_job_count > 0
    THEN
        -- COMMIT; -- free lock
        RAISE EXCEPTION ”Unable to create a new job: a job is currently running.”;
    END IF;

    DELETE FROM cs_active_job;
    INSERT INTO cs_active_job(job_id) VALUES (v_job_id);

    SELECT count(*) into a_num
    FROM cs_jobs
    WHERE job_id=v_job_id;
    IF NOT FOUND THEN  -- If nothing was returned in the last query
        -- This job is not in the table so lets insert it.
        INSERT INTO cs_jobs(job_id, start_stamp) VALUES (v_job_id, sysdate());
        RETURN 1;
    ELSE
        RAISE NOTICE ”Job already running.”;❶
    END IF;

    RETURN 0;
END;
’ LANGUAGE ’plpgsql’;
```

❶ Notice how you can raise notices (or errors) in PL/pgSQL.

19.11.4. Packages

> **Note:** I haven’t done much with packages myself, so if there are mistakes here, please let me know.

Packages are a way Oracle gives you to encapsulate PL/SQL statements and functions into one entity, like Java classes, where you define methods and objects. You can access these objects/methods with a “`.`” (dot). Here is an example of an Oracle package from ACS 4 (the ArsDigita Community System[4]):

4. http://www.arsdigita.com/doc/

```
CREATE OR REPLACE PACKAGE BODY acs
AS
  FUNCTION add_user (
    user_id     IN users.user_id%TYPE DEFAULT NULL,
    object_type     IN acs_objects.object_type%TYPE DEFAULT 'user',
    creation_date   IN acs_objects.creation_date%TYPE DEFAULT sysdate,
    creation_user   IN acs_objects.creation_user%TYPE DEFAULT NULL,
    creation_ip     IN acs_objects.creation_ip%TYPE DEFAULT NULL,
  ...
  ) RETURN users.user_id%TYPE
  IS
    v_user_id       users.user_id%TYPE;
    v_rel_id        membership_rels.rel_id%TYPE;
  BEGIN
    v_user_id := acs_user.new (user_id, object_type, creation_date,
                creation_user, creation_ip, email, ...
    RETURN v_user_id;
  END;
END acs;
/
show errors
```

We port this to PostgreSQL by creating the different objects of the Oracle package as functions with a standard naming convention. We have to pay attention to some other details, like the lack of default parameters in PostgreSQL functions. The above package would become something like this:

```
CREATE FUNCTION acs__add_user(INTEGER,INTEGER,VARCHAR,TIMESTAMP,INTEGER,INTEGER,...)
RETURNS INTEGER AS '
DECLARE
    user_id ALIAS FOR $1;
    object_type ALIAS FOR $2;
    creation_date ALIAS FOR $3;
    creation_user ALIAS FOR $4;
    creation_ip ALIAS FOR $5;
    ...
    v_user_id users.user_id%TYPE;
    v_rel_id membership_rels.rel_id%TYPE;
BEGIN
    v_user_id := acs_user__new(user_id,object_type,creation_date,creation_user,creation
    ...

    RETURN v_user_id;
END;
' LANGUAGE 'plpgsql';
```

19.11.5. Other Things to Watch For

19.11.5.1. EXECUTE

The PostgreSQL version of `EXECUTE` works nicely, but you have to remember to use `quote_literal(TEXT)` and `quote_string(TEXT)` as described in Section 19.5.4. Constructs of the type `EXECUTE ”SELECT * from $1”;` will not work unless you use these functions.

19.11.5.2. Optimizing PL/pgSQL Functions

PostgreSQL gives you two function creation modifiers to optimize execution: `iscachable` (function always returns the same result when given the same arguments) and `isstrict` (function returns NULL if any argument is NULL). Consult the `CREATE FUNCTION` reference for details.

To make use of these optimization attributes, you have to use the `WITH` modifier in your `CREATE FUNCTION` statement. Something like:

```
CREATE FUNCTION foo(...) RETURNS INTEGER AS ’
...
’ LANGUAGE ’plpgsql’
WITH (isstrict, iscachable);
```

19.11.6. Appendix

19.11.6.1. Code for my `instr` functions

```
--
-- instr functions that mimic Oracle’s counterpart
-- Syntax: instr(string1,string2,[n],[m]) where [] denotes optional params.
--
-- Searches string1 beginning at the nth character for the mth
-- occurrence of string2. If n is negative, search backwards. If m is
-- not passed, assume 1 (search starts at first character).
--
-- by Roberto Mello (rmello@fslc.usu.edu)
-- modified by Robert Gaszewski (graszew@poland.com)
-- Licensed under the GPL v2 or later.
--

CREATE FUNCTION instr(VARCHAR,VARCHAR) RETURNS INTEGER AS ’
DECLARE
    pos integer;
BEGIN
    pos:= instr($1,$2,1);
    RETURN pos;
END;
’ LANGUAGE ’plpgsql’;
```

```
CREATE FUNCTION instr(VARCHAR,VARCHAR,INTEGER) RETURNS INTEGER AS ’
DECLARE
    string ALIAS FOR $1;
    string_to_search ALIAS FOR $2;
    beg_index ALIAS FOR $3;
    pos integer NOT NULL DEFAULT 0;
    temp_str VARCHAR;
    beg INTEGER;
    length INTEGER;
    ss_length INTEGER;
BEGIN
    IF beg_index > 0 THEN

       temp_str := substring(string FROM beg_index);
       pos := position(string_to_search IN temp_str);

       IF pos = 0 THEN
          RETURN 0;
      ELSE
          RETURN pos + beg_index - 1;
      END IF;
    ELSE
       ss_length := char_length(string_to_search);
       length := char_length(string);
       beg := length + beg_index - ss_length + 2;

       WHILE beg > 0 LOOP
           temp_str := substring(string FROM beg FOR ss_length);
          pos := position(string_to_search IN temp_str);

          IF pos > 0 THEN
             RETURN beg;
          END IF;

          beg := beg - 1;
       END LOOP;
       RETURN 0;
    END IF;
END;
’ LANGUAGE ’plpgsql’;

--
-- Written by Robert Gaszewski (graszew@poland.com)
-- Licensed under the GPL v2 or later.
--
CREATE FUNCTION instr(VARCHAR,VARCHAR,INTEGER,INTEGER) RETURNS INTEGER AS ’
DECLARE
    string ALIAS FOR $1;
    string_to_search ALIAS FOR $2;
    beg_index ALIAS FOR $3;
    occur_index ALIAS FOR $4;
```

```
    pos integer NOT NULL DEFAULT 0;
    occur_number INTEGER NOT NULL DEFAULT 0;
    temp_str VARCHAR;
    beg INTEGER;
    i INTEGER;
    length INTEGER;
    ss_length INTEGER;
BEGIN
    IF beg_index > 0 THEN
        beg := beg_index;
        temp_str := substring(string FROM beg_index);

        FOR i IN 1..occur_index LOOP
            pos := position(string_to_search IN temp_str);

            IF i = 1 THEN
                beg := beg + pos - 1;
            ELSE
                beg := beg + pos;
            END IF;

            temp_str := substring(string FROM beg + 1);
        END LOOP;

        IF pos = 0 THEN
            RETURN 0;
        ELSE
            RETURN beg;
        END IF;
    ELSE
        ss_length := char_length(string_to_search);
        length := char_length(string);
        beg := length + beg_index - ss_length + 2;

        WHILE beg > 0 LOOP
            temp_str := substring(string FROM beg FOR ss_length);
            pos := position(string_to_search IN temp_str);

            IF pos > 0 THEN
                occur_number := occur_number + 1;

                IF occur_number = occur_index THEN
                    RETURN beg;
                END IF;
            END IF;

            beg := beg - 1;
        END LOOP;

        RETURN 0;
    END IF;
END;
' LANGUAGE 'plpgsql';
```

Chapter 20. PL/Tcl - Tcl Procedural Language

PL/Tcl is a loadable procedural language for the PostgreSQL database system that enables the Tcl language to be used to write functions and trigger procedures.

This package was originally written by Jan Wieck.

20.1. Overview

PL/Tcl offers most of the capabilities a function writer has in the C language, except for some restrictions.

The good restriction is that everything is executed in a safe Tcl interpreter. In addition to the limited command set of safe Tcl, only a few commands are available to access the database via SPI and to raise messages via `elog()`. There is no way to access internals of the database backend or to gain OS-level access under the permissions of the PostgreSQL user ID, as a C function can do. Thus, any unprivileged database user may be permitted to use this language.

The other, implementation restriction is that Tcl procedures cannot be used to create input/output functions for new data types.

Sometimes it is desirable to write Tcl functions that are not restricted to safe Tcl --- for example, one might want a Tcl function that sends mail. To handle these cases, there is a variant of PL/Tcl called `PL/TclU` (for untrusted Tcl). This is the exact same language except that a full Tcl interpreter is used. *If PL/TclU is used, it must be installed as an untrusted procedural language* so that only database superusers can create functions in it. The writer of a PL/TclU function must take care that the function cannot be used to do anything unwanted, since it will be able to do anything that could be done by a user logged in as the database administrator.

The shared object for the PL/Tcl and PL/TclU call handlers is automatically built and installed in the PostgreSQL library directory if Tcl/Tk support is specified in the configuration step of the installation procedure. To install PL/Tcl and/or PL/TclU in a particular database, use the `createlang` script, for example `createlang pltcl` *`dbname`* or `createlang pltclu` *`dbname`*.

20.2. Description

20.2.1. PL/Tcl Functions and Arguments

To create a function in the PL/Tcl language, use the standard syntax

```
CREATE FUNCTION funcname (argument-types) RETURNS return-type AS '
    # PL/Tcl function body
' LANGUAGE 'pltcl';
```

PL/TclU is the same, except that the language should be specified as `pltclu`.

The body of the function is simply a piece of Tcl script. When the function is called, the argument values are passed as variables `$1` ... `$n` to the Tcl script. The result is returned from the Tcl code in the usual way, with a `return` statement. For example, a function returning the greater of two integer values could be defined as:

```
CREATE FUNCTION tcl_max (integer, integer) RETURNS integer AS '
    if {$1 > $2} {return $1}
    return $2
' LANGUAGE 'pltcl' WITH (isStrict);
```

Note the clause `WITH (isStrict)`, which saves us from having to think about NULL input values: if a NULL is passed, the function will not be called at all, but will just return a NULL result automatically.

In a non-strict function, if the actual value of an argument is NULL, the corresponding `$n` variable will be set to an empty string. To detect whether a particular argument is NULL, use the function `argisnull`. For example, suppose that we wanted `tcl_max` with one null and one non-null argument to return the non-null argument, rather than NULL:

```
CREATE FUNCTION tcl_max (integer, integer) RETURNS integer AS '
    if {[argisnull 1]} {
        if {[argisnull 2]} { return_null }
        return $2
    }
    if {[argisnull 2]} { return $1 }
    if {$1 > $2} {return $1}
    return $2
' LANGUAGE 'pltcl';
```

As shown above, to return a NULL value from a PL/Tcl function, execute `return_null`. This can be done whether the function is strict or not.

Composite-type arguments are passed to the procedure as Tcl arrays. The element names of the array are the attribute names of the composite type. If an attribute in the passed row has the NULL value, it will not appear in the array! Here is an example that defines the overpaid_2 function (as found in the older PostgreSQL documentation) in PL/Tcl:

```
CREATE FUNCTION overpaid_2 (EMP) RETURNS bool AS '
    if {200000.0 < $1(salary)} {
        return "t"
    }
    if {$1(age) < 30 && 100000.0 < $1(salary)} {
        return "t"
    }
    return "f"
' LANGUAGE 'pltcl';
```

There is not currently any support for returning a composite-type result value.

20.2.2. Data Values in PL/Tcl

The argument values supplied to a PL/Tcl function's script are simply the input arguments converted to text form (just as if they had been displayed by a SELECT statement). Conversely, the `return` command will accept any string that is acceptable input format for the function's declared return type. So, the PL/Tcl programmer can manipulate data values as if they were just text.

20.2.3. Global Data in PL/Tcl

Sometimes it is useful to have some global status data that is held between two calls to a procedure or is shared between different procedures. This is easily done since all PL/Tcl procedures executed in one backend share the same safe Tcl interpreter. So, any global Tcl variable is accessible to all PL/Tcl procedure calls, and will persist for the duration of the SQL client connection. (Note that PL/TclU functions likewise share global data, but they are in a different Tcl interpreter and cannot communicate with PL/Tcl functions.)

To help protect PL/Tcl procedures from unintentionally interfering with each other, a global array is made available to each procedure via the `upvar` command. The global name of this variable is the procedure's internal name and the local name is `GD`. It is recommended that `GD` be used for private status data of a procedure. Use regular Tcl global variables only for values that you specifically intend to be shared among multiple procedures.

An example of using `GD` appears in the `spi_execp` example below.

20.2.4. Database Access from PL/Tcl

The following commands are available to access the database from the body of a PL/Tcl procedure:

`spi_exec ?-count` *`n`*`? ?-array` *`name`*`?` *`query`* `?`*`loop-body`*`?`

Execute an SQL query given as a string. An error in the query causes an error to be raised. Otherwise, the command's return value is the number of rows processed (selected, inserted, updated, or deleted) by the query, or zero if the query is a utility statement. In addition, if the query is a SELECT statement, the values of the selected columns are placed in Tcl variables as described below.

The optional `-count` value tells `spi_exec` the maximum number of rows to process in the query. The effect of this is comparable to setting up the query as a cursor and then saying `FETCH n`.

If the query is a `SELECT` statement, the values of the statement's result columns are placed into Tcl variables named after the columns. If the `-array` option is given, the column values are instead stored into the named associative array, with the SELECT column names used as array indexes.

If the query is a SELECT statement and no *`loop-body`* script is given, then only the first row of results are stored into Tcl variables; remaining rows, if any, are ignored. No store occurs if the SELECT returns no rows (this case can be detected by checking the result of `spi_exec`). For example,

```
spi_exec "SELECT count(*) AS cnt FROM pg_proc"
```

will set the Tcl variable `$cnt` to the number of rows in the `pg_proc` system catalog.

If the optional *loop-body* argument is given, it is a piece of Tcl script that is executed once for each row in the SELECT result (note: *loop-body* is ignored if the given query is not a SELECT). The values of the current row's fields are stored into Tcl variables before each iteration. For example,

```
spi_exec -array C "SELECT * FROM pg_class" {
    elog DEBUG "have table $C(relname)"
}
```

will print a DEBUG log message for every row of pg_class. This feature works similarly to other Tcl looping constructs; in particular `continue` and `break` work in the usual way inside the loop body.

If a field of a SELECT result is NULL, the target variable for it is "unset" rather than being set.

`spi_prepare` *query typelist*

Prepares and saves a query plan for later execution. The saved plan will be retained for the life of the current backend.

The query may use *arguments*, which are placeholders for values to be supplied whenever the plan is actually executed. In the query string, refer to arguments by the symbols `$1` ... `$n`. If the query uses arguments, the names of the argument types must be given as a Tcl list. (Write an empty list for *typelist* if no arguments are used.) Presently, the argument types must be identified by the internal type names shown in pg_type; for example `int4` not `integer`.

The return value from `spi_prepare` is a query ID to be used in subsequent calls to `spi_execp`. See `spi_execp` for an example.

`spi_execp ?-count` *n*`? ?-array` *name*`? ?-nulls` *string*`?` *queryid* `?`*value-list*`? ?`*loop-body*`?`

Execute a query previously prepared with `spi_prepare`. *queryid* is the ID returned by `spi_prepare`. If the query references arguments, a *value-list* must be supplied: this is a Tcl list of actual values for the arguments. This must be the same length as the argument type list previously given to `spi_prepare`. Omit *value-list* if the query has no arguments.

The optional value for `-nulls` is a string of spaces and `'n'` characters telling `spi_execp` which of the arguments are null values. If given, it must have exactly the same length as the *value-list*. If it is not given, all the argument values are non-NULL.

Except for the way in which the query and its arguments are specified, `spi_execp` works just like `spi_exec`. The `-count`, `-array`, and *loop-body* options are the same, and so is the result value.

Here's an example of a PL/Tcl function using a prepared plan:

```
CREATE FUNCTION t1_count(integer, integer) RETURNS integer AS '
    if {![ info exists GD(plan) ]} {
        # prepare the saved plan on the first call
        set GD(plan) [ spi_prepare \\
                "SELECT count(*) AS cnt FROM t1 WHERE num >= \\$1 AND num <= \\$2"
                [ list int4 int4 ] ]
    }
    spi_execp -count 1 $GD(plan) [ list $1 $2 ]
    return $cnt
' LANGUAGE 'pltcl';
```

Note that each backslash that Tcl should see must be doubled when we type in the function, since the main parser processes backslashes too in CREATE FUNCTION. We need backslashes inside the query string given to `spi_prepare` to ensure that the `$n` markers will be passed through to `spi_prepare` as-is, and not replaced by Tcl variable substitution.

`spi_lastoid`

Returns the OID of the row inserted by the last `spi_exec`'d or `spi_execp`'d query, if that query was a single-row INSERT. (If not, you get zero.)

`quote` *`string`*

Duplicates all occurrences of single quote and backslash characters in the given string. This may be used to safely quote strings that are to be inserted into SQL queries given to `spi_exec` or `spi_prepare`. For example, think about a query string like

```
"SELECT '$val' AS ret"
```

where the Tcl variable val actually contains `doesn't`. This would result in the final query string

```
SELECT 'doesn't' AS ret
```

which would cause a parse error during `spi_exec` or `spi_prepare`. The submitted query should contain

```
SELECT 'doesn''t' AS ret
```

which can be formed in PL/Tcl as

```
"SELECT '[ quote $val ]' AS ret"
```

One advantage of `spi_execp` is that you don't have to quote argument values like this, since the arguments are never parsed as part of an SQL query string.

`elog` *`level`* *`msg`*

Emit a log or error message. Possible levels are `DEBUG`, `LOG`, `INFO`, `NOTICE`, `WARNING`, `ERROR`, and `FATAL`. Most simply emit the given message just like the `elog` backend C function. `ERROR` raises an error condition: further execution of the function is abandoned, and the current transaction is aborted. `FATAL` aborts the transaction and causes the current backend to shut down (there is probably no good reason to use this error level in PL/Tcl functions, but it's provided for completeness).

20.2.5. Trigger Procedures in PL/Tcl

Trigger procedures can be written in PL/Tcl. As is customary in PostgreSQL, a procedure that's to be called as a trigger must be declared as a function with no arguments and a return type of `trigger`.

The information from the trigger manager is passed to the procedure body in the following variables:

`$TG_name`

The name of the trigger from the CREATE TRIGGER statement.

`$TG_relid`

The object ID of the table that caused the trigger procedure to be invoked.

$TG_relatts

A Tcl list of the table field names, prefixed with an empty list element. So looking up an element name in the list with Tcl's `lsearch` command returns the element's number starting with 1 for the first column, the same way the fields are customarily numbered in PostgreSQL.

$TG_when

The string `BEFORE` or `AFTER` depending on the type of trigger call.

$TG_level

The string `ROW` or `STATEMENT` depending on the type of trigger call.

$TG_op

The string `INSERT`, `UPDATE` or `DELETE` depending on the type of trigger call.

$NEW

An associative array containing the values of the new table row for INSERT/UPDATE actions, or empty for DELETE. The array is indexed by field name. Fields that are NULL will not appear in the array!

$OLD

An associative array containing the values of the old table row for UPDATE/DELETE actions, or empty for INSERT. The array is indexed by field name. Fields that are NULL will not appear in the array!

$args

A Tcl list of the arguments to the procedure as given in the CREATE TRIGGER statement. These arguments are also accessible as `$1` ... `$n` in the procedure body.

The return value from a trigger procedure can be one of the strings `OK` or `SKIP`, or a list as returned by the `array get` Tcl command. If the return value is `OK`, the operation (INSERT/UPDATE/DELETE) that fired the trigger will proceed normally. `SKIP` tells the trigger manager to silently suppress the operation for this row. If a list is returned, it tells PL/Tcl to return a modified row to the trigger manager that will be inserted instead of the one given in $NEW (this works for INSERT/UPDATE only). Needless to say that all this is only meaningful when the trigger is BEFORE and FOR EACH ROW; otherwise the return value is ignored.

Here's a little example trigger procedure that forces an integer value in a table to keep track of the number of updates that are performed on the row. For new rows inserted, the value is initialized to 0 and then incremented on every update operation:

```
CREATE FUNCTION trigfunc_modcount() RETURNS TRIGGER AS '
    switch $TG_op {
        INSERT {
            set NEW($1) 0
        }
        UPDATE {
            set NEW($1) $OLD($1)
            incr NEW($1)
```

```
            }
            default {
                return OK
            }
        }
        return [array get NEW]
    ' LANGUAGE 'pltcl';

    CREATE TABLE mytab (num integer, description text, modcnt integer);

    CREATE TRIGGER trig_mytab_modcount BEFORE INSERT OR UPDATE ON mytab
        FOR EACH ROW EXECUTE PROCEDURE trigfunc_modcount('modcnt');
```

Notice that the trigger procedure itself does not know the column name; that's supplied from the trigger arguments. This lets the trigger procedure be re-used with different tables.

20.2.6. Modules and the `unknown` command

PL/Tcl has support for auto-loading Tcl code when used. It recognizes a special table, `pltcl_modules`, which is presumed to contain modules of Tcl code. If this table exists, the module `unknown` is fetched from the table and loaded into the Tcl interpreter immediately after creating the interpreter.

While the `unknown` module could actually contain any initialization script you need, it normally defines a Tcl "unknown" procedure that is invoked whenever Tcl does not recognize an invoked procedure name. PL/Tcl's standard version of this procedure tries to find a module in `pltcl_modules` that will define the required procedure. If one is found, it is loaded into the interpreter, and then execution is allowed to proceed with the originally attempted procedure call. A secondary table `pltcl_modfuncs` provides an index of which functions are defined by which modules, so that the lookup is reasonably quick.

The PostgreSQL distribution includes support scripts to maintain these tables: `pltcl_loadmod`, `pltcl_listmod`, `pltcl_delmod`, as well as source for the standard unknown module `share/unknown.pltcl`. This module must be loaded into each database initially to support the autoloading mechanism.

The tables `pltcl_modules` and `pltcl_modfuncs` must be readable by all, but it is wise to make them owned and writable only by the database administrator.

20.2.7. Tcl Procedure Names

In PostgreSQL, one and the same function name can be used for different functions as long as the number of arguments or their types differ. Tcl, however, requires all procedure names to be distinct. PL/Tcl deals with this by making the internal Tcl procedure names contain the object ID of the procedure's `pg_proc` row as part of their name. Thus, PostgreSQL functions with the same name and different argument types will be different Tcl procedures too. This is not normally a concern for a PL/Tcl programmer, but it might be visible when debugging.

Chapter 21. PL/Perl - Perl Procedural Language

PL/Perl is a loadable procedural language that enables you to write PostgreSQL functions in the Perl[1] programming language.

To install PL/Perl in a particular database, use `createlang plperl` *`dbname`*.

> **Tip:** If a language is installed into `template1`, all subsequently created databases will have the language installed automatically.

> **Note:** Users of source packages must specially enable the build of PL/Perl during the installation process (refer to the installation instructions for more information). Users of binary packages might find PL/Perl in a separate subpackage.

21.1. PL/Perl Functions and Arguments

To create a function in the PL/Perl language, use the standard syntax:

```
CREATE FUNCTION funcname (argument-types) RETURNS return-type AS '
    # PL/Perl function body
' LANGUAGE plperl;
```

The body of the function is ordinary Perl code.

Arguments and results are handled as in any other Perl subroutine: Arguments are passed in `@_`, and a result value is returned with `return` or as the last expression evaluated in the function. For example, a function returning the greater of two integer values could be defined as:

```
CREATE FUNCTION perl_max (integer, integer) RETURNS integer AS '
    if ($_[0] > $_[1]) { return $_[0]; }
    return $_[1];
' LANGUAGE plperl;
```

If an SQL null value is passed to a function, the argument value will appear as “undefined” in Perl. The above function definition will not behave very nicely with null inputs (in fact, it will act as though they are zeroes). We could add `STRICT` to the function definition to make PostgreSQL do something more reasonable: if a null value is passed, the function will not be called at all, but will just return a null result automatically. Alternatively, we could check for undefined inputs in the function body. For example, suppose that we wanted `perl_max` with one null and one non-null argument to return the non-null argument, rather than a null value:

```
CREATE FUNCTION perl_max (integer, integer) RETURNS integer AS '
    my ($a,$b) = @_;
    if (! defined $a) {
```

1. http://www.perl.com

```
        if (! defined $b) { return undef; }
        return $b;
    }
    if (! defined $b) { return $a; }
    if ($a > $b) { return $a; }
    return $b;
' LANGUAGE plperl;
```

As shown above, to return an SQL null value from a PL/Perl function, return an undefined value. This can be done whether the function is strict or not.

Composite-type arguments are passed to the function as references to hashes. The keys of the hash are the attribute names of the composite type. Here is an example:

```
CREATE TABLE employee (
    name text,
    basesalary integer,
    bonus integer
);

CREATE FUNCTION empcomp(employee) RETURNS integer AS '
    my ($emp) = @_;
    return $emp->{"basesalary"} + $emp->{"bonus"};
' LANGUAGE plperl;

SELECT name, empcomp(employee) FROM employee;
```

There is currently no support for returning a composite-type result value.

> **Tip:** Because the function body is passed as an SQL string literal to `CREATE FUNCTION`, you have to escape single quotes and backslashes within your Perl source, typically by doubling them as shown in the above example. Another possible approach is to avoid writing single quotes by using Perl's extended quoting operators (`q[]`, `qq[]`, `qw[]`).

21.2. Data Values in PL/Perl

The argument values supplied to a PL/Perl function's script are simply the input arguments converted to text form (just as if they had been displayed by a `SELECT` statement). Conversely, the `return` command will accept any string that is acceptable input format for the function's declared return type. So, the PL/Perl programmer can manipulate data values as if they were just text.

21.3. Database Access from PL/Perl

Access to the database itself from your Perl function can be done via an experimental module `DBD::PgSPI`[2] (also available at CPAN mirror sites[3]). This module makes available a DBI-compliant database-handle named `$pg_dbh` that can be used to perform queries with normal DBI syntax.

PL/Perl itself presently provides only one additional Perl command:

`elog` *`level`*, *`msg`*

Emit a log or error message. Possible levels are `DEBUG`, `LOG`, `INFO`, `NOTICE`, `WARNING`, and `ERROR`. `ERROR` raises an error condition: further execution of the function is abandoned, and the current transaction is aborted.

21.4. Trusted and Untrusted PL/Perl

Normally, PL/Perl is installed as a "trusted" programming language named `plperl`. In this setup, certain Perl operations are disabled to preserve security. In general, the operations that are restricted are those that interact with the environment. This includes file handle operations, `require`, and `use` (for external modules). There is no way to access internals of the database backend process or to gain OS-level access with the permissions of the PostgreSQL user ID, as a C function can do. Thus, any unprivileged database user may be permitted to use this language.

Here is an example of a function that will not work because file system operations are not allowed for security reasons:

```
CREATE FUNCTION badfunc() RETURNS integer AS '
    open(TEMP, ">/tmp/badfile");
    print TEMP "Gotcha!\n";
    return 1;
' LANGUAGE plperl;
```

The creation of the function will succeed, but executing it will not.

Sometimes it is desirable to write Perl functions that are not restricted --- for example, one might want a Perl function that sends mail. To handle these cases, PL/Perl can also be installed as an "untrusted" language (usually called PL/PerlU). In this case the full Perl language is available. If the `createlang` program is used to install the language, the language name `plperlu` will select the untrusted PL/Perl variant.

The writer of a PL/PerlU function must take care that the function cannot be used to do anything unwanted, since it will be able to do anything that could be done by a user logged in as the database administrator. Note that the database system allows only database superusers to create functions in untrusted languages.

If the above function was created by a superuser using the language `plperlu`, execution would succeed.

2. http://www.cpan.org/modules/by-module/DBD/APILOS/
3. http://www.cpan.org/SITES.html

21.5. Missing Features

The following features are currently missing from PL/Perl, but they would make welcome contributions:

- PL/Perl functions cannot call each other directly (because they are anonymous subroutines inside Perl). There's presently no way for them to share global variables, either.
- PL/Perl cannot be used to write trigger functions.
- DBD::PgSPI or similar capability should be integrated into the standard PostgreSQL distribution.

Chapter 22. PL/Python - Python Procedural Language

The PL/Python procedural language allows PostgreSQL functions to be written in the Python[1] language.

To install PL/Python in a particular database, use `createlang plpython dbname`.

> **Note:** Users of source packages must specially enable the build of PL/Python during the installation process (refer to the installation instructions for more information). Users of binary packages might find PL/Python in a separate subpackage.

22.1. PL/Python Functions

The Python code you write gets transformed into a function. E.g.,

```
CREATE FUNCTION myfunc(text) RETURNS text
    AS 'return args[0]'
    LANGUAGE 'plpython';
```

gets transformed into

```
def __plpython_procedure_myfunc_23456():
        return args[0]
```

where 23456 is the OID of the function.

If you do not provide a return value, Python returns the default `None` which may or may not be what you want. The language module translates Python's `None` into the SQL null value.

The PostgreSQL function parameters are available in the global `args` list. In the `myfunc` example, `args[0]` contains whatever was passed in as the text argument. For `myfunc2(text, integer)`, `args[0]` would contain the `text` variable and `args[1]` the `integer` variable.

The global dictionary `SD` is available to store data between function calls. This variable is private static data. The global dictionary `GD` is public data, available to all Python functions within a session. Use with care.

Each function gets its own restricted execution object in the Python interpreter, so that global data and function arguments from `myfunc` are not available to `myfunc2`. The exception is the data in the `GD` dictionary, as mentioned above.

22.2. Trigger Functions

When a function is used in a trigger, the dictionary `TD` contains trigger-related values. The trigger rows are in `TD["new"]` and/or `TD["old"]` depending on the trigger event. `TD["event"]` contains the event as a string (`INSERT`, `UPDATE`, `DELETE`, or `UNKNOWN`). `TD["when"]` contains one of `BEFORE`, `AFTER`, and

1. http://www.python.org

UNKNOWN. TD["level"] contains one of ROW, STATEMENT, and UNKNOWN. TD["name"] contains the trigger name, and TD["relid"] contains the relation ID of the table on which the trigger occurred. If the trigger was called with arguments they are available in TD["args"][0] to TD["args"][(n-1)].

If the TD["when"] is BEFORE, you may return None or "OK" from the Python function to indicate the row is unmodified, "SKIP" to abort the event, or "MODIFY" to indicate you've modified the row.

22.3. Database Access

The PL/Python language module automatically imports a Python module called plpy. The functions and constants in this module are available to you in the Python code as plpy.*foo*. At present plpy implements the functions plpy.debug("msg"), plpy.log("msg"), plpy.info("msg"), plpy.notice("msg"), plpy.warning("msg"), plpy.error("msg"), and plpy.fatal("msg"). They are mostly equivalent to calling elog(*LEVEL*, "msg") from C code. plpy.error and plpy.fatal actually raise a Python exception which, if uncaught, causes the PL/Python module to call elog(ERROR, msg) when the function handler returns from the Python interpreter. Long-jumping out of the Python interpreter is probably not good. raise plpy.ERROR("msg") and raise plpy.FATAL("msg") are equivalent to calling plpy.error and plpy.fatal, respectively.

Additionally, the plpy module provides two functions called execute and prepare. Calling plpy.execute with a query string and an optional limit argument causes that query to be run and the result to be returned in a result object. The result object emulates a list or dictionary object. The result object can be accessed by row number and field name. It has these additional methods: nrows() which returns the number of rows returned by the query, and status which is the SPI_exec return variable. The result object can be modified.

For example,

```
rv = plpy.execute("SELECT * FROM my_table", 5)
```

returns up to 5 rows from my_table. If my_table has a column my_field, it would be accessed as

```
foo = rv[i]["my_field"]
```

The second function plpy.prepare is called with a query string and a list of argument types if you have bind variables in the query. For example:

```
plan = plpy.prepare("SELECT last_name FROM my_users WHERE first_name = $1", [ "text" ])
```

text is the type of the variable you will be passing as $1. After preparing a statement, you use the function plpy.execute to run it:

```
rv = plpy.execute(plan, [ "name" ], 5)
```

The limit argument is optional in the call to plpy.execute.

In the current version, any database error encountered while running a PL/Python function will result in the immediate termination of that function by the server; it is not possible to trap error conditions using Python try ... catch constructs. For example, a syntax error in an SQL statement passed to the plpy.execute() call will terminate the function. This behavior may be changed in a future release.

When you prepare a plan using the PL/Python module it is automatically saved. Read the SPI documentation (Chapter 17) for a description of what this means.

In order to make effective use of this across function calls one needs to use one of the persistent storage dictionaries `SD` or `GD`, see Section 22.1. For example:

```
CREATE FUNCTION usesavedplan ( ) RETURNS TRIGGER AS ’
   if SD.has_key("plan"):
      plan = SD["plan"]
   else:
      plan = plpy.prepare("SELECT 1")
      SD["plan"] = plan
   # rest of function
’ LANGUAGE ’plpython’;
```

22.4. Restricted Environment

The current version of PL/Python functions as a trusted language only; access to the file system and other local resources is disabled. Specifically, PL/Python uses the Python restricted execution environment, further restricts it to prevent the use of the file `open` call, and allows only modules from a specific list to be imported. Presently, that list includes: `array`, `bisect`, `binascii`, `calendar`, `cmath`, `codecs`, `errno`, `marshal`, `math`, `md5`, `mpz`, `operator`, `pcre`, `pickle`, `random`, `re`, `regex`, `sre`, `sha`, `string`, `StringIO`, `struct`, `time`, `whrandom`, and `zlib`.

Bibliography

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Some white papers and technical reports from the original POSTGRES development team are available at the University of California, Berkeley, Computer Science Department web site[1]

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